ENCYCLOPEDIA OF DISASTERS

Environmental Catastrophes and Human Tragedies

VOLUME 1

ANGUS M. GUNN

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Preface

This encyclopedia is a descriptive, illustrated account of disasters, both natural and human-induced, that have occurred throughout the world at different times over the past two thousand years. They include experiences of earthquakes, tsunamis, volcanic eruptions, floods, extremes of weather, droughts, pandemic illnesses, land subsidence and landslides. Most troubling of all is a newcomer to the world of disasters, the terrorist attack. While terrorists have, from time to time in the past, wrought havoc on human environments, the expanded volume and brutality of their activities over the past thirty years has gone beyond all previous acts of violence. Terrorism is the type of disaster that may become increasingly destructive in the future.

Sometimes disasters are so named if a large number of people are killed. At other times, the criteria is the amount of damage done to homes and other structures. A third identifying characteristic is the long-term consequences of the event. In this encyclopedia, disaster events have been selected on the bases of all three of these characteristics. A calamitous event that occurred at a given point in time is selected if it caused great damage, significant loss of life, and carried important consequences for subsequent years. The majority of the events included are natural disasters such as earthquakes, floods, and volcanic eruptions because, for the better part of the past two thousand years, catastrophes of this kind were the costliest and deadliest in human experience. Natural disasters were also, and still are, highly unpredictable, so there are good reasons to study them and so continue the search for answers to their predictability.

Human tragedies, events that involve human choices, though fewer in number over the course of the two thousand years that this encyclopedia covers, must also be included in any study of disasters because they, unlike natural tragedies, will continue to increase in both frequency of occurrence and extent of damage. Furthermore, the understanding, prevention, or minimization of the destruction of any disaster anywhere in the world is vital to the preservation of our global environment. The enormous power and influence that can be wielded by one person raises the need for a better understanding of human behavior. A single error by one person, as happened in the Chernobyl nuclear power station in the Soviet Union in 1986, can cause extensive damage to a whole continent. In the Bhopal Chemical Factory in India in 1984, the mistakes of one or two workers led to the deaths of 8,000 and the injury of 250,000.

Human-induced disasters appear to be fundamentally different from natural ones. They are regarded as the results of human error or malicious intent, and whatever happens when they occur leaves us with the feeling that we can prevent a recurrence. In fact, the difference between these human-induced and natural disasters is not clear. More and more we find that human activity affects our natural environment to such an extent that we often have to reassess the causes of so-called natural disasters, recognizing that preventable human error might have contributed to the damage. Take, for example, the San Francisco earthquake of 1906. The firestorm that swept over the city immediately after the quake, causing far more damage than the direct impact of the earthquake, could have been less destructive if the city's fire prevention plans had been better organized.

The intended audience for this encyclopedia ranges in age from the beginning of elementary school to senior citizens. I have always found that if a topic is sufficiently important and interesting to gain space in newspapers and popular magazines, almost everyone wants to know about it. There is still stronger evidence for the popular interest in disasters in the large number of movies that have been made about them. Disasters initiated by terrorists have recently begun to appear; one is based on the murder of Israeli athletes at the Munich Olympics in 1972; the terrorist assault on New York and Washington in 2001 was the basis for two others. Movie directors in China produced a movie based on the atrocities committed by Japanese soldiers in China's old capital, Nanking, in 1937. Some disaster movies have hit the highest levels of financial success.

The problem with this kind of movie is that accuracy of detail is a victim. Hollywood takes liberties with historical events, shaping them to fit the goals of the producer. All of this poses a special problem for me because I made every effort to stick to historical accuracy. It is important that readers recognize this disparity between the facts of the event and the additions and subtractions included by the film producer. I recommend that you read about a disaster in this book before you see a movie about it. In this way you can tell what is true and what is fiction. In addition to the information about the disaster that you can read in this encyclopedia, references are provided for further study. A reader can also go the many web sites for descriptions and photos of an event.

The complete list of disasters is arranged chronologically, beginning with one from pre-history and followed by two from the times of the Roman Empire. Many countries are represented in the whole collection and each one constitutes a single event occurring within a short span of time.

Wartime events are excluded except for the bombing of Hiroshima in 1945, which was included because of the vast environmental consequences that followed from it in later years. Alternative ways of categorizing the various disasters are provided and these, along with the index, simplify searches. In each description of a disaster there is first a summary overview of the event with details of its location, time of occurrence, and type of disaster. A detailed description with explanations of causes follows next, and the account then deals with remedial actions, where possible, together with recommendations to ameliorate damage in the event of similar disasters occurring in the future.

Acknowledgments

I am indebted to very many people who helped me in researching, selecting content, and writing this encyclopedia. Everybody seems interested in stories of disasters. I found colleagues at my university, friends, and especially my family members, always ready to talk about disastrous events from the past, and to focus on the ones that impacted them most—tragedies such as the assault on the Twin Towers in 2001 or the tsunami of Boxing Day, 2004, that swept across the Indian Ocean, killing over 200,000 people. In addition to help from the rich literature on both natural and human-induced catastrophes from the past, I was greatly assisted by journal articles and e-mail replies from scholars in The U.S. Geological Survey, The Geological Society of America, The Seismological Society of America, and the Smithsonian Institution. Last, but certainly not least, I am very appreciative of my editor at Greenwood Press, Kevin Downing, whose quick and helpful responses, and courteous treatment of problems, enabled me to complete the manuscript far ahead of my expectations.

Introduction

These two volumes on disasters deal mainly with environmental catastrophes, earthquakes, volcanic eruptions and extremes of weather, because they are the causes of the costliest and deadliest events throughout history. They are also the least predictable among the many kinds of disasters, so there are good reasons to study them and to continue the search for answers to their predictability. Human tragedies, events that frequently involve human choices, must also be included in the study of disasters because they, unlike the environmental disasters, will continue to increase in the future in both frequency of occurrence and extent of damage. Understanding of disasters anywhere in the world is vital to the preservation of our global environment. Unfortunately, all too often, as will be evident in the events that are documented in these books, we fail to learn from past disasters and so we encounter them again at a later time, augmented expressions of tragedies that could have been avoided.

We tend to think of the environment as the natural world around us—the physical ground beneath our feet, the rocks, water, vegetation, and life forms, together with the atmosphere above. This outlook probably comes from earlier times when humanity was greatly influenced by the vagaries of weather and the quality of crops grown. We are still very dependent on these things, but our dependence is greatly reduced to the point where we become serious players in the shaping of our natural environment. Global warming is one example of this. While climatic shifts take place over long periods of time, these shifts are now being accelerated by our widespread use of materials that raise average temperatures faster than would occur naturally.

Our independence from the controlling influence of the natural world is largely related to technology. The traditional necessity of having to travel considerable distances for almost every activity has been enormously reduced by computers, television, and the Internet. University degrees can be earned at home and the most intricate items of clothing or furniture can be manufactured at a distance using computer technology.

Our rate of consumption of almost all natural resources has dropped greatly because of the efficiency of new methods and new materials. In some instances we create the new materials we need from the fundamental elements of matter. Cars run faster and farther on less fuel and other machines use less electricity to do the same work they formerly did. As a result, we consume less of irreplaceable oil and gas supplies.

While the more obvious benefits of technology are easily identified the dark side must also be acknowledged. Chemical industries worldwide are causing havoc in our air and water, greatly endangering our health. Several case studies in these books address the problem. They are not isolated events. The enormous power and influence that can be wielded by one person raises human behavior to a new level of concern. A single error by one person in a major chemical factory can kill thousands of people. In a nuclear installation such as Chernobyl, one person's mistake can and did damage a continent. A terrorist can blackmail a whole city by threatening to contaminate its water supply. Relationships and the social life of humans are now key elements of our environment because they may determine errant individual behavior. Are we going to see more and more natural as well as human disasters as population and human activity of all kinds continue to increase? For disasters involving human activity, yes. For those caused by volcanoes, earthquakes, and extremes of weather, maybe. Before examining that last statement further, the word "disaster" needs to be defined.

MEANING OF DISASTER

The titles of both books, *Encyclopedia of Disasters: Environmental Catastrophes and Human Tragedies*, need to be defined because there are many reasons behind the usage of the word "disaster." Sometimes a disaster is defined by the number of people killed, sometimes by the damage done to homes and other structures, and at other times we call an event a disaster if there are long-term negative consequences. The definition followed in these books is this: a calamitous event at one point of time causing great damage, loss, and destruction. The majority of the events will be natural disasters such as earthquakes and volcanic eruptions because of the time frame chosen, the past two thousand years. Throughout that period of time, most disasters were caused by natural happenings. There are large gaps in the history of such disasters because the details of many events that in all likelihood happened are just not available in any of the documentary records. Occasionally field research will unearth a famous disaster and it is then added to the records we have. The massive earthquake in the Pacific Northwest in 1700, described in this book, is a good example of this kind of finding.

The research regarding the 1700 earthquake is also an example of a new and intriguing branch of geology, determining the recurrent rates of major earthquakes and volcanic eruptions. Through examination of past surface deposits, as well as underground evidences of past disruptions of bedded layers, it is possible to date the approximate times of past events. Thus, for some powerful earthquakes like the one in 1700, the technologies available can identify when the most recent event before 1700 occurred and often several of the ones from still farther back. Once a series of times are found, our ability to predict similar disasters in the future is greatly enhanced. In the case of the 1700 earthquake, identifying the time of its occurrence, a time that was before the arrival of people from Eastern United States, was greatly aided by accurate Japanese records and both the year and the date of the event became known. Additionally, the dates for past eruptions of Yellowstone Volcano are known for two or three past eruptions. The last eruption was over 600,000 years ago. Because of the great time periods involved and the few past records available it is impossible to predict when the next one will come. More will be said later in this introduction regarding predicting earthquakes.

Natural disasters—earthquakes, hurricanes, floods, droughts—are familiar events, and we feel that we have little control over them. All we think we can do is minimize damage to people and property. Human-induced disasters, however, appear to be fundamentally different. They are regarded as the results of human error or malicious intent and whatever happens when they occur leaves us with the feeling that we can prevent a recurrence. In fact, the difference between these two types of disasters is not at all crystal clear. More and more we find that human activity is affecting our natural environment to such an extent that we often have to reassess the causes of so-called natural disasters, recognizing that preventable human error might have contributed to some of the damage. Take, for example, the great San Francisco earthquake of 1906. The firestorm that swept over the city immediately after the quake, causing far more damage than the direct impact of the earthquake, could have been minimized had alternatives to the city's water mains been in place.

The story was similar when the Loma Prieta earthquake struck in 1989. The Marina District of San Francisco that was known to be unstable and had been severely damaged in 1906 was subsequently developed and built up. When Loma Prieta struck, the area collapsed due to liquefaction. The shaking of the relatively loose soil changed the land into a liquid and buildings sank into the ground. These secondary effects of human action or inaction are increasingly important considerations in the study of disasters. However, they were not the primary elements in the two examples quoted. The main causes were still the unpredictable and uncontrollable forces of nature and these will be examined in some detail before looking at human-induced disasters. Worldwide, earthquakes both in the past and today, along with their associated events, tsunamis and volcanic eruptions, are the most costly of all natural hazards and so they will be given first place in the following descriptions. Floods are second in importance in terms of costs but first in relation to loss of life. Other major natural hazards are hurricanes, tornadoes, fires, drought, and landslides.

CITIES AT RISK

Earlier I mentioned that there is a question, a 'maybe' about whether purely natural disasters will get worse with time. In general, there is little doubt that there have been disasters as bad as or worse than current disasters all through time and pre-history and the processes, like the plate tectonics that cause them, will continue in the future to affect the same places as they have always done. Worldwide there are at the present time, on average, two or more earthquakes of magnitude 8 per year, twenty of magnitude 7, one hundred of magnitude 6, and three thousand of magnitude 5. Below magnitude 5 there can be fifteen thousand or more earthquakes every year. The reason for the 'maybe' in future rates of natural disasters is related to a major human activity, the growth of large cities.

Throughout most of human history, the total number of people increased very slowly. Birth rates were high and death rates were also high. Famine, disease, and wars prevented substantial population increases. From about 1 AD to the year 1700 the world's population doubled and reached one billion. Even after 1700, growth rate remained slow. The death of one in every four children in the first year of life was common. In spite of these challenges and with a life expectancy of only thirty-five years, the world's population doubled again by 1950. The benefits of the industrial revolution, especially the ability to control some diseases, contributed to this growth. However, the very big increases in the world's population and the constant increases in its rate of growth—the development that we called the "Population Explosion" in the 1950s and 1960s—all relate to events from 1950 onwards.

Improvement in medical services throughout the world in the aftermath of World War II caused a dramatic cut in death rates. Birth rates, however, remained high. Thus, from 1950 to 2000 the world's population jumped from 2.5 billion to 6 billion. Alongside these rapid changes came urbanization, the movement of people away from rural settings into cities; a movement that became so big by the 1970s that the majority of a nation's population in many developed countries would be found in cities. Some cities, because of their locations or their local resources, were more attractive than others and, before long, there began to emerge the super cities, the ones with extremely large numbers of people. In 1950, New York was the first to have a population of more than ten million. By 1970 there were three cities with more than ten million each, and by 1990 there were ten. Any disaster in one of these super cities, whether caused by natural or unnatural events, would inevitably be a terrible tragedy.

The following table will illustrate the nature of this new problem.

The world's ten biggest urban centers at different times.
Population data are all in millions.

1950	1970	1990	2010
New York, 12	Tokyo, 16	Tokyo, 25	Tokyo, 29
London, 9	New York, 16	Sao Paulo, 18	Sao Paulo, 25
Tokyo, 7	Shanghai, 11	New York, 16	Bombay, 24
Paris, 5	Mexico City, 9	Mexico City, 15	Shanghai, 22
Moscow, 5	London, 9	Shanghai, 13	Lagos, 21
Shanghai, 5	Paris, 8	Bombay, 12	Mexico City, 18
Essen, 5	Buenos Aires, 8	Los Angeles, 11	Beijing, 18
Buenos Aires, 5	Bombay, 8	Buenos Aires, 11	Dacca, 18
Chicago, 5	Los Angeles, 8	Seoul, 11	New York 17
Calcutta, 4	Beijing, 8	Rio de Janeiro, 11	Jakarta, 17

What has happened is this: over the sixty-year period from 1950 to 2010, the big urban areas that are in the locations of greatest risk of earthquakes have increased their populations much more than those that face a lesser risk. In 1950, sixteen million people lived in high-risk urban centers, Tokyo, Shanghai, and Calcutta. In 2010 there are 122 million people at risk in six vulnerable urban centers, Tokyo, Shanghai, Mexico City, Beijing, Dacca, and Jakarta, an increase of more than 600 percent. In 2010, the other four of the top ten cities that are located in less vulnerable locations only add up to eighty-seven million, a much smaller percentage growth. The augmented destruction that can occur in these more vulnerable cities was vividly portrayed in Mexico City's earthquake in 1985. Although the epicenter was hundreds of miles away from Mexico City, about 9,500 people were killed and 30,000 injured. The cost of all the damage reached three billion dollars.

Even in cities much smaller than the above groups of ten, the high concentrations of people and buildings can lead to devastating costs when an earthquake strikes. The following illustrations from Kobe and Los Angeles (Northridge) show how the destruction is greatly increased when an earthquake strikes any urban area. Kobe has a population of 1.5 million. It is a seaport, the main economic center for western Japan, and it has a high concentration of transportation systems and high-rise buildings. When it was hit with an earthquake in 1995, about 5,400 were killed, another 26,800 injured, and 300,000 left homeless. In addition, over 100,000 buildings were destroyed beyond repair. Costs amounted to 150 billion in U.S. dollars. In Northridge, on the northern outskirts of Los Angeles, when the city was hit with an earthquake one year before Kobe, 57 were killed, 9,000 injured, and 20,000 left homeless. Damages amounted to $20 billion, one of the costliest in U.S. history. These two examples are far from being super cities so we can imagine the increase in damage if today a large earthquake struck Tokyo.

EARTHQUAKES

To understand earthquakes and volcanic eruptions the fundamental role of tectonic plates needs to be examined. At their points of collision with a neighbor, or when tension or pressure builds up through encounters with obstructions, earthquakes occur and the area affected by the interference is shaken. Waves of different types and strengths are radiated from the shaken location, referred to as the epicenter. The fastest and most widely distributed of these waves are known as "P" waves. They transmit shock waves of alternating compression and dilation that can pass through gases, liquids, and solids and so reach most of the earth at all levels of depth depending on their strengths. There are other, slower types of waves that emanate from the epicenter. One of them, known as an "L" wave, moves rapidly in and out of the outermost layer of the earth and is responsible for much of the physical damage caused by earthquakes.

The Alaskan earthquake of 1964 was one of the strongest to be recorded since seismograph records began. Its "L" or long waves lasted for five minutes and, since their strength was very high, they were felt in places all over the world. Their strength was so high that the instruments at that time were unable to measure the maximum shocks. Later, as evidences of its destructive power were examined in detail, its strength according to the Richter Scale was known to be 9.2. See Appendix 4 for explanations of the measures in use for different types of disaster. Because of the strength of its long waves, the Alaskan quake made the surface of the earth shake up and down like the ringing of a bell. Three thousand miles away, in the Great Lakes on the U.S./Canada border, the same long waves set up several series of surface waves known as seiches and, on the other side of the globe in South Africa, there were seiches in lakes and on the ocean. The same long waves lifted up the surface of the surrounding earth surface by more than forty feet and pulled it down ten feet below its normal level. This is still regarded as the greatest deformation ever known from an earthquake.

A powerful tsunami emanated from the Alaskan earthquake. This is a phenomenon commonly associated with earthquakes and will be described in more detail in the next section of this introduction. The tsunami resulting from the 1964 earthquake carried wave heights greater than thirty feet and they swept down the west coasts of Canada and the United States all the way to San Diego, causing damage wherever they went. In Crescent City, California, a location that always experiences some destruction whenever a tsunami reaches northern California, over thirty city blocks were flooded. In Canada, at the head of an ocean inlet leading to the city of Port Alberni, eighty miles from the sea, a small subdivision was destroyed. All along the coastal area of southern Alaska, landslides and land subsidence occurred in places where the underlying soil happened to be clay. Additionally, liquefaction happened in areas close to the epicenter. All three of these surface disruptions—landslides, land subsidence, and liquefaction—are common concomitants of earthquakes and they will be found as parts of the records of some earthquakes in this book.

The first two of these three disruptions, landslides and land subsidence, are familiar because they occur in small ways wherever there are steep slopes and the danger of their recurrence can be anticipated by putting up protective barriers. Liquefaction is not so easy to anticipate because it occurs on flat ground and most frequently on shorelines that are presently above the elevation of high water. During an earthquake, the long waves vibrate the surface, create spaces among the particles of hardened soil, and allow water to seep in and change the surface to a muddy surface that cannot hold up buildings. Again and again, as will be found in accounts of earthquakes in this book, developers of land for residential or industrial uses discovered that these shorelines are low cost flat land that needs no clearing and so they have built on them, often in violation of building regulations. Such developments are low-cost because they are built on dangerous locations. Sometimes, as in the case of the San Francisco earthquake of 1906, in which liquefaction destroyed areas that were close to the water, those same areas were rebuilt in later years, only to be destroyed again by liquefaction in a subsequent earthquake.

In certain earthquakes, landslides have proved to be extraordinarily destructive forces. In the case of the greatest earthquake of all time, as far as loss of human life is concerned, the Shaanxi Province earthquake of 1556 in China, the long waves of the earthquake encountered one of the lightest types of soil found anywhere on earth, those of the loess regions of northwest China. They were deep deposits, often hundreds of feet thick, easy to demolish and, in modern times, their destruction would never have led to the death toll of 1556—more that 800,000. But, in that time, loess soil, because it was dry and easy to excavate, provided low cost homes for the people who lived and farmed there. People dug out loess caves and they proved to be warm in the cold winters and cool in the hot summers. When the long waves created high, massive landslides of loess, hundreds of thousands of Chinese were smothered or crushed before they could escape. A similar story of landslide power related to an underwater earthquake in Unimak, Alaska, in 1946, from which a massive landslide was triggered. The amount of seawater displaced by the landslide gave rise to one of the biggest tsunamis ever experienced in the Pacific Ocean. It destroyed local areas of Alaska and swept across the Pacific to do enormous damage in Hawaii. The details of the event are included in this book.

The vast majority of the half-million earthquakes that occur every year are located at the margins of tectonic plates. However, as will be seen from two events that are described in this book, one in the interior of the United States and the other in Siberia, some very powerful earthquakes occur in the middle of continents, far from the margins of any tectonic plate. The causes of these interior earthquakes relate to the fault lines that develop at weak places underground as continents and ocean floors together continue to move across the surface of the earth. Tensions build up over time and, since the rate of movement in the interior of a continent is slower than on the ocean floor, it takes a long time for stresses to build up to a crisis. Something finally gives way at the place of tension and there is an earthquake. The quake is strong because it has built up for a long time and the local population is unprepared for it because they have lived through a long quiescent period with no evidence to indicate an impending quake.

Every year, on average, earthquakes kill thousands of people and cause damage that adds up to hundreds of millions of dollars. In one fifteen-year period toward the end of the twentieth century, half a billion people lost their lives from earthquakes. Most of these deaths occurred in countries that are less developed than North America or Northwest Europe. Why is this? One explanation may be the type of surface layers of rock beneath the cities or rural areas hit. If there are numerous faults as was the case in the Guatemala City earthquake of 1976 the long waves will and they did shatter the surface rocks, with the result that a very large number of people died and damage was enormous and widespread. Additionally, in Guatemala City, and this was also true in many other places in Latin American earthquakes, the typical adobe-type homes collapse easily and people are killed by falling buildings. Engineers who work in earthquake zones repeatedly point out that buildings, not earthquakes, kill people, and they urge authorities to push for safer building codes.

TSUNAMIS

The word "tsunami" comes from Japan where it has always been a frequent visitor and where it originally meant a wave in harbor. Before there was a clear understanding of the tsunami phenomenon, Japanese fishermen would frequently return home from sea and observe their whole harbor area devastated by water. Nothing had been experienced while they were in deeper water so they were very puzzled about the event and described it as a wave in harbor. In Japanese usage, the plural of the word is also tsunami but in English it is tsunamis. Because it is a wave formed when water is displaced in an area of ocean from events such as earthquakes, mass movements above or below the ocean's surface, volcanic eruptions, or landslides, there is little evidence of a tsunami in deep water. Even if a wave is forty feet high it makes little difference in water that is a thousand feet deep but, as it comes into shallow water, the wave rises higher and higher and finally strikes the shore area with devastating force.

A tsunami can be generated when tectonic plate boundaries at subduction sites abruptly deform and vertically displace the overlying water. This happens in most places as tension builds up between two plates due to some obstruction preventing the natural movement of the plates. The tension builds up until something finally snaps, pushing one of the plates up or down and, by doing so, displacing a quantity of ocean water. Around the Pacific Rim, known as the Ring of Fire because of the many massive earthquakes of this type that occur, these displacements are greater than anywhere else. This is because the main subduction sites are located at the edge of continental areas like Alaska, California, South America, and Indonesia, in all of which the resistance to plate movement is particularly strong. As a result, a build up of tension persists for a long time between the two very big plates and a powerful earthquake then ensues. The displaced mass of water moves under the influence of *gravity* and radiates across the ocean like ripples on a pond.

Although there have been many examples of huge destructive tsunamis from subduction earthquakes around the Pacific Rim, there is nothing in the historical record like the one that originated in an Indonesian earthquake offshore from the Island of Sumatra on Boxing Day, 2004. The displacement of one of the plates and, therefore, the extent of the seabed that was moved upwards, was more than seven hundred miles. Indonesian fishermen who were at sea at the time, true to Japanese experience, felt nothing and had they stayed at sea for a time their lives could have been saved. Unfortunately, even today, tsunamis are not well understood; both in Indonesia and all over the stretch of ocean from Indonesia to Africa where the tsunami went, few people took advantage of what is known about tsunamis to run to higher ground. The tsunami, traveling at 500 mph as is common for such, devastated shore areas and even whole nations that were generally low in elevation, all the way from Indonesia to Eastern Africa. The earthquake was so powerful and the tsunami so big that the speed of the earth's rotation was slowed down for a fraction of a second.

Just as this one was part of the Ring of Fire, so were most of the other big tsunamis that occurred globally over the previous century. Krakatau was a volcanic eruption in another part of Indonesia. The tsunami that accompanied it killed 36,000 in the two major islands of Indonesia on either side of the eruption—Java and Sumatra. Japan, thirteen years after Krakatau, experienced a monster tsunami from an offshore earthquake that took the lives of 26,000. In many other places across the Pacific since that time, lethal tsunamis took away many other people and did major damage in Hawaii, Alaska, and Papua New Guinea. While the Rim of Fire was the setting for most tsunamis from the past, Europe and the Eastern Mediterranean Sea have also seen powerful tsunamis in past times when, because of their lack of knowledge of tsunamis, many thousands were killed. The Lisbon tsunami of 1755 that followed an offshore earthquake killed many thousands and, much earlier in time, in Alexandria in the year 365, a tsunami generated by a distant earthquake in Greece killed thousands of Egyptians.

A tsunami wave generated by an earthquake and carried from the epicenter of the quake by gravity is like waves generated by dropping a stone in a pond. More than one wave results from the impact of the stone and its displacement of some water. Similarly, in the greater setting of a tsunami, many waves are generated and they can be close together or widely spaced depending on the volume of water displaced and the shape of the seabed around the epicenter. As the first wave nears shore it encounters friction from the seabed as water depth decreases and the shape of the wave is distorted. It may rise as high as thirty, forty, or more feet at this point. The first wave often retreats back out to sea leaving the seabed dry for great distances from shore. This aspect of tsunamis gave rise to the observation that they are far more dangerous than the earthquakes that generate them. A tsunami might be as long as sixty miles and, since it is not pushing water ahead of it but rather carrying water along with it, strange things like the retreat back out to sea happen when the sixty miles of water hits a small shore.

A tsunami is really a crashing wall of water, a bit like the giant waves off the coast of Hawaii that are so loved by surf riders; however, tsunamis are far more dangerous and not to be played with by these surfers because the tsunami is really a mass of water carried along in a series of waves. It is not just a local wave created by wind or the displacement caused by passing ships. A more accurate picture of tsunamis might be a river overflowing its banks because a high volume of water was added to the river upstream and it can no longer carry it. Some tsunamis come ashore and move huge volumes of water, along with the masses of debris that it collected along the way, far inland. Later, sometimes hours later, it retreats far from shore. As has already been noted, thousands of people were killed, both in the past and in the recent Indonesian tsunami, when they ventured out on to the newly-dried seafloor and were drowned in the next phase of the tsunami. In Thailand, as the Indonesian tsunami of 2004 reached its shores, a young girl was close to the shore when the first wave arrived and then retreated far out to sea. She and her family were on holiday in Thailand. This girl attended a school in Edmonton, Canada, and she had learned about tsunamis in a geography lesson. Immediately she saw the wave retreating she shouted, "run for higher ground" and then ran in that direction. Only a few followed her.

Tragically there was no tsunami warning systems in the Indian Ocean when the Indonesian earthquake and tsunami struck. It had been such a long time since the previous big tsunami had affected the area that authorities became complacent about this danger. Attitudes were still somewhat indifferent even when the earthquake happened as became evident in the responses from some countries in the region. Thus it was the Pacific Tsunami Warning Center in Hawaii that gave the quickest information to the rest of the world. This center along with its associated seismic stations and tidal gauges in places all over the Pacific Ocean, including Chile, New Zealand, Japan, Alaska, and all places in between, was established in the late 1940s after Hawaii experienced severe damage from several tsunamis. It is expected that there will be a similar system in place in the Indian

Ocean in the future. Huge tsunamis have struck many places around the Pacific and Indian oceans in the past but little is known about these where historical records go back for only two or three hundred years. The west coast of North America is one of these places and Australia is a second. Research work is needed on the evidences of these past tsunamis, including the oral records of native peoples, so that there is a greater awareness of the possibilities of future mega-tsunamis.

PREDICTING EARTHQUAKES

In spite of the fact that we know now exactly what causes earthquakes, their sudden, repetative appearance is as disturbing as the former ignorance of causes, so the quest to be able to predict their arrival has become a central interest of geologists. In fact, from earliest times, alongside the fanciful reasons for the occurrence of earthquakes, there were theories that pointed in the direction of predictions. Aristotle, for example, tried to explain the existence of earthquakes by theorizing that air was trapped in cavities below the surface of the earth and the rumbling of earthquakes was the result of that as the blocked cavities sought to free themselves. Pliny the Elder of Roman times, the man who died at the time of the eruption of Vesuvius, thought similarly to Aristotle, that there was a blockage of air inside the earth and caves and wells were necessary to release this trapped air. Often he would propose a solution that would involve drilling holes to allow the trapped air to escape.

A variety of attempts have been made over the years to predict earthquakes by looking at the minor seismic events that always occur around the time of an earthquake, hoping that the way these appear and their strength might indicate when the earthquake would occur. These have been successful to a point. For example, at the time of the Mount St. Helen's earthquake and volcanic eruption in 1980, the small shakings that preceded the earthquake and the major eruption were an accurate forecast of what was going to happen. But the exact time of the explosion was not predictable and so the nearest that experts could come to a prediction was to say that there would be an explosion within a few weeks. That level of accuracy has been proved successful, not only in the case of Mount St. Helen's, but also in the many earthquakes that recur in Alaska, where patterns are frequently repeated over long periods of time. The Tangshan earthquake of 1976 was kept secret for three years because the Chinese felt they had developed similar methods for predicting earthquakes but, unfortunately, they were totally wrong in regard to the Tangshan quake.

Many reports, some dating back hundreds of years, have pointed out that animals of all sizes and kinds seem to detect earthquakes hours or even days before humans. At the time of the tsunami that followed the Indonesian quake of 2004 it was observed that almost no animals were caught in the event. It seems that they moved away from danger areas in good time. This behavior of animals was also noted and recorded in 1755 at the time of the Lisbon earthquake and tsunami. In the year 2004, a book by a Japanese geologist, Motoji Ikeye, was published in Singapore by World Scientific Publishing Company and titled *Earthquakes and Animals*. In this book he describes in detail one possible explanation for animals being able to sense an oncoming earthquake. Ikeye was aware that, in recent years, in major earthquakes in Japan, China, and India, there were numerous reports of animals fleeing from the scene twelve to twenty-four hours before the earthquakes struck. Ikeye also knew, from his own experiments, that flashes of lightning or lights of some kind accompany earthquakes, perhaps due to collisions or friction among rocks as they are shaken. The thesis that he developed related to these lights. He concluded that they frightened animals and so they moved away from them. It seems to be a very persuasive argument, one that is likely to be investigated further in the future.

Ikeye's book included list of animals that were seen to be running away from a place that later experienced an earthquake. This list is more detailed than any other similar record. His list includes reports of avoidance of earthquakes by dogs, cats, sea lions, hippopotamai, squirrels, rats, seagulls, snakes, turtles, fish, dolphins, octopus, crocodiles, and rabbits. Each had its own pattern of behavior and the following details concerning dog and cat activities will indicate the varieties within each category of animal. Some dogs howled like wolves while others refused to be separated from their owners, either insisting on staying inside or trying to get the owner outside. Some dogs left their homes before the earthquake and returned several days later while others barked continually up to thirty minutes before the earthquake. With cats, some tried to get into bed with their owners, waking them up and even biting them. Forty-five minutes before an earthquake other cats meowed to be let out of the house. The places selected by Ikeye for the collection of his data about animal behavior prior to earthquakes were taken from Japan, Turkey, Taiwan, and India.

Most research on prediction still remains focused on the characteristics of rocks and terrain in areas that have a history of earthquakes. Tilting of the ground, changes in elevation, even rising water levels in wells can all be indicators of stresses deeper down. Appearance of small cracks may be the surface manifestation of a fault hundreds of miles below ground. In places that were hit by very powerful earthquakes in the past, it is possible to predict the frequency of recurrence by examining soil and rock layers below ground and calculating the likelihood of another quake. This is a very rough method of prediction, making it possible to say no more than that an earthquake of such and such magnitude will recur sometime within the next so many years. In California, at Pallet Creek on the San Andreas Fault a little over fifty miles north of Los Angeles, a location where slippages on the San Andreas Fault have been repeatedly noted in the form of disrupted sedimentary layers, an expert from the California Institute of Technology decided to dig down at this location and make accurate assessments of the soil layers to discover when past quakes had occurred. His purpose was earthquake prediction. He thought that if he could date older slippages he might be able to draw up a timetable of recurrences and thus an average frequency of earthquakes for this part of the San Andreas Fault. It was already well known that most California earthquakes occur on or near this fault. A history of 1,400 years of earthquakes was identified and from these the average recurrence interval was calculated at about 150 years. Since the last great earthquake on the San Andreas near Pallet Creek was in 1857, the finding from this investigation and prediction came uncomfortably close to the year 2007.

Earthquake prediction is always an inexact science. No one can claim certainty about the future, yet scientists are always at work seeking to gain as much predictability as possible. Occasionally a successful forecast occurs and then efforts are redoubled to capitalize on the event. In China, in 1969 on a particular morning, zookeepers noticed unusual animal behavior—swans avoided water, pandas screamed, and snakes refused to go into their holes. About noon on that same day a 7.4 magnitude earthquake struck the city. Ever since then, and especially now in the light of Ikeye's 2004 report, scientists take careful note of any relevant animal behavior. Although probability seems to be a very weak method of prediction at first glance, it is turning out to be the best of all. When dealing with a very large number of variables in a situation where most of the variables operate independently of one another, the ordinary predictive methods of science do not apply. Scientific prediction requires stability in several variables so that the behavior of one can be evaluated.

Weather forecasters were among the first to recognize the value of probability prediction but the idea did not originate with them. It came from scientists working with very small things, like cells or atoms, where all the common laws of physics give way to random behaviors. Only probability is predictable in those domains. Meteorologists trying to cope with increases in the frequency and power of both hurricanes and tornadoes decided to settle for probability methods in giving storm warnings. It is now the same in geology. The basis of the method is the record of past events. If there are extensive records of say earthquakes in a given region, including magnitudes and dates, it can be said with a stated degree of probability that an earthquake of a certain size will hit within a given time period. This approach has become standard practice over the past twenty or thirty years with the Global Seismograph Network (GSN) that was set up in the early 1960s. In 1990 it rated the probability as high, of a magnitude 6 quake striking the eastern United States before 2010.

FLOODS

Floods are not as costly nor are they as destructive, on average, as earthquakes. At the same time, they are the deadliest of all environmental hazards. In the course of the twentieth century, worldwide, close to seven million died as a result of floods, one million were injured and over one hundred million were rendered homeless. The majority of the deaths occurred in China, almost all of them from the Yellow River, or Huanghe as it is known today, often and appropriately named the "River of Sorrow." In its long journey from the high ground of Northwest China the Yellow River flows through territory bordered by hundreds of miles of deep deposits of loess, a very light soil that is easily eroded and added to the river. By the time the Yellow River reaches the lowland areas near its mouth and slows down, its water level is high because of the load of yellow loess deposits. All it takes at that stage to create a crisis is an unexpected heavy rainfall. Such an event can raise the river level above the levees, making it overtop the banks and flood the farmland below.

Again and again, in the more than 2,000 years since levees were first built on the banks of the Yellow River, overtopping has happened and hundreds of thousands of the farmers who lived and worked on the fertile land beside the river were drowned. In response to each of these tragedies, the levees were built up a bit higher than they had been in order to forestall another flood. As a result, over time, the river flows along high above the villages below. When rainfall triggers another overtopping the destruction is greater than that of previous similar occasions because of acceleration in the flow of water from the higher elevation of the river. Additionally, because it is a slow-moving river as it reaches its mouth, alternative channels are carved out in the delta area. On one occasion, late in the nineteenth century, the river carved out a channel farther south than it had ever done before, linking it with the other great river of China, the Yangtze, so that both rivers flowed together into the East China Sea.

The Mississippi River drainage basin is the largest in the world and certainly the largest in North America. Flood risks are annual threats and, historically, flood events were left to states to resolve. There was an assumption that nothing could be done on a collective, national, basis to anticipate and prevent flood damage. All of that kind of thinking changed after the massive flood of 1927 when 246 lost their lives, about 137,000 buildings were flooded, and 700,000 lost their homes. Pressure on the national government led to the Flood Control Act in the year following the big flood. Levees, two thousand miles of them, together with a number of floodwalls and floodways, were installed by joint state and federal authorities. In 1993 there was a much worse flood than the one in 1927. The 1993 flood affected more than half of the total area of the river basin. A rare combination of highs and lows raised rainfall levels from the Dakotas to the upper areas of Mississippi. The loss of life from this event was considerably lower than in 1927, thanks to the precautions taken after 1927. Nevertheless, about 74,000 people were left homeless and 1,000 levees collapsed.

The tragedy of Hurricane Katrina and the flooding that ensued may have led to new concerns about the relationships between hurricanes and floods. Whether it was because of Katrina or otherwise, the National Oceanic and Atmospheric Administration (NOAA) decided in 2005 to document the details of hurricanes that made landfall in the contiguous United States and, in the course of their first two or three days, caused nine or more inches of rainfall in their landfall areas. There is another aspect of Katrina that should be noted because they have national implications—the insurance claims. Residents in New Orleans who had taken out insurance policies against damage from hurricanes were refused benefits from their insurance companies because, in the opinion of the insurance companies, the damage elements that residents suffered and that had been caused by flooding was not covered. Far away from the United States, on the other side of the earth, in Australia, there are new concerns and many public protests over the failure of the national government to protect people from floods. On this normally very dry continent major floods in 1973 and 1990 did extensive destruction and state and federal authorities were totally unprepared to deal with them.

VOLCANIC ERUPTIONS

Somewhere on earth, a volcanic eruption is either happening or about to happen. About 1,500 of them have erupted at different times within the last 10,000 years and, because we never know when one becomes extinct, it is possible that any one of the 1,500 could spring into life again. Over five hundred have erupted within the past four hundred years. A volcanic eruption can occur at times because of a nearby earthquake triggering it but, in general, volcanic eruptions occur for a variety of reasons, all of which distinguish them from the world of earthquakes and tsunamis. From the times of Rome when Mount Vesuvius erupted and the entire town of Pompeii was smothered with lethal ash, volcanic eruptions have created intense interest. Pompeii's ruins are still being studied at the present time, especially the findings of the outlines of the bodies of those who died because they were preserved by a special technique. Even the name of Pliny the Elder, a Roman leader who died in Pompeii's destruction, has been taken to define the eruptions that are like the Vesuvius one. They are known as Plinian eruptions, continuous flows of pumice, ash, and volcanic gases forming a deadly cloud.

One of the easiest volcanic eruptions to study can be found in Hawaii. Mount Kilauea on the Island of Hawaii, often referred to as the Big Island, is an intra-plate volcano, that is to say it is erupting from inside a tectonic plate rather than at the junction of two plates. It is erupting almost daily at the present time and at such a low level of violence that its activity can be easily observed. Molten magma just oozes out. The entire island group that constitutes the state of Hawaii is formed from volcanic action and the Big Island, the island of Hawaii, is the principal actor at the present time. Other islands of the state were active in the past and this condition is a reminder of another feature of Hawaii—it is a hot spot. There are more than thirty of these hot spots around the world and some of them will feature in the events of this book. What is a hot spot? They are places deep in the earth below the level of mountains and ocean crust from which magma is escaping to the surface. In sharp contrast to everything we see on the surface of the earth these hot spots do not move with respect to the surface of the earth. Instead the tectonic plates pass over them as they move.

The huge volume of molten rock that reaches the surface in the island of Hawaii over time from the hot spot is evident in the thousands of feet to which a volcano such as Kilauea has risen above sea level and its height is achieved after it has already risen many thousands of feet from the ocean floor up to sea level. Over a period of a few million years, Kilauea will move way from the hot spot as the Pacific Tectonic Plate on which it sits continues its westward movement. A new mountain will take shape over the hot spot and Mount Kilauea will gradually cool down to become inactive like the rest of the state of Hawaii. The long history of this process, over a period of more than seventy million years, can be observed today in the islands above and below sea level that stretch from Kilauea to the other islands of the state of Hawaii, and then across the Pacific all the way to the Kamchatka Peninsula of Russia. These islands form the Hawaiian-Emperor Chain and identification of their age, that is to say, the lapse of time since they were magma rising from the hot spot, tells the story of the movement of the Pacific Tectonic Plate over time.

The two tallest volcanic mountains on the chain lie on the Big Island of Hawaii. They are Mauna Kea and Mauna Loa. Each is more than 12,000 feet high but if their total individual heights, counting from the ocean floor, is calculated, they each stand more than 30,000 feet high, higher than that of Mount Everest in the Himalayas. The gentle rate at which magma flows upward into the mountains of Hawaii is common in intra-plate volcanic eruptions. Yellowstone National Park stands on the remnants of an ancient volcano and it, like Kilauea, stands today on a hot spot on an intra-plate site. Furthermore, its activity is quite benign and so thousands of tourists visit it every year. But Yellowstone was not always so quiet. Three extremely large explosive eruptions have occurred there in the past 2.1 million years and scientists have estimated Yellowstone's recurrence interval as about 600,000 to 800,000 years. It is difficult to be more precise with such long intervals. The most recent of these explosive eruptions was about 640,000 years ago. Given the estimates for recurrence rates it is possible, despite assurances from USGS experts that there are no indications now of the likelihood of such an event, that another explosive eruption could come within the next one or two hundred years.

The consequences of such an event are unimaginable. The eruption of about 640,000 years ago, among other things, covered most of what is now North America with six feet of hot ash. Thus the USGS, from time to time, issues reminders of the kinds of things that need to be considered so that the area is as prepared as possible for the future. There are potential future hazards that could affect as many as 70,000 people even though the area is sparsely populated and this fact has to be kept in mind by all who are responsible for the care of the park. The plateau on which the park sits was built by one of the earth's youngest, but largest, volcanic systems. It has been the scene of eruptions for more than two million years. The three largest of these eruptions sent out ash that was so hot that it welded into sheets of rock. Each of the three produced a crater-like depression, a caldera, tens of miles wide, formed by the collapse of the ground surface into the partly emptied magma chamber beneath. Faults within the present caldera are small and they produce small earthquakes from time to time that reflect strains in the earth's crust. The active hydrothermal system of Yellowstone is one of the largest on earth and, although accidents involving hot water occasionally injure visitors, these can be avoided if park regulations are followed.

At the places where tectonic plates interact, especially at subduction zones, most of the most violent eruptions of the twentieth century have occurred. The interaction of the Nazca and South American plates is one general location that experienced catastrophic eruptions, particularly because the coastal area is high in elevation and lahars rush down from eruptions to overwhelm the towns and cities below. The 1985 eruption of Colombia's Nevado del Ruiz volcanic mountain carried plenty of warnings of the coming event, both in the minor eruptions that were observed for days before the main explosion and in the opinions given by local authorities. Despite these warnings, there seems to be little understanding of when one must escape to some protected place. In the case of Nevado del Ruiz, the lahars rushed down from the mountain, from 17,500 feet above sea level, devastating everything in their path. About 21,000 people lost their lives in one town, Armero, which only had a population of 28,000. The USGS scientists, particularly horrified by the things that happen to people at volcanic sites, decided to do something to alert people to the dangers and to inform them about how to avoid an imminent event. They devised a three-part action plan.

First, they produced a video depicting the typical phases of volcanic eruptions and what happens to people, buildings, and environment when they erupt. It was quite a scary video, deliberately so, not suitable for younger people. Second, they selected fifteen volcano sites from around the world to study intensely and to examine along with the various local authorities in order to have the details of a collection of representative case studies. The third element was instrumental usage for predicting when a volcano would blow given that the advance signals were evident. In 1991 the video was rushed to the Philippines when Mount Pinatubo was threatening to erupt. The day after it was shown on television, about 50,000 chose to evacuate voluntarily. A few days later the volcano erupted. Tens of thousands of lives had been saved. Convincing people to evacuate as they had done in the Philippines was the biggest challenge everywhere it was attempted but it was the key to survival. What also was secured by Mount Pinatubo's eruption was a dramatic lowering of temperature worldwide for two years, more than countering the amounts that would have risen in that time as part of global warming.

Just as earthquakes pose enormous risks for big cities if their epicenters are nearby, so the proximity of cities to volcanic sites is an equally great risk and there are many cities in that kind of setting. Historically there are good reasons for such a condition. We tend to think of the destructive aspect of eruptions, and rightly so, but we need to remember that volcanic soils are among the most fertile anywhere. People were drawn to those great farming locations in earlier times and cities grew up there over the years. At least 500 million people live today under the shadow of a potential volcanic eruption and many big cities are included in that number—Tokyo, Manila, Jakarta, Mexico City, and Quito are examples of these. Mount St. Helens that erupted in 1980 was a good example of how to do the right thing. Advance indicators in the form of small vibrations alerted local officials to move access to the mountain farther back that had been customary. A day before the violent eruption a general clearance was ordered for everyone to move far away from the mountain and people did as they were told. The only casualties close to the mountain was a reporter and a man who had lived for much of his life near the mountain and refused to leave.

To compare the magnitude of volcanic eruptions geologists have developed a Volcanic Explosivity Index (VEI), similar in principle to the Richter Scale for measuring earthquake magnitudes. This index is based on the volume of explosive products and the height of the eruption cloud. Each category in the index represents a ten-fold increase in power over the previous one. Eruptions with magnitudes of 0 or 1, common patterns in Hawaii, ooze lava with little or no violent activity. Tristan da Cunha, 1961, was a 2; Iceland, 1973, was 3; Martinique, 1902, was 4; and Mount St. Helens, 1980, was 5. Mount Vesuvius, 79, and Krakatau, 1883, had VEIs of 6, and Tambora had 7. Tambora erupted in 1815 in Indonesia, presenting us with the greatest eruption known in history and giving us a glimpse into the incredible power and potential of such events. Their destructive power is frightening when we examine one like Tambora. Details of these scales for measuring different types of disasters are assembled in Appendix 4 at the end of the book. Toba was a supervolcano of VEI 8 and it is the only one from ancient times for which we have a large volume of data, a valuable reference if our planet ever experiences a supervolcano.

TROPICAL CYCLONES

Cyclonic storms are centers of low pressure with inward-spiraling winds that form where warm and cold air masses meet. Hurricanes develop over water about 10 degrees north or south of the equator in a manner similar to cyclonic storms elsewhere in the world, then move westward through the trade wind belt. Sea surface temperatures in these latitudes are close to 80 degrees, enough to stimulate high-speed inward-spiraling winds of 65–125 mph. The shape of the storm is circular with a diameter averaging 100–300 miles. As the hurricane moves toward the eastern seaboard of the United States, or into the Gulf of Mexico, the National Weather Service begins its warning and forecasting activities. As the storm approaches land, the biggest concerns relate as much to the expected rainfall as they do to any physical damage.

Attempts were made in the 1960s to reduce the severity of hurricanes by cloud seeding. The theory was that by seeding the clouds closest to the point of lowest pressure, latent heat would be released, raising the temperature and therefore decreasing the pressure. As a result the pressure gradient would be reduced and the maximum wind speeds as well because energy is redistributed around the storm center. Four of these storms were seeded on eight different days and results showed a 30 percent drop in wind speed on four of these days. Subsequently the experiment was dropped because additional research revealed that hurricane clouds carry a large volume of natural ice! Reliance is now placed on accurate forecasting and protective measures on shore.

Occasionally a hurricane takes an unexpected path because of cold air masses over the continent's interior. This can greatly increase the rainfall. Hurricane Agnes, in 1972, was one of these. It originated in the Caribbean and moved northward across the Florida panhandle through the Carolinas to New York State. In some places eighteen inches of rain fell in two days. Many streams experienced peak flows several times greater than the previous maxima on record. One hundred and seventeen lives were lost in the twelve states affected. Hurricane Hugo struck the United States mainland in mid-September 1989 just north of Charleston, South Carolina, with winds of 140 mph and a storm surge reaching nineteen feet. The barrier islands were completely inundated by the storm and their beaches severely eroded with sand being either washed landward or carried offshore. Altogether twenty-nine people from South Carolina lost their lives in the course of the storm and damage to buildings and property amounted to $6 billion.

Where there was a wide high beach and sand dunes, damage was greatly reduced and those buildings that had been built to withstand high winds and flooding survived. By contrast, where beaches had been severely narrowed through long-term erosion, as in Folly Beach, south of Charleston, there was substantial destruction. Homeowners had tried to compensate by dumping boulders and concrete rubble on the beach, hoping they might serve as a retaining wall. They failed. It is good that the USGS and other agencies have become more and more active in preparing for future hurricanes. While the probability that any one of these storms will hit land at a given point in a given year is low, and still less likely in the case of a category 4 or 5 hurricane, there is the danger that a false sense of security may develop. It can be said, for instance, that for any one building within the general zone of historic hurricanes, a category 3, 4, or 5 storm will strike it sometime in its lifetime. It also needs to be said that, given the many uncertainties associated with predicting hurricanes, there is no assurance that a second powerful storm will not hit again one year later in the same spot as the previous year.

North Carolina was struck by two hurricanes in 1996. The same rare sequence of two storms happened again in 1999. Hurricane Dennis struck the coast for several days early in September and Floyd made landfall later in that same month, causing record floods across eastern parts of the state and damaging shoreline structures. Bonnie, a fifth storm, just as big as the other four, reached North Carolina in 1998. Experts described the first of these five storms in 1996 as a fifty-year storm, that is to say one that would be expected to recur once every fifty years, yet all five of these storms were of equal strength. Obviously, concepts of fifty-year storms need to be reconsidered. Long-term forecasting at the present time must, therefore, remain as a difficult if not impossible task. The damage from Hurricane Katrina that devastated New Orleans in 2005 was mainly flood damage, not unlike the many floods that hit this city from high water on the Mississippi or one of its tributaries. This event was described as a hurricane, Hurricane Katrina, and all preparations for its impact were based on the city's understanding of hurricanes.

In all of the twentieth century there were only three category 5 hurricanes that made landfall in the contiguous United States. They provide a valuable historical perspective on the impact of hurricanes. The first was the Labor Day Hurricane of 1938. It earned the name "Storm of the Century" on account of three characteristics: 200 mph wind gusts, storm surge of fifteen feet, and a record low pressure. The year 1938 was still early days in the expertise of the weather bureau people. On the day before the storm hit the Florida Keys, the Bureau decided it would pass through the Keys and enter the Gulf. The Bureau was off by about three hundred miles on the storm's location on Labor Day morning. By the middle of the day, the administrator of a veteran's project involved in road construction, linking the Keys to mainland Florida, received the news that a direct hit on the keys was now certain. He decided to get all the veterans out of the area and requested that a train be backed down to the work site on the one-track line as soon as possible. Delays in delivery held up the train until 8 P.M. and by that time the full force of the storm was battering the track. Cars were tossed off the train as if they were toys. More than four hundred lost their lives.

Camille was the second of the three most powerful hurricanes. It entered U.S. waters via Cuba and moved into the Gulf where the warm waters increased its strength. It reached Bay St. Louis late in the evening of August 1969 with sustained winds of 190 mph and, in the course of the following ten hours, the entire Mississippi coast was devastated. As it moved inland, homes, motels, apartments, restaurants, even trees were swept away. The next morning the bewildered survivors searched among the wreckage for anything that might still be there. There was no semblance of normal life in the region around New Orleans for days, but fortunately the levees around the city were not affected because the storm was centered a few miles way to the east. About 15,000 people were homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Added to the devastated landscape there was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on rotting food. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. Before it left mainland United States, Camille had caused the deaths of more than 250 people and injured 8,900, destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars.

The third and by far the most expensive of the three category 5 hurricanes was Andrew. Hurricane Andrew reached the built up area of South Florida in August of 1992 with peak wind gusts of 164 mph. Before it moved on it had caused damages amounting to more than $26 billion. In the forty years from 1926 to 1966, Miami was hit with hurricanes about thirteen times, but from the quarter century 1966 to 1992 there were none and during that period of time people flocked to Miami, doubling its population. New subdivisions sprung up but supervision of building codes and other regulations was lax. There were fewer than twenty building inspectors for a population of one million. The sudden arrival of Andrew was a great shock. Its fierce winds caused most of the damage. Houses were torn apart, cars lifted off the streets, and trees uprooted. Boarding up their windows proved useless as a protection in the face of the wind and very few homes had basements where people could shelter. It was an almost total destruction of whole subdivisions. Reports from private barometers helped establish that Andrew's central pressure at landfall was 27.23 inches, which made it the third most intense U.S. hurricane of record. Andrew's peak winds in south Florida were not directly measured due to the official measuring instruments having been destroyed. A storm surge of seventeen feet was recorded.

TORNADOES

Tornadoes, like hurricanes, form in warm climates, but the tornado is the most intense cyclone of all. Its most frequent and violent occurrences are found in the United States, mainly in the Great Plains Region and to a lesser extent in the Central Lowlands. April, May, and June seem to be the favorite times for strikes with an average of more than four hundred in the United States as a whole in these months. The famous "Wizard of

Oz" movie was one of the first media events to raise awareness of a tornado's destructive power. The tornado is a small dark funnel cloud, a few hundred feet in diameter at its base with a cumulonimbus cloud above it. Its dark color comes from the dust it picks up by its powerful inward-spiraling winds. These wind speeds can reach 250 mph as the storm twists and turns and races along the surface of the ground. It can devastate almost everything in its path, yet at other times it can rise in the air and leave the ground below completely unscathed.

The National Weather Service maintains a tornado forecasting and warning system similar to the one for hurricanes. Whenever weather conditions seem to favor tornado development, places at risk are warned and arrangements for observing and reporting conditions are set in motion. Western Ohio is not a high risk area compared with states in the Great Plains but, on April 4, 1974, at Xenia, near Dayton, this state was hit with one of the worst tornadoes of the century. Ohio was not alone. Over the two days, April 4 and 5, a rash of 148 tornadoes attacked twelve states, killing 300 people and injuring 6,000. At Xenia some 3,000 structures were demolished. Elsewhere, entire towns were wiped out and $600 million worth of property devastated. The atmospheric conditions were ideal for triggering tornadoes: a cool mass of humid air lay over Chicago while farther west dry air was encountering a cold air mass from the northwest. Against both of these came a moist warm air mass from the south. The combination of all three created an explosive series of thunderstorms extending more than seven hundred miles from Texas to Illinois.

An earlier tornado swept through three states in 1925. It touched down first in Annapolis, Missouri, with a base at times as wide as one mile. Main Street's buildings were flattened in a few seconds and the twister then swept on into Murphysboro, Illinois, tossing trees, buildings, and even underground pipes as if they were toys. Over 230 people died in Murphysboro. The tornado moved next to DeSoto, a town of about six hundred, where it knocked down every structure more than one story high. Sixty-nine people lost their lives. The twister finally vanished in southern Indiana. Fortunately, storms like this one or those of 1974 are rare but, sadly, not unique. On the evening of May 3, 1999, the worst tornado of the century, as far as costs are concerned, touched down on Oklahoma City. It was the nation's first billion-dollar tornado. It was not alone. Other parts of Oklahoma, the state that gets more tornadoes per square mile than anywhere else on earth, were hit with sixty of these storms on that same evening, all of them in areas close to Oklahoma City. Within a period of five hours 8,000 buildings were in partial or total ruin as the rash of storms swept from southwest Oklahoma diagonally across the state toward Wichita, Kansas.

The difficulties involved in forecasting were evident on that fateful evening in May. The Storm Prediction Center (SPC) based at Norman, Oklahoma, issues bulletins every day and on that morning's statement announced it as unlikely that any tornado would appear during the day.

By early afternoon SPC raised its estimate to moderate. Not until close to 4:00 in the afternoon did SPC change its prediction to high risk, and then only because a powerful computer had shown that storms were charging across the state. One hour later, across a 150 mile swath that included Oklahoma City, the swarm of storms struck. The greatest damage was caused in Oklahoma City and one or two of its suburbs. On the F-scale of tornado strength, the one that hit the city was at 5, the top of the scale. Any F5 tornado is unusual and one that hits a major city even more rare. Street and after street was devastated. A typical sequence in a single family home would be: windows shattered, roof lifted off, walls caved in. Even homes that were carefully built to withstand 75 mph winds were unable to withstand this tornado.

Mobile homes fared very poorly as they usually do. An F1 tornado is usually enough to knock them over. With an F5 at speeds of 300 mph they were completely shattered. While the overall death toll was low for a storm of this size most of the fatalities occurred in the mobile home areas. Almost every one of the tornadoes that hit over the six hours from 5:00 to 11:00 in the evening was an F5 or close to that strength. They were super cells, sustained severe thunderstorms, and experts were left with the problem of how such a powerful series of storms could be sustained at that level of strength for so long. Most tornadoes develop within very large storms called super cells. These storms are found in unstable environments in which wind speeds vary with height and where cool, dry air rests on top of warm, moist air with a thin stable layer separating the two air masses, a condition similar to temperature inversion in other settings. If a weather system reaches this unstable mass, the status quo is disrupted, the low level air is forced upward and a vertical vortex gradually takes shape as the warm air ascends, cools to the point of condensation, and then is triggered into faster ascent as the latest heat of condensation warms the surroundings.

PANDEMICS

A pandemic is an outbreak of an infectious disease that spreads across a large region, a continent, or even the world. According to the World Health Organization (WHO), a pandemic can start when three conditions have been met: the emergence of a disease new to the population, a disease that infects humans, causing serious illness, and one that spreads easily and persists among humans. A disease is not a pandemic because it is widespread or kills a large number of people. It must also be infectious. For example, cancer is responsible for a large number of deaths but is not considered a pandemic. The plague of Justinian in the sixth century that devastated the eastern capital of the Roman Empire in Constantinople was the first well-known pandemic in Europe. It also marks the first detailed record of the bubonic plague that later would be known in London as the

Black Death. In Constantinople, while Justinian was the Roman Emperor, large quantities of grain were shipped from Egypt and it is thought that the disease was brought into Europe via rat and flea populations in the grain.

The bubonic plague came to be known in London, England, as the Black Death of 1664 because of the black boils in the armpits, neck, and groin of infected people, which were caused by dried blood accumulating under the skin after internal bleeding. People first experienced the bacterium of Black Death as chills, fever, vomiting, and diarrhea. Frequently the disease spread to the lungs and, almost always in these cases, the victims died soon afterward. For reasons unknown at the time some people never caught the disease even though they were in close contact with those who had. In 2005 Dr. Stephen O'Brien of the National Institutes of Health in Washington D.C. searched for descendants of those seventeenth century survivors. He was able to locate a number of them and from those people he took blood samples and recorded their DNA. Dr. O'Brien had been working with HIV patients and to his great surprise he discovered that the critical gene that saved the lives of Black Death survivors was the same gene that today enables people infected with the HIV virus to survive. It is known by the common name Delta 32.

In the twenty-first century two well-known experiences of pandemics, one closely related to terrorism and one accidental, illustrate the nature of this problem in contemporary society. The anthrax series of events that hit the United States in the same year as the terrorist attacks of September 11 was clearly an attempt to terrify the leadership of the nation because it was directed at government, media, and communications in general. In mid October, a few weeks after the devastation of 9/11 when the World Trade Center towers were destroyed and the Pentagon hit, letters containing anthrax spores began to arrive at various United States media centers and government offices in Washington, D.C. A photo editor in a Florida news agency was the first to be affected. He opened an envelope that arrived on October 15 and unknowingly inhaled some of the anthrax that fell out. Several days passed before the contents of the envelope were tested and identified. By then it was too late to do anything for the photo editor. He died two weeks later. By the end of October 2001, five people were dead from anthrax. The White House mail was quarantined and several government offices locked in order to check for spores while their staffs met elsewhere. For the first time in its history the Supreme Court convened away from its own chambers. The State Department cut off all mail to its 240 embassies and consulates worldwide.

The other pandemic, first known as "The Scars Epidemic," appeared toward the end of the year 2002. It was a deadly form of pneumonia that appeared in southern China and quietly spread, ignored for a long time, and during that period of time spread within China and to various places around the world. As its deadly nature became clear to public authorities, it was given the name "Severe Acute Respiratory Syndrome (SCARS)" and fears arose that it might be a repeat of the 1918 flu pandemic. When the World Health Organization investigated the disease they found that the majority of cases occurred in food handlers and chefs in the Guangdong Province of Southern China who were engaged in a particular kind of food preparation and delivery. These workers were always in close contact with exotic snakes and birds that were kept alive and killed immediately before being served to customers. Once the nature and characteristics of the disease was defined and isolation of patients became standard practice around the world SCARS slowly disappeared.

The present fear of a human pandemic stems from the appearance of a new virus in birds that quickly causes death. As soon as it is observed in flocks of poultry the whole flock is killed. This virus has already mutated so that a few humans have caught it. The mutated strain has been analyzed and found to be without any parallel to previous viruses. That means humans have no immunity to use against it and this is why the few who have contracted it died quickly. In 2005 the United Nations General Assembly called for immediate international mobilization against this new avian flu because of the possibility of a mutation appearing that would spread easily from human to human. The present mutation does not do that. So far, the number of humans that have died from the disease is less than a hundred and they are almost all in Asia. There are fears that this virus might become a pandemic like the one of 1918. That flu pandemic originated from birds just as this one has. Fortunately, to date, it has not yet mutated into the form that the 1918 one took and which led to the deaths of tens of millions of people all over he world. This present virus could be worse than that of 1918 because, while there is much greater knowledge on how to cope with it, there is at the same time far greater and more frequent travel around the world.

TERRORISM

The role of terrorists in the history of disasters is different from all others in that it is a sustained activity over time, a deliberate destruction of people or buildings in order to raise awareness of a political problem and use the publicity generated to gain some political result. The destruction of the Twin Towers of New York's World Trade Center (WTC) in 2001 and parallel atrocities represent the worst disasters of this kind ever experienced in the United States. They illustrate the worst features of terrorists' methods and define in quite a new way the nature of those disasters we label as terrorism. The beginning of the attack on the Twin Towers was a pair of flights from Boston. Of course, this was not really the beginning. Such attacks actually begin in the ghastly, inhuman mindsets of the people who conduct acts of terrorism. They plan for years ahead of action, sometimes for decades and, as part of their preparations for this particular series of acts, they exploit the good natures of the U.S. citizens who assisted them as they took flight training in the United States. On September 11, 2001, American Airlines Flight 11 left Boston for Los Angeles with ninety-two passengers and crew aboard. Sometime shortly afterward, the plane was taken over by five passengers who were hijackers. Just before 9 A.M. the plane crashed into the upper floors of the North WTC Tower. Fifteen minutes later a second plane, United Airlines Flight 175, also bound from Boston to Los Angeles, hit the upper part of the South Tower. It too had been taken over by hijackers.

The planes were flown into the buildings at full speed in what can only be compared to the kamikaze tactics used by Japan in World War II when young pilots crashed their bomb-laden planes into American ships. Flames engulfed the upper floors of both towers within moments and every branch of New York's fire and rescue organizations sprang into action. It was a chaotic situation and they knew they faced a daunting task. The places where rescuers were needed most were above floor eighty and they knew that both electricity and elevators would soon be cut off there. Fortunately, there were only 14,000 people in both towers at the time of the explosions, far fewer than in an earlier 1993 attack. Later in the day there would have been three times that number. Those inside first experienced a gigantic blast and felt the towers swaying backwards and forwards. Sprinklers came on as electricity and lights went off. For a time, the elevators below the eightieth floor continued to operate and many were able to get into them. Fires started in different places, many of them triggered by aviation fuel, then sustained by the flammable materials in the offices. Thousands of pieces of glass, papers, debris, soot and ash, even clothing and body parts from the passengers who were in the planes, rained down on the streets below. Temperatures reached thousands of degrees in parts of the towers.

For about an hour the main supports of the towers held firm, allowing many to escape. Fires, sustained by chairs, desks, and other flammables, raced up from the level at which the planes struck to the twenty or more floors above, steadily weakening the main steel supports. At these heights steel is thinner as the total weight to be supported is much less than at lower down. Finally there came a general collapse as the upper floors buckled and sides caved in. Like battering rams in ancient warfare, successive masses of thousands of tons of steel stomped on the floors below until they could no longer absorb the pressure. Both towers gave way in a cloud of dust. The noise of hundreds of thousands of tons of steel crashing down could be heard all over southern New York City as people ran from the scene as fast as they could. All public transportation had stopped. Among the most horrific of all the things that had to be endured was the sight of people jumping to their deaths from the top floors rather than be incinerated. The scale of destruction and the reckless indifference to civilian life rightly identified the event as war, a new kind of war, and subsequent actions in Afghanistan and elsewhere were in keeping with that analysis.

First response by the U.S. government was to stop all flights at U.S.

airports in case further attacks might be in process. Incoming planes from other countries were routed to neighboring countries. Canada, because of its proximity to the United States received most of these flights and for a time its airports were filled to overflowing. The pilots were not informed of the changes and were only told where to go. It was felt that unnecessary panic would be avoided by maintaining silence until the planes were on the ground. The towers had been designed to withstand an impact from a modern jet plane but not an impact that involved maximum speed and maximum amount of fuel. The flights that were hijacked were meant to fly to Los Angeles so they were fully loaded with fuel. Modern steel skyscrapers had never previously collapsed because none had ever been subjected to the levels of stress imposed on the WTC. It was feared at first that as many as 6,000 might have died within the towers. Later it became clear that the count was close to 3,000. Among them were 350 firemen who had climbed up into the towers to help. More than a million tons of debris had to be removed at a rate of 10,000 tons a day, so it took several months just to clear the site. Some of the individual pieces of steel weighed twenty-five tons. Excavators with a reach of 100 feet and cranes that could pick up as much as 1,000 tons were needed for the work.

All of this debris had to be hauled by barge or truck to a landfill location on Staten Island. Nothing at this scale had ever previously been tackled and costs for the whole project soared beyond a billion dollars. The dangers from toxic materials at the time of the attack were largely ignored because more urgent matters commanded attention. All who were near the towers as they came down were covered with dust that came from fibrous glass, computer screens, asbestos, and a host of products that had been made from different chemicals. Spills of mercury, dioxin, and lead were all around. Some initial testing was done after a week and it showed levels of toxic chemicals as being below danger standards. Few of the local residents were satisfied with these results. They continued to wear masks and protective clothing. Before the full impact of the destruction of the Twin Towers was known across the country a third plane had hit the Pentagon in Washington D.C., and a fourth that many believe was headed for the White House, crashed in Pennsylvania when passengers, at the cost of their lives, fought the hijackers but were unable to take control of the plane. The type of terrorism represented by the destruction of the Twin Towers is the one we have seen again and again over the past forty years. The future may introduce the more terrifying types represented by biological elements and nuclear material.

PREVENTING BIOTERRORISM

The American Society for Microbiology (ASM) discusses with the U.S. Congress issues related to the adequacy of federal law relating to dangerous biological agents. It is the largest single life science society in the world with a membership of 42,000, and represents a broad spectrum of sub-disciplines, including medical microbiology, applied and environmental microbiology, virology, immunology, and clinical and public health microbiology. The Society's mission is to enhance microbiology worldwide to gain a better understanding of basic life processes and to promote the application of this knowledge for improved health, economic and environmental well being.

It has a long history of bringing scientific, educational and technical expertise to bear on the safe study, handling and exchange of pathogenic microorganisms. The exchange of scientific information, including microbial strains and cultures, among scientists is absolutely essential to progress in all areas of research in microbiology.

It understands the unique nature of microbiology laboratories, the need for safety precautions in research with infectious agents and the absolute necessity for maintaining the highest qualifications for trained laboratory personnel. It conducts education and training programs, as well as publication of material related to shipping and handling of human pathogens. Through its Public and Scientific Affairs Board, it provides advice to government agencies and to Congress concerning technical and policy issues arising from control of biological weapons. The Society's Task Force on Biological Weapons Control assists the government on scientific issues related to the verification of the Biological Weapons Convention (BWC).

It is acutely aware of the threat posed by the possible misuse of microbial agents as weapons of terror. Concerns that bioterrorists will acquire and misuse microorganisms as weapons have resulted in stricter controls on the possession, transfer, and use of biological agents to restrict access to only legitimate and qualified institutions, laboratories, and scientists. Over the past ten years, the ASM has worked with the Department of Health and Human Services (DHHS), the Centers for Disease Control and Prevention (CDC), the Department of Agriculture (USDA), and Congress to develop and establish legislation and regulations that are based on the key principle of ensuring protection of public safety without encumbering legitimate scientific and medical research or clinical and diagnostic medicine for the diagnosis and treatment of infectious diseases. The ASM has been an advocate of placing responsibility for the safe transfer of select agents at the level of individual institutions supported by government oversight and monitoring to minimize risks without inhibiting scientific research.

It notes that national security efforts to control biological weapons require that the United States increase biodefense and public health capabilities at the same time that it tries to develop safeguards to prevent the misuse of biological agents to harm the public health. Limiting the threat of bioterrorism includes reducing access to biological agents that might be used as weapons; however, combating infectious diseases and increasing medical preparedness against bioterrorism necessitates increasing biodefense, biomedical, and other life sciences research, including work on the same "threat" agents that could be used as biological weapons. As safeguards are developed, we must ensure that biomedical research, public health, and clinical diagnostic activities are not inhibited or we risk jeopardizing the public's health and welfare.

Congress already has established a legal and regulatory framework to prevent the illegitimate use of toxins and infectious agents, outlawing virtually every step that would be necessary for the production and use of biological weapons. In doing so it has balanced assuring the availability of materials to the scientific and medical community for legitimate research purposes with preventing access to these agents for bioterrorism. For instance, the 1989 Biological Weapons Act authorizes the government to apply for a warrant to seize any biological agent, toxin, or delivery system that has no apparent justification for peaceful purposes, but exempts agents used for prophylactic, protective, or other peaceful purposes. Prosecution under this statute requires the government to prove that an individual did not intend to use the biological agents or toxins in a peaceful manner. The law also enables federal officials to intervene rapidly in cases of suspected violations, thereby decreasing the likelihood of bioterrorism while protecting legitimate scientific endeavors, such as biomedical research and diagnosis of infectious diseases.

The Antiterrorism and Effective Death Penalty Act of 1996 (the Act) broadens penalties for development of biological weapons and illegitimate uses of microorganisms to spread disease. ASM testified before the 104th Congress with respect to the control of the transfer of select agents that "have the potential to pose a severe threat to public health and safety" and contributed to the passage of Section 511(d) of the Act. The Act was intended to protect dual public interests of safety and free and open scientific research through promulgation of rules that would implement a program of registration of institutions engaging in the transfer of select agents. The transport of clinical specimens for diagnostic and verification purposes are exempt, although isolates of agents from clinical specimens must be destroyed or sent to an approved repository after diagnostic procedures are completed. The CDC is responsible for controlling shipment of those pathogens and toxins that are determined to be most likely for potential misuse as biological weapons. The ASM believes the CDC regulatory controls provide a sound approach to safeguard select agents from inappropriate use and should serve as a worldwide model for regulating shipment of these agents.

In her April 22, 1998, testimony before the Senate Subcommittee on Technology, Terrorism and Government Information Committee on the Judiciary and Select Committee on Intelligence, Attorney General Janet Reno stated that "mere possession of a biological agent is not a crime under federal law unless there is proof of its intended use as a weapon, notwithstanding the existence of factors, such as lack of scientific training, felony record, or mental instability, which raise significant questions concerning the individual's ultimate reason for possessing the agent." She, like other law enforcement officials, are troubled by the fact that someone can possess a biological agent that could be used as a weapon and not be in violation of a law unless one can establish intent. It is our understanding that the Department of Justice and other federal agencies have reviewed federal criminal statutes that could be expanded to make possession of certain biological agents illegal.

The ASM agrees that enhancing security and safety is a critical necessity when bioterrorism poses a credible threat to society. However, proposals intended to promote safety should not pose a threat to biomedical or other life sciences research and clinical diagnostic activities that are essential for public health. Unintended consequences could stifle the free exchange of microbial cultures among members of the scientific community and could even drive some microbiologists away from important areas of research. Ironically, extreme control measures to prevent bioterrorism, instead of enhancing global security, could prove detrimental to that goal if scientists can no longer obtain authenticated cultures. A key point is that natural infectious diseases are a greater threat than bioterrorism. Infectious diseases remain the major cause of death in the world, responsible for seventeen million deaths each year. Microbiologists and other researchers depend upon obtaining authenticated reference cultures as they work to reduce the incidence of and deaths due to infectious diseases. Dealing with the threatened misuse of microorganisms, therefore, will require thoughtful consideration and careful balancing of three compelling public policy interests.

We must acknowledge the terrible reality of terrorism within the United States and abroad from both foreign and United States origins. We cannot discount the possibility that, as unfathomable as it may be to the civilized mind, terrorism may take the form of bioterrorism. Most certainly, therefore, the government and scientific communities are duty bound to take every reasonable precaution to minimize any risk of terrorist use of microorganisms. The ASM is taking a proactive role in this regard.

Even as we strive to prevent bioterrorism, we must candidly recognize that no set of regulations can provide absolute assurance that no act of bioterrorism will ever occur. Therefore, as we strive to prevent such acts, we also have a duty to pursue research and public health improvements aimed at developing the most effective possible responses to acts of biological terror. Research and public health responses related to effectively combating an act of terror are a critical component of the public policy response to the threat that exists.

While the possibility of a future act of biological terrorism is a terrible threat with which we must and will deal, the scourge of infectious diseases is a terrible reality that daily takes the lives of thousands of Americans and tens of thousands around the world. Infectious diseases are now the third leading cause of death in the United States. Research on the prevention and treatment of such diseases is critical to the well being of our entire population. In responding to the threat of terror, therefore, we must minimize any adverse impact upon vital clinical and diagnostic research related to infectious diseases.

Congress and federal agencies have appreciated these competing considerations and have sought to minimize interference with research through such measures as recognizing appropriate exemptions in regulating the handling of pathogenic microorganisms. As we have stated, past legislation has recognized the need for balancing these concerns. We know that such balancing will continue, and the ASM is committed to providing all available assistance in achieving balanced and effective responses to the threat to the public welfare.

It supports making it more difficult for bioterrorists to acquire agents that could be used as biological weapons and to make it easier for law enforcement officials to apprehend and to prosecute those who would misuse microorganisms and the science of microbiology. Its code of conduct specifies that microorganisms and the science of microbiology should be used only for purposes that benefit humankind and bioterrorism certainly is inimical to the aims of it and its members. The ASM established its Task Force on Biological Weapons to assist the government and the scientific and biomedical communities in taking responsible actions that would lower the risks of biological warfare and bioterrorism.

It supports measures to prohibit possession of listed biological agents or listed toxins unless they are held for legitimate purposes and maintained under appropriate biosafety conditions. Accordingly, it supports extending the current regulations implemented by the CDC to oversee the shipment of listed agents to include possession of cultures of those agents.

Although the ASM will not offer specific proposals today, we do think it will be useful to outline certain basic principles that we believe should be considered. Governmental responsibility for establishing, implementing, and monitoring programs related to biosafety should remain with the DHHS and CDC for human health and the USDA for animal and plant health. The CDC possesses institutional knowledge and expertise related to issues of biosafety and the designation, transportation, storage, and use of select agents. The CDC is well qualified to balance the real need for biosafety regulation with the critical need for scientific research, especially clinical and diagnostic research for the prevention, treatment, and cure of infectious diseases.

The CDC's responsibilities should include duties to continue to establish and periodically revise the list of select agents; and in accord with proper administrative procedures, promulgate any additional regulatory measures related to registration of facilities, establishment of biosafety requirements, institution of requirements for safe transportation, handling, storage, usage, and disposal of select agents, and the auditing, monitoring, and inspection of registered facilities. The CDC should notify the Department of Justice about any concerns that it may have about institutions that possess select agents. Congress and the Administration must recognize that any expansion of existing regulations will require additional financial and other resources by the CDC. Based on surveys that ASM has performed, it is estimated that approximately 300 institutions possess select agents. Approximately half of those institutions are currently registered with the CDC pursuant to existing law. Registration of an additional 150 institutions, therefore, would impose additional expense and resource burdens upon the CDC that should be recognized and funded to ensure the timely and complete fulfillment of the CDC's critical mission.

Congress, the CDC, and any other relevant governmental agencies must maintain their focus on the legitimate, important, and fundamental issues related to biosafety. In this regard, biosafety initiatives should be directed toward, and focused on institutions that utilize select agents for scientific purposes, regardless whether such institutions are in the academic, commercial, or governmental sectors. As in other areas concerning biological, chemical, and radiological safety, the focus for ensuring safety should be on the institution. The institution rather than any individual scientist should be responsible for registering possession and maintaining the proper biosafety conditions for storage and usage of the agent.

In this context, ASM supports registration with the CDC of every institution that possesses and retains viable cultures (preserved and actively growing) of select agents along with the concomitant duty to follow all regulatory requirements related to such possession and usage. Institutions and individuals, thus, would be prohibited from possessing cultures of select agents unless the agents are maintained under appropriate biosafety conditions.

The DHHS/CDC, acting in cooperation with the scientific and biomedical communities and with public notice and input, should establish the rules and provide for governmental monitoring. However, the registered institution must be responsible for assuring compliance with mandatory procedures and for assuring fully appropriate biosafety mechanisms, including appointment of a responsible official to oversee institutional compliance with biosafety requirements.

These institutional responsibilities include assuring safety through proper procedures and equipment and through training of personnel. Thus, the institution would bear the responsibility for training employees regarding the biosafety requirements, including the absolute necessity for following those requirements, and such duties as reporting isolation of select agents or any breach in a biosafety protocol.

As institutions comply with appropriate safeguards, scientists may undertake their research with knowledge of clear procedures and with assurance that compliance with such procedures will fulfill all governmental requirements related to select agents. The institutions would be required to maintain records of authorized users and to ensure that they are properly trained as is currently the case for work with radioisotopes. Intentional removal of select agents from a registered facility would subject the individual to criminal sanctions.

Congress and the CDC must balance the public interests of minimizing the threat of bioterrorism and assuring vigorous scientific research, especially research relating to clinical and diagnostic methods and to protecting the nation's food supply. We must recognize that we are dealing with naturally occurring organisms that cause natural diseases. The focus should be on cultures of biological agents and quantities of toxins on the CDC select agent list in order to address any problem arising from an individual who may unknowingly pick up a dead deer mouse with Hantavirus, a handful of soil with Bacillus anthracis, a jar of honey with Clostridium botulinum, or contract an infectious disease with one of the select agents, and who could be in technical violation of a law prohibiting possession. Because microorganisms, including listed agents, are invisible and widely distributed, there is no way of knowing what you might possess unless you culture the organisms or use sophisticated molecular diagnostic procedures.

The CDC, working with the scientific community, should develop a comprehensive definition of a culture of a biological agent that would include microorganisms growing in artificial media, animal cells, and preserved viable materials from such cultures, which are the materials of concern.

Congress should recognize that the need to deal with the threat of biological terrorism will be an ongoing duty for the indefinite future and will continually require balancing competing considerations as discussed in our earlier testimony. Therefore, Congress, acting through the DHHS and CDC, should provide for continuing consultation with the scientific and biomedical communities regarding the substance and procedures of regulations governing select agents. The CDC should be empowered to act swiftly to adjust definitions, substantive duties, and procedural requirements to the inevitable changes resulting from scientific research. ASM is committed to working with Congress and the DHHS and CDC to protect against threats of terrorism while engaging in vigorous research for the betterment of humankind.

PREVENTING NUCLEAR TERRORISM

In 1986, the Nuclear Control Institute, in cooperation with the Institute for Studies in International Terrorism of the State University of New York, convened the International Task Force on Prevention of Nuclear Terrorism, comprised of twenty-six nuclear scientists and industrialists, current and former government officials, and experts on terrorism from nine countries. The report issued by the Task Force, along with more than twenty commissioned studies, remains the most definitive examination of nuclear terrorism in the unclassified literature. The Task Force warned that the "probability of nuclear terrorism is increasing" because of a number of factors including "the growing incidence, sophistication and lethality of conventional forms of terrorism," as well as the vulnerability of nuclear power and research reactors to sabotage and of weapons-usable nuclear materials to theft. The Task Force's warnings and its recommendations for reducing vulnerabilities, many of which went unheeded, are all the more relevant in today's threat environment of sophisticated and suicidal terrorists dedicated to mass killing and destruction.

There is now intense national and international attention to the risks of nuclear terrorism. The possibilities that al Qaeda might acquire the materials and the knowledge for building nuclear weapons or "dirty bombs" or might attack commercial nuclear-power facilities to trigger a nuclear meltdown, are of particular concern. The Nuclear Control Institute has been alerting the public and policymakers to these risks, seeking emergency measures to reduce the vulnerabilities, and monitoring and assessing the responses of industry, governments and international agencies.

DISASTER MOVIES

Fascination with disasters seems to be widespread as evidenced by the rapidity with which Hollywood picks up on so many, in many cases finding them extremely lucrative with a few hitting the top levels of popularity and income. One book listed more than a hundred successful disaster movies. Disasters engineered by terrorists have recently hit the screen. Munich is one, based on the murder of Israeli athletes at the 1972 Olympics in Munich, and now come two from the disasters of 2001, *The World Trade Center* and *Flight 93*. Even China has decided to get into movies of this kind by reliving the horrors of Nanking in the 1930s. The problem with this kind of movie is that accuracy of detail is a victim. Hollywood takes liberties with historical events, shaping them to fit the goals of the producer. For a book of this kind it is a particular problem. Many of the events documented in these two books have been the subjects of disaster movies and many people have seen them. It is important that readers recognize this disparity between the facts of the event and the additions and subtractions included by the film producer.

PLAN OF THESE TWO BOOKS

The disasters described in these books deal mainly with natural ones since they have been the dominant ones throughout history. Records of human tragedies become more frequent in modern times as our involvement in the total environment becomes more frequent and more pervasive. Sometimes a human-induced disaster is the result of ignorance, and at other times it is either error or poor judgment. There are also instances, fortunately few, where those responsible deliberately intended to destroy people and property. The terrorists who bombed Air India and Pan American flights are examples of these. All the events in the two books are scattered in terms of time throughout the past two millennia and are drawn from many countries. The United States has the biggest number from a single country because it tends to acknowledge publicly and in detail all of its disasters. Few other countries are as willing or as able as the U.S. to publicize disasters. As a result, there are fewer documented records of disasters from some parts of the world.

I selected each disaster on the basis of its impact on the social or physical environments of humans, both immediately and over longer periods of time. Oil spills are included because they are a continuing threat to our physical environment and we need to learn from the past. Coalmine deaths were far too numerous in the past and even today there are too many. They are an affront to human values. The unique nature of disasters creates its own rare responses. Emotions are triggered in new ways. There is a sense of isolation felt by both individuals and communities and this can sometimes lead to passivity or even paralysis if the event is catastrophic. For these people the human body is in shock, like recovering from major surgery, feeling that it cannot absorb any more change. Some react in other ways. There are individual acts of extraordinary bravery as when the captain of the Hindenburg ran back into the flaming wreckage to search for survivors. There are also the opposites of these selfless behaviors: looting and assault occur as people react to what they see as the total breakdown of their social order.

Each study is a single event, not a process, and so the disasters of wars and epidemics that are not pandemics are excluded. The nuclear bombing of Hiroshima, although a war event, is included because of the vast environmental consequences that followed from it in later years. In these books, in order to avoid having a catalogue of thousands of low intensity events, only earthquakes with strengths of magnitude 7 or more on the Richter Scale are included. Occasionally, some of lesser strengths are added when their impact is significant elsewhere. Events are arranged in chronological order, and lists of alternative ways of categorizing are provided at the ends of the books in appendixes. After a summary overview of the event there is a detailed description of what happened. Causes of the disaster and remedial actions to ameliorate damage or prevent recurrence are described and references are added for further study. Additional information on twentieth and twenty-first century events can usually be obtained in the archives of local or national newspapers for the day after each event.

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1

Supervolcano Toba, Indonesia

ca. 74,000 BC
Sumatra Island, Indonesia

The greatest volcanic eruption about which we know quite a lot

Lake Toba is in the middle of Northern Sumatra. It lies about two hundred miles from the epicenter of the magnitude 9.3 earthquake that devastated Asia in late December 2004, as its tsunami swept across the Indian Ocean. This lake is known as a caldera, the technical term for the crater formed by a volcanic eruption. It is a big lake, eighteen by sixty miles in extent and as deep as five thousand feet in places. The size of the lake can be attributed to Toba's eruption, which was the largest that has occurred, anywhere on earth, within the past two million years. About 74,000 years ago a high volcanic mountain that stood on the area, now occupied by Lake Toba, erupted and blew skyward a mass of ash and volcanic debris that was three thousand times as big as the total amount that erupted from Mount St. Helens in 1980. The entire subcontinent of India was covered with ash. All around the globe sunshine was reduced and temperatures dropped by about 3 degrees, and stayed at that level for years. During that time, throughout the world, millions of all forms of life died. Thousands of species vanished.

The naysayers of our time are busy telling us that increases of carbon dioxide in the atmosphere will destroy human life and our cities before the end of this century unless we change our ways and reduce the present levels of carbon dioxide. Yet, beneath our feet are forces of change far more destructive for the earth's environment and all of its occupants than anything that human activity has done or can ever do. Ordinary volcanic activity is familiar to us because we see it frequently. It is no surprise to visitors in Hawaii when magma pours on to the surface from deep volcanic vents. It is a common occurrence. Occasionally, however, a super volcanic eruption occurs—one that affects the entire globe. Fortunately, they appear rarely in human history but their destructive power is enormous and, unfortunately, their timing is not predictable. We give the name supervolcanoes to them. Toba was one of these, the biggest of all of them within the last two million years with a Volcanic Explosivity Index (VEI) of 8. It is now the model by which geologists assess worst-case scenarios for the future.

There are only about half a dozen locations around the world where geologists have identified supervolcanoes. One location is in New Zealand, one in Japan, and one in Russia. In the United States there is one in Yellowstone National Park where there was an eruption of strength 8 on the VEI, about 640,000 years ago. That strength represents a tenth of Toba's and a hundred times the strength of Krakatau. The past geological history of Yellowstone reveals that it builds up to the level of a super volcanic eruption approximately every 600,000 years so it is reasonable to say, as some geologists have already said, that another terrible explosion is overdue. Geological specialists have been checking the movement of magma deep below Yellowstone Park. The presence of this magma is well known by the surface manifestations of boiling hot springs and mud pots. Precise measurements over time show that the land within the caldera that is now Yellowstone rose thirty-five inches between 1923 and 1984. Later in the 1980s it subsided slightly.

A Yellowstone eruption on the scale of the previous one is a terrifying

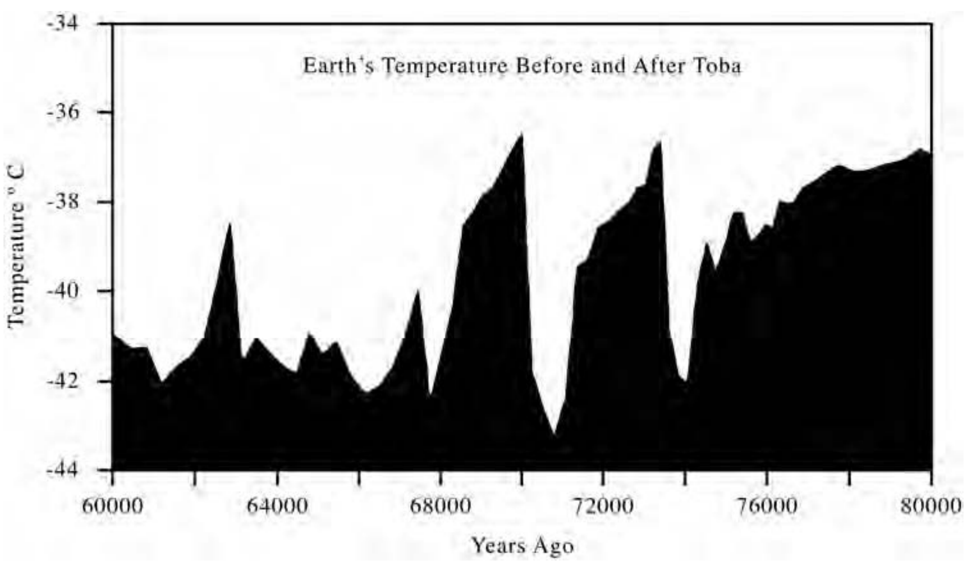

Figure 1 Impact of Toba on global temperature.

concept. It would transform all aspects of human life worldwide. The death toll would be huge. Although its VEI would only be one-tenth that of Toba, it would be disastrous. Tambora, an Indonesian volcanic eruption of 1815, was ten times stronger than Krakatau and only a tenth as strong as the ancient Yellowstone one yet it caused widespread destruction of life and agriculture all over the world. If no one wants to see a repeat of the ancient Yellowstone eruption, then it is even more certain that we do not want to see another Toba, especially since the scale of its destructive activity is now known through seafloor cores and ice cores from Greenland. From both of these data banks we can define climatic conditions around the time of Toba's eruption. Overall it is clear that the dust cloud from the explosion, one that reached high into the atmosphere because it happened near the equator, reduced the amount of sunshine that could reach the earth. Thus, temperatures worldwide were lowered by as much as seven degrees Fahrenheit and this condition remained for more than seven years. Had the eruption occurred near the North Pole the atmospheric dust would have stayed at a lower level within the atmosphere.

It is tempting to think that once the seven or more years had passed everything would come back to its former state. The reality was quite different. To begin with, the eruption coincided with one of the last phases of the last Ice Age, the Wisconsin Ice Age. The years of lower temperatures were an addition to the influences that ice was already exerting on the environment. Overall, geologists concluded that the damage caused by Toba was similar to the scenario drawn up by scientists for the effects of a nuclear war, generally described as nuclear winter. The aftermath of this global environmental disaster was most severe in tropical areas where vegetation is unprepared for coldness. In these tropical areas all the plant tissues above ground would die. Even temperate forests would suffer from the relatively sudden drop in temperatures and 50 percent of them would die. Large amounts of dead wood, aided by drought, typical of ice age regimes, would likely lead to an increase in forest fires. The story would be similarly destructive for life in the oceans but the elements involved would be different.

Geneticists believe that Toba had a particularly catastrophic effect on humans who, 74,000 years ago, were still at an early stage of development. The population on Earth may have been reduced to a few thousand people, pushing humanity to the edge of extinction. Homo sapiens had become an endangered species. The evidence for the catastrophic reduction of numbers around the time of Toba comes from an analysis of mitochondrial DNA that revealed a limited genetic diversity, far lower than the known age of humans would indicate. The total numbers of humans in the years following Toba seemed to be no more than ten thousand. Not until 50,000 years ago, 20,000 years after Toba, was there evidence of a rapid and widespread increase in the numbers of humans. In order to test the validity of their calculations regarding humans, geneticists examined the mitochondrial DNA of chimpanzees to find out if they too had been victims of the same environmental disaster. The results were conclusive. They had experienced a bottleneck similar to human DNA.

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2

Rome, Italy, fire

July 19, 64
Rome, Italy

Most of Rome, the Capital of the Roman Empire, was destroyed by fire in 64

On July 19, 64, the same date four and a half centuries earlier when the Gauls set fire to Rome, a fire broke out near the Circus Maximus and quickly spread all over the city of Rome. Large numbers of people lived in timber-framed tenements and, in the warmer weather of July, these readily provided the needed fuel for a fire. Over a period of six days, and then after a short lull, bursting into flames again for a further three days, the flames destroyed 70 percent of the city. Many of the most important buildings were destroyed and thousands lost their lives. One archeologist, examining the ground twenty feet below present levels, found nails that were partly melted by the heat before they fell from burning timber. Coins too were found in the same area, remnants of the possessions of the hapless victims that could not escape the fire.

The aristocrats lived on the higher ground of Rome and once a few tenements were ablaze, firestorms swept upward to higher and higher ground and burned their mansions. Experiments by archeologists trying to reconstruct the scene from 64 discovered that temperatures quickly rose beyond a thousand degrees Fahrenheit. This level of heat readily creates a vortex of swirling flames that reach higher and higher in order to find oxygen, to places like Capitoline Hill where the larger homes were. Attempts to put out the fire were hampered by the terrified cries of the many people who had nowhere to go. The speed of the flames soon caught up with them as they ran away from burning buildings. The emperor, Nero, was away in the eastern part of the empire at this time and he quickly returned as soon as news of the tragedy reached him.

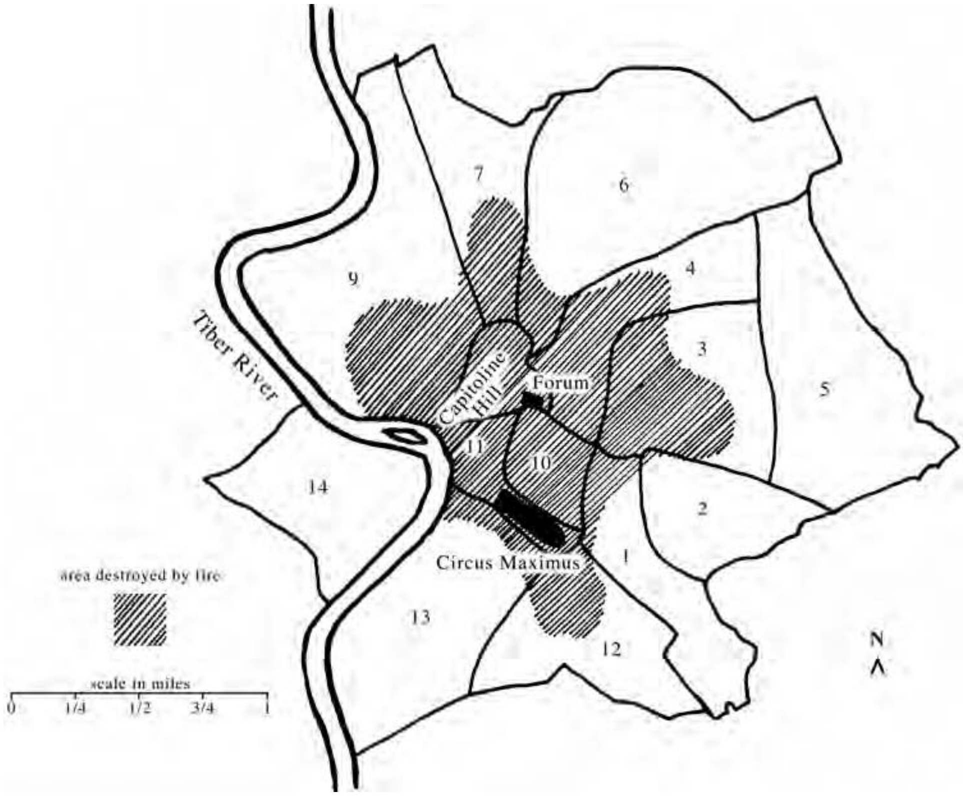

Figure 2 Extent of destruction during Rome's fire.

Emperor Nero opened the Field of Mars and the Vatican Gardens to refugees and arranged food and shelter for them. Supplies were brought in from neighboring towns and the price of corn was cut back for a time to a small fraction of its normal price. Roman society attached great importance to anniversaries of any kind and on this occasion, because it was such a vivid reminder of the earlier malicious attack by the Gauls, the people wondered if this, the worst fire in the history of the city, was an omen of good or a harbinger of evil. In spite of his generosity to survivors, it was not long before rumors began to circulate that Nero was responsible for all that had happened. Had he started the fire, people asked, in order to make space for another building he wanted to erect? This kind of thinking was typical of the times. When news was good the ruler is praised. When a disaster occurs, the ruler is blamed. Furthermore, it was generally known that Nero had grandiose ideas about the city, wanting to demolish the older tenements in favor of elegant buildings that fitted the greatness of Rome.

Nevertheless, historians were doubtful about Nero's involvement because his palace was a victim of the fire. This building, the Domus Transitoria was a magnificent structure that stretched from the Palatine Hill to the Esquiline. It was also noted that Nero was in the eastern Mediterranean at the time of the fire. Fires were commonplace in Rome. Dozens broke out every day. Roman historian Tacitus was one person who was convinced that Nero was responsible but many Romans thought it had been triggered accidentally. In the course of the conflagration some people were seen to be spreading the fire while others prevented attempts to extinguish it. Was this the work of people acting under orders or were they just looters taking advantage of the chaotic situation? They were neither but rather were gangs of irresponsible people wandering the streets looking for anything they could steal. When the fire finally burned out only four of the city's fourteen districts had been untouched by the fire. Lost in the flames were all kinds of art works, both Greek and Roman, and many of the temples were also destroyed including Vesta and Jupiter Stator.

Fire fighting at the time of Nero was sharply contrasted to everything we know today about fighting fires. The people involved were slaves. They were the losers in the military campaigns that Roman generals waged around the empire and they were brought back to Rome to serve the city by doing the jobs that no one else wanted. These fire-fighting slaves had been organized into seven groups, each responsible for two of Rome's districts. Each group was given buckets for use in case of fire. Whenever they were called to deal with a fire they formed bucket lines through which water was passed by hand to the fire where it was squirted on to the flames with a hand-held device that served this purpose. As soon as the fire stopped, Nero closed off the devastated places so that the debris could be removed. Even those who were owners of homes or renters were prevented from returning. They had to fend for themselves in areas outside the city, finding food and shelter as best they could, wondering if and where they might ever again have a place within the city. All of this added to Nero's already poor reputation among the lower classes.

As soon as the old sites were cleared, Nero began the reconstruction. He had a number of triumphal arches erected throughout the city and he rebuilt the temples of Vesta and Jupiter Stator and other places of importance that had been destroyed. His tendency to be extravagant soon became evident in these new buildings as the new Rome took shape. Each building was bigger and more ornate than the one that had been lost in the fire. Nero added a huge arena close to the site of the present Vatican City. When he came to rebuild his former palace, Domus Transitoria, Nero's megalomania became obvious. In the new palace, which he named the Golden House because of all the gold, precious stones, and ivory that it contained, he envisioned an imperial residence, something far beyond the former palace. He added numerous pavilions, each linked to another with covered walkways, forming a small city within the larger one. Additionally, there were temples, baths, gardens, fountains, and a large artificial lake covering 200 acres that later became the site of the Roman Coliseum. To top off all this madness Nero had a bronze statue of himself erected close to the palace's entrance. It stood more than a hundred feet high and could be seen from any part of Rome.

Whether arson or accident was the explanation for the fire, Nero continued to be suspected so he felt he had to take action to clear his name from all suspicion of culpability. He singled out the Christians of Rome as the public scapegoats and, in a style very familiar to us today, was able to secure a few traitors among this group who were willing to confess to the crime. Tacitus described Nero's choice as choosing the notoriously depraved Christians, a phrase that was frequently used in Rome to identify them. They were considered cannibals because they spoke of eating the flesh and drinking the blood of their leader and they were described as incestuous because of their love for one another. To Tacitus, because the Christians' leader Christ had been executed in Tiberius' reign by the governor of Judea, Pontus Pilate, thirty years earlier, it was unthinkable that people would continue to be followers of such a criminal. He called their belief a deadly superstition, one that had broken out in Judea in spite of the death of their leader and had now spread to Rome. Tacitus concluded that all degraded and shameful practices seem to collect and even flourish in Rome.

In spite of the explanation proposed by Tacitus for selecting the Christians, it is unlikely that Nero was thinking of their beliefs when he blamed them. He just needed to find an unpopular and defenseless group, which he could blame, and his choice of the Christians was a popular one. They were seen as enemies of the human race because they were strange and, therefore, in the popular mind, always liable to behave in strange ways, perhaps stirring up civil strife or causing violent outbreaks. Strangeness is the term that Romans used to define every foreign cult. There was a strong feeling that only the ancestral gods of Rome ought to be worshipped and the only way to do that was by following traditional procedures. Any adherence to non-Roman religion was superstition, a label that could at any time imply crimes. Many of these superstitions successfully survived in Rome, especially when they happened to be in favor with the authorities, but safety and survival were never assured things.

The Jews too were considered strange and there were about several thousand of them in Rome. They were no more popular than the Christians. Why then were they not the scapegoats selected by Nero? There were two reasons for this: first, some Jews had helped the Roman army on one occasion so they inherited a sort of protected status for a long time. The second reason related to their attempts at revolution in Palestine, which began to appear during Nero's reign. The Emperor was anxious to avoid any action that would make it difficult for the Roman army in Palestine to stamp out these revolts. There was another development that made it easy for Nero to pick on the Christians. For the thirty years following the execution of their leader, Christians in Rome formed part of the Jewish community and attended their synagogues. A few years before the fire, a letter arrived from Paul, the Apostle, in which he defined the sharp differences between the Jewish ancient religion and the new Christian faith. As a result of this letter, Christians in Rome left the synagogues and met in their own communities. They had become an identifiable group completely separate from the Jewish ones.

Thus began the persecution of Christians in Rome, soon to spread throughout the empire. Hundreds of Roman Christians were arrested and put to death by Nero in the most cruel and farcical ways imaginable. Many were dressed in wild animal skins and torn to pieces by dogs. Others were crucified or made into torches to be lit after dark to illuminate Nero's gardens. It is probable that the two great Christian leaders, Peter and Paul, both of whom were in Rome at the time of the fire, met their deaths at this time. Tradition indicates that Peter was crucified while Paul was beheaded. So brutal was the treatment of the Christians that people began to feel sorry for them. Romans became convinced that they had nothing to do with the fire and that they were being sacrificed for one man's mania. Within four years of the fire Nero would be dead. Following rejection by the army and the Roman Senate he took his own life. His fourteen years of rule had ended but the persecutions he had inaugurated went on.

Nero's extremes seemed to spur the growth of Christianity rather than impede it. Late in the first century, the large numbers of Christians he encountered everywhere made Emperor Domitian decide to send a team of people to Galilee to find out who Jesus was and how he had attained such influence among his followers. Domitian's period of rule was marked with a series of violent persecutions against any individual or group that was different from the norms of Roman life as he understood it and his thoroughness in attacking Christians is a good example of his treatment of enemies. He discovered that Christians consistently refused to adhere to the imperial cult of Caesar worship and this gave him a rationale for launching a mass execution of Christians wherever he found them. Like Nero before him, his hatred of Christians was not based on any particular aspect of their beliefs but solely because they did not conform to Roman norms. For this reason they, along with other divisive groups, met terrible fates at the hands of Domitian.

A few years after the death of Domitian, when Trajan was emperor, some correspondence about Christians between a regional governor and the emperor, gives a good picture of the status of Christians around the year 100. Trajan, in sharp contrast to Domitian, tended to be sympathetic toward dissident groups but he forbade meetings of secret societies because he thought they might be subversive. This edict, inevitably, clashed with the behavior of Christians. They were different from all others around them and they knew it. Their leader had been crucified because he did not conform to the society within which he grew up. Their only opportunity for social life was to meet privately. They knew that they would get into trouble if they were seen meeting publicly. They posed no threat whatever to Roman authority. Their apostle Paul had made that very clear in his letters of instruction. Nevertheless, in the mind of Trajan, with the empire's history of rebellions and revolutionaries, secret meetings were dangerous. It was during Trajan's reign that a letter came to him from Pliny, a governor of one of the regions, asking for clarity about his edict concerning secret societies.

Pliny explained in his letter that he had never been present when

Christians were being examined about their loyalty to the Roman Empire but he now was faced with making a decision about some Christians who had been accused of opposing Roman laws. He went on in his letter to outline the procedure he took in these cases but he felt he needed assurance or correction about it because of his inexperience. The procedure he had followed in these particular cases was as follows: he asked each individual whether he or she was a Christian. If the answer was yes he repeated the question two more times, adding at each repetition of the question that serious punishment would follow if the answer continued to be yes. Anyone who persisted with yes three times he punished by sending him or her to Rome. In Pliny's mind, the Christian's stubbornness and unshakable obstinacy was something that ought to be punished. He added that he had dismissed those who denied that that they were Christians or who had left the Christian community provided they repeated after him a formula of invocation to the gods, made offerings of wine and incense to your statue, and cursed the name of Christ. Pliny knew that real Christians would never do these things. To make sure that the statements from those who cursed Christ were accurate Pliny investigated what he called the truth, from two slave women, using torture, but found nothing other than a degenerative cult.

The reply from Trajan was a firm endorsement of what he had done and it included an interesting double addition: first, Christians must not be hunted down but only questioned when specific charges are brought before a ruler; second, accusations must not be laid against Christians on the basis of pamphlets that criticize them and are circulated anonymously. This was an interesting recognition of the many conflicts and disagreements about Christianity that circulated at that time. Trajan's successor, Hadrian, seemed indifferent to Christians although, in all probability, they became involved in the massive purges that he enacted on Jews. If we look farther ahead to the second half of the third century, when Marcus Aurelius was emperor, we find a recurrence of the earlier hatreds. His persecutions of Christians were particularly bloody. Under Emperor Diocletian, at the beginning of the fourth century, violence against Christians began again and lasted for a number of years until, with the conversion of the Emperor Constantine, Christianity became the official religion of the Roman Empire. Perhaps Constantine had learned that persecution always adds more Christians rather than diminishes their numbers.

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3

Pompeii, Italy, volcanic eruption

August 25, 79
On the Bay of Naples in southern Italy

Eruption of Mount Vesuvius destroyed Pompeii and killed its residents

In the early morning of August 25, 79, a mass of pyroclastic material erupted from Mount Vesuvius and, traveling at more than 60 mph, collapsed over the town of Pompeii. Hot ash, lava fragments, and poisonous gases were blasted into homes through tiny openings in windows, doors and roofs. Every one in the town was killed, but not instantaneously. As people inhaled the hot gases their lungs quickly filled with fluid. It was just like swallowing fire. With subsequent breathing the victims found themselves gradually suffocating in a painful death as their windpipes became clogged and their lungs stopped working. It was all over in a short time and, before the end of the day, Pompeii had been covered and destroyed by a twenty-foot blanket of volcanic debris. For more than 1,500 years the town lay buried and forgotten. All that remained was the memory until, after a long time, it was discovered by accident.

Mount Vesuvius is one of a chain of volcanoes stretching northward along the length of Italy. These volcanoes lie at the junction of the African Tectonic Plate and the Eurasian one, a location where there is always a zone of either pressure or tension. For millions of years the African Plate has been pushing against the Eurasian one along a line of action that stretches from Gibraltar to Turkey. From time to time, in the short term, a weak area gives way and either an earthquake or a volcanic eruption is the result. Over a much longer period, the influence of the African Plate gave rise to the Alps. The peak of Mount Vesuvius is about four thousand feet above sea level and six miles from Pompeii.

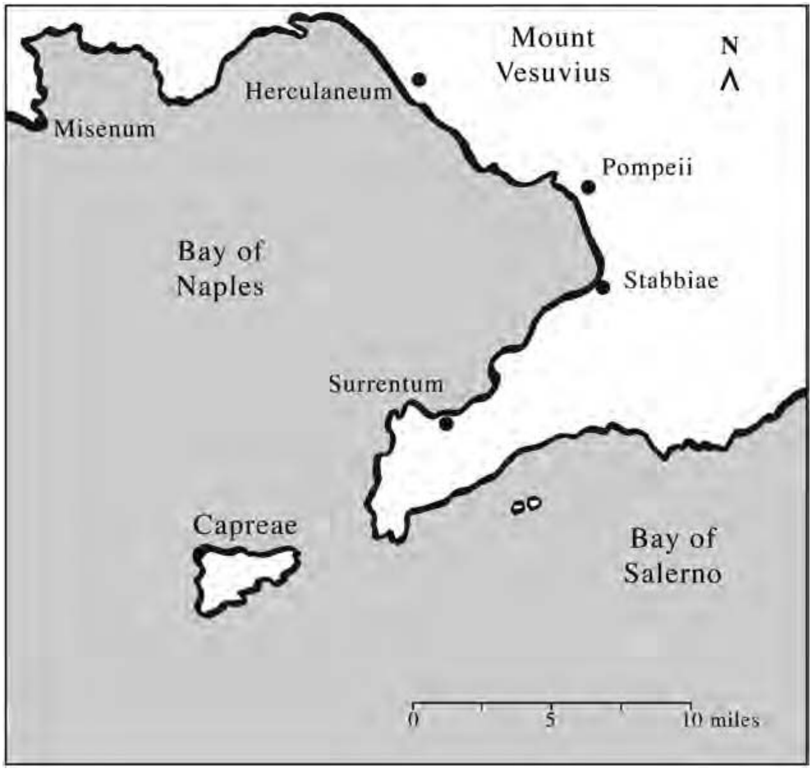

Figure 3 Location of Pompeii.

The accidental discovery of Pompeii's ruins happened in the sixteenth century when an underground irrigation canal was being dug and the workers found themselves cutting through old buildings. An inscription "Pompeii" was found on one wall and people thought it was the name of a house belonging to a wealthy person. Nothing was done about this discovery and two more centuries elapsed before further attention was paid to the buried buildings and even then the focus of interest lay in a search for any valuable objects that might be there. Many people visited the ruins in the eighteenth century but it was only after Italy became a united nation in 1860 that serious study was devoted to it. King Emmanuel II commissioned Giuseppe Fiorelli, a well-known archeologist, to conduct a thorough excavation of the ancient city of Pompeii. He worked on the project with great precision, creating a series of zones in which each one represented a number of houses. He arranged an identifying number for each building.

Fiorelli kept a meticulous record and also made sure that buildings would remain intact by excavating from the roof down. His plan was to leave as much as possible of the site in its original form and location. He did something else that was his own idea. It turned out to be the unique contribution that enables us today to see in three dimensions exactly what happened within individual homes as the volcanic ash arrived. In 1863 he noticed as debris was being cleared away that cavities resembling bodies began to appear in the volcanic material, so he found a kind of plaster that he could force into these cavities under pressure to prevent them collapsing. The result was extraordinary. The volcanic ash had solidified around human and animal bodies to such a degree that the smallest detail could be identified. The addition of the plaster meant that Fiorelli now had complete three-dimensional models of people and animals exactly as they had been in their last moments of life. Victims frequently died in agony as the ash smothered them and the pain of their experiences was clearly etched in their faces.

No one in living memory ever expected to see Mount Vesuvius erupt. It had been quiescent for many centuries and generation after generation had worked the land up the slopes of the mountain. Volcanic ash from time past had provided an ideal foundation for good soil so all kinds of crops were grown, often as many as two crops from a single field in a year. Wine, wheat, and a variety of sauces were shipped regularly to France, Greece, and Egypt. The warm Mediterranean climate, proximity to the ocean, and the advantage of being part of the Roman Empire all gave Pompeii a huge advantage for trade. It is not clear how many people lived in the town at the time of the eruption because Pompeii had been hit with an earthquake, a common occurrence in that area, seventeen years earlier and it had destroyed much of the town. At that time the population was more than ten thousand. Every effort was made to restore the town in the

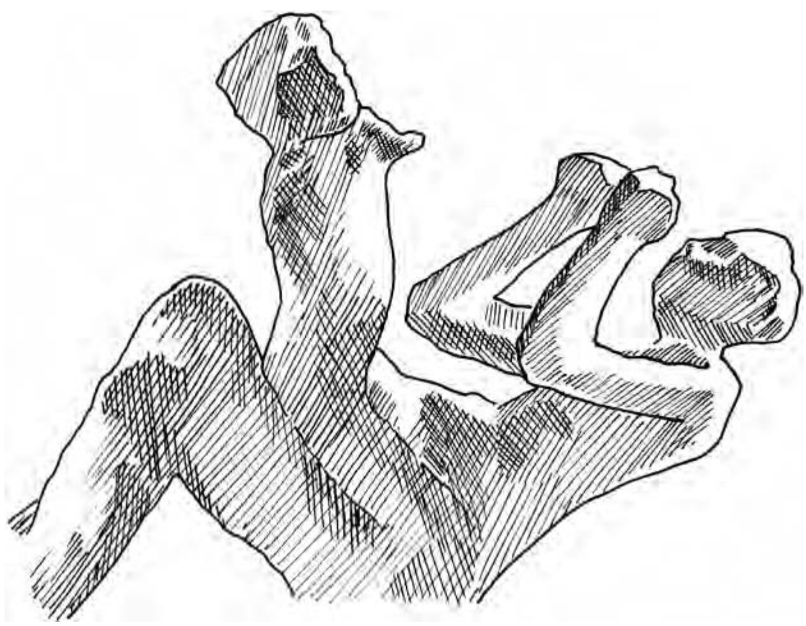

Figure 4 Drawing of reconstructed human body.

wake of the earthquake because it was such an agricultural paradise and every person benefited from its success. We may not know the exact population in 79 but we do know that thousands died instantly when the eruption occurred.

Fortunately for us today there were many historians in Italy and we have first-hand accounts from some of them. Pliny the Elder was a much-respected historian and he happened to be near Pompeii at the time of the eruption of Mount Vesuvius. He was fifty-six years of age, old for that time, a bit overweight, and suffering from asthma, so Emperor Titus decided to give him an easy responsibility, looking after the Roman fleet at Misenum, twenty miles northwest of Pompeii in the Bay of Naples. It seemed like a very comfortable position for him but he arrived at the wrong time for any ease, in the early part of August of 79. On the morning of the twenty-fourth of that month a servant came to him to report the appearance of a strange cloud hovering over the Bay of Naples. Pliny's description of the cloud and his experiences throughout the remainder of that day were recorded carefully by those who were with him, especially by his nephew, later known as Pliny the Younger. They provide a vivid picture of the impact of the eruption on individuals. In the case of Pliny senior, despite all the efforts by him and his staff to safeguard their lives, the twenty-fifth of August proved to be Pliny's, as well as Pompeii's, last day.

Pliny the Elder described the cloud as an immense tree trunk rising high into the air and opening out into many branches. He realized at once that he was witnessing a major natural event so he ordered his staff to make ready a small galley to take him closer to the cloud. Just as he was about to leave he received an urgent call for help from some friends who lived on the slopes of Mount Vesuvius. He immediately ordered several additional boats to go with him toward Pompeii to help in the rescue. As the boats approached the nearest beach to Pompeii, Pliny noticed that ashes were falling in increasing density, getting thicker and hotter and accompanied with black pumice stones and cinders, as they got closer. Suddenly, as they reached shallow waters, they found they could not go further as the waters had become blocked with debris from the mountain. They changed course southward and landed at Stabbiae, about five miles to the south of Pompeii. Panic had overtaken the crew of the ships as night approached and the night sky continued to be lit up with flashes of fire. Pliny made every effort to calm things down. He took a bath and a leisurely dinner and encouraged everyone to have a good night's sleep. The morning of the twenty-fifth of August seemed to come suddenly as they awoke to loud noises with the walls of their house violently swaying backwards and forwards. The ships in the harbor were being tossed about like toys. Although daylight had come it was still pitch-dark and as Pliny stepped outside the house he was met with sulfur fumes and a hail of pumice particles and ash. He collapsed, unable to breathe, and died.

The beginning of the eruption of Mount Vesuvius began on the afternoon of the previous day, the twenty-fourth of August, in the form of the cloud of ash and smoke that Pliny had observed from Misenum. Molten ash and pumice was being ejected from the volcano at a rate equivalent to 600 mph. Ten thousand tons of it left Mount Vesuvius every second. Much of the pumice consisted of pieces larger than a baseball. Within minutes, of the start of the eruption, the cloud of debris had risen nine miles into the sky, a height well beyond that of Mount Everest. Normally, in August, the wind direction over the Bay of Naples is from the northeast. On this occasion, however, it came from the northwest so the fallout was carried over Pompeii. The sky was dark and all over Pompeii people were lighting lamps in the middle of what would normally be bright daylight. Layers of pumice and ash were accumulating on roofs and buildings were shaking constantly from the earth tremors. From time to time a large piece of volcanic rock would crash through the roof of a building. By late afternoon the column of material from the mountain had risen to a height of ten miles, a hundred million tons of ash and pumice had been ejected and Pompeii's streets were twenty inches deep in volcanic debris.

Early in the morning of August twenty-fifth a series of pyroclastic surges emerged from Mount Vesuvius. The volcano's mouth had collapsed and volcanic material was being ejected at fifteen times the earlier rate. This column of ash and pumice was now so dense that it began to collapse and flow down the mountain slope as a glowing red cloud. Its temperature exceeded 1,500 degrees Fahrenheit and, as it rushed toward Pompeii at sixty miles an hour, the town was smothered. Pliny the Younger, the nephew of the Pliny who died at Sabbiae on the twenty-fifth of August, was still at Misenum when the final destruction of Pompeii occurred. He took time to write an account of it all and he sent it to the historian Tacitus a few years later. His descriptions are the best records we have of Pompeii's final day. So widespread was the destructive power of these final pyroclastic surges from Mount Vesuvius that places like Misenum, twenty miles away from the mountain, were so badly shaken and so heavily covered with volcanic material that people felt they had to get as far away as they could. Pliny persuaded his mother to follow him out of Misenum and together they managed to get to a place that was beyond the reach of the falling debris.

From his vantage point north of Misenum, Pliny saw the entire area between him and Pompeii covered with one black cloud. The sea was like the land and we know now that pumice fragments, the main part of the material that flowed from Vesuvius, is lighter than water so it formed a new surface on the ocean. He felt like a person who had been locked in a sealed room without light because in every direction he saw darkness all through the next day. All around him the cries of people and children went on throughout that day. Occasionally there was a flash of light, not from the sun but from the fire that accompanied the cloud and fortunately never reached Pliny's location. All around him ashes were falling steadily and to avoid being buried and crushed beneath them he had to get up periodically and shake them off. Finally, Pliny saw some glimmers of light and then he saw the sun. It was very faint, as if an eclipse was occurring. He and his mother began the journey back to Misenum. Everything and every place were different because of the thick layer of ashes that looked like a giant snowfall.

Mount Vesuvius has erupted dozens of times since that fateful day in 79, including ten times between 200 and 1100. Then, for five hundred years from 1100 to 1600, just as it had been in the period before 79, it was quiescent. No doubt people were lulled into a false sense of security in those times too because their knowledge of geological activities was as inadequate as it was in Roman times. In 1631 Vesuvius burst into action once again and continued frequently until its final eruption in 1944. It seems to an onlooker now that the crater is sealed shut with not even a sign of smoke emerging from it. The one thing we do know, and this was not known even as recently as 1944, is that the underground motions of the great tectonic plates that cover the earth are constantly in motion and always will be. In particular the two plates that meet in Italy are today pressing against each other, building up pressures that some day will give rise to new earthquakes and fresh volcanic eruptions.

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4

Alexandria, Egypt, tsunami

365 AD
Harbor of Alexandria, Egypt

A tsunami generated by an earthquake in Greece destroyed Alexandria

In the summer of 365, the port of Alexandria in Egypt was hit with a powerful tsunami that traveled across the eastern Mediterranean from a sea-floor earthquake near Turkey. Italy, Greece, and other places were also hit but the heaviest blow fell on Alexandria. It was in direct line with the direction that the wave took and it was one of the first places to feel the impact of this wall of water traveling at more than 500 miles an hour. As is always the case with large tsunamis, when the wave reaches shallow water, as it would in the harbor of Alexandria, it first rises to a great height, then recedes back out to sea before coming back a second time with renewed force. The people of Alexandria, unaware of the nature of tsunamis, walked out on to the new beach to collect fish. The seabed had been laid bare and all kinds of sea life could be seen. People wandered freely far out from land gathering fish and they were caught in the returning wave. As many as 50,000 people were killed either from the returning wave or in the destruction that followed on shore.

Ships were picked up by the wave as it reached the harbor and they were thrown some distance on to land. In some cases they landed on roofs. The strength of the tsunami was evidence that the earthquake that caused it was a major one, probable at least 8 on the Richter Scale. Sediment cores taken from the harbor in recent years enabled geologists both to date the event and to establish the probable location of the earthquake that caused it. Alexandria does not lie on a geologic fault like so many other places

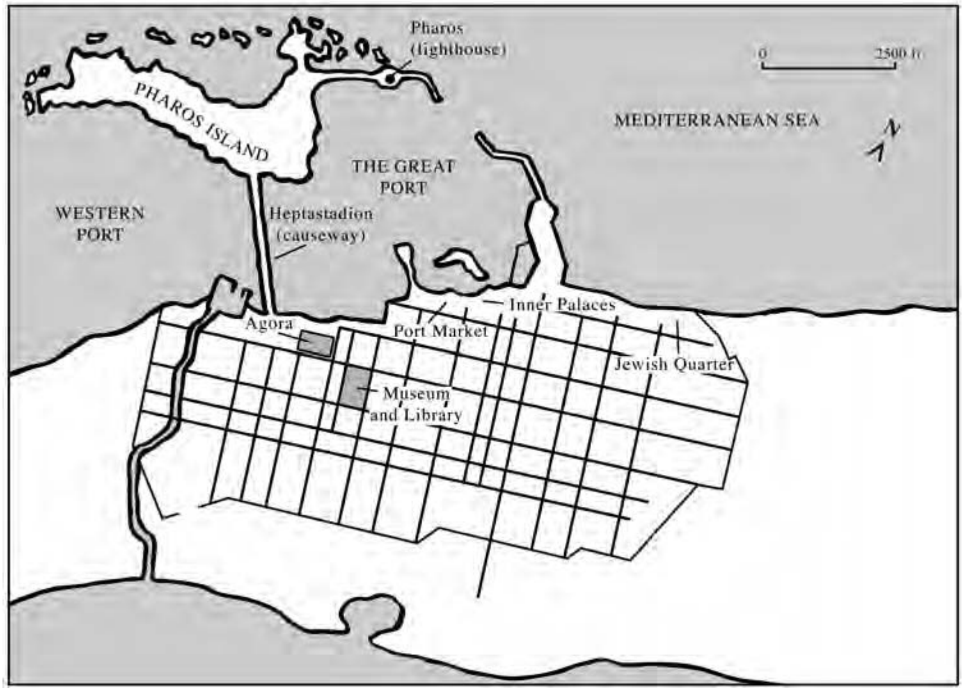

Figure 5 Alexandria at the time of the destructive tsunami.

in the eastern Mediterranean so it has no record of earthquakes and the occurrence of a tsunami is so unlikely that the port authorities of Alexandria gave no thought to it. Royal palaces and the obelisks that were known as Cleopatra's Needles were built along the shore and one of the ancient wonders of the world, Pharos Lighthouse, stood on the outermost extremity of land around the port. Alexandria, founded by Alexander the Great more than 300 years BC, was the biggest commercial and cultural center of the whole Greco-Roman world in 365. It was from here that the Roman Empire's main supply of wheat was shipped. The Nile Valley was the best wheat-growing region in the empire. It had also been the seat of the world's oldest university, located next door to the biggest if not also the oldest library of antiquity.

Powerful earthquakes are known to have occurred previously in the same location that originated Alexandria's tsunami. One of these earlier quakes was so powerful that it created a hole, deep into the sea floor. Not every earthquake gives rise to a tsunami but, whenever the level of the seabed is changed over a significant distance, the displacement of water that it causes creates a special wave, a tsunami. That was what happened when the level of the seabed was changed in the 2004 Indonesian earthquake. The power of the initial release of energy sends the tsunami across the ocean at more than 500 miles an hour. In the deeper parts of the ocean the huge displacement of water is barely visible on the surface and it has little effect on ships in the same place. Once it approaches land, however, it changes dramatically. The lower part of the wave slows down as it encounters the friction of the seabed in shallower waters while the upper part increases in height as the same volume of water enters shallow water. As it rises in height it creates a vacuum that sucks water away from the shoreline, leaving as much as two miles of the seabed exposed. This was the condition that caught Alexandrians off guard. They had never before encountered a tsunami. Today we know that the withdrawal of water is the prelude to a sudden and fast destructive wave crashing on to the shore.

Saint Jerome, whose original work led to the famous Latin Vulgate Bible, was so moved by the destruction of Alexandria in 365 that he thought the world was returning to its original chaos. Like other great scholars, both of that time and from earlier years, he knew that Alexandria was one of the greatest cultural and literary centers of the world and he hoped that its famous library would be preserved. Hundreds of thousands of manuscripts were stored there. Euclid's work in mathematics was there as was also the work of another famous Greek mathematician, Eratosthenes, the man who was the first to calculate the length of the earth's circumference. The Greek version of the Old Testament, known as the Septuagint because it was assumed that seventy Jewish writers wrote it, was compiled in Alexandria. It was the version widely used by Paul and others in the first century of Christendom before other translations of the Old Testament were available. Unfortunately, Jerome's wish was not to be, not because of the tsunami but rather on account of the many conflicts that were centered on Alexandria as different religious and military powers fought for ascendancy there. The library dated from the times of the Ptolemaic rulers of Egypt. Over the years it suffered major damage from accidental fires. In 47 BC, during his military campaign in Egypt, Caesar set fire to ships in the Port of Alexandria and the fires spread to the library.

In 391 riots were instigated by fanatical Christians because of the collections of heretical documents that were stored in the library. Their actions caused serious damage. Over the two hundred years that followed, the library was restored to a condition close to its former greatness as manuscripts were added and lost ones replaced with copies. Then, in 641, the Caliph of Baghdad, in another moment of religious fanaticism, ordered the burning of the entire library. Archaeologists have found what they believe to be the former site of this library. A Polish-Egyptian team excavated parts of Alexandria and discovered what looked like lecture halls or auditoria. They found thirteen of these lecture halls, sufficient space to accommodate five thousand students. The question most-frequently asked is, how did this, the greatest collection of books in the ancient world, came to an end? In fact, as archeological research has revealed, there were two libraries in Alexandria, the royal one and a daughter library. Both were within the city of Alexandria. The Royal Library was destroyed in the aftermath of Christianity becoming the official religion of the Roman Empire. The daughter library survived a bit longer but it too was destroyed before the year 400. One thing about this library's demise is known: when Arabs conquered Egypt in 642, there was no library there.

In the thousand and more years that followed this event, the underlying threat of another tsunami never disappeared because the tectonic forces that caused the tsunami in 365 continued to operate as they had always done. The people of Alexandria had no understanding of these forces and so the memory of what had happened remained as an inexplicable event. Fortunately, in relation to this risk of another tsunami, Alexandria ceased to exist as a seaport and important city in the centuries that followed the conquest of Egypt. The new authorities had little interest in a major seaport and decided to make their capital on a site that is now the city of Cairo. The waterways that connected Alexandria to the Nile gradually silted up and maritime trade dropped off. People who were connected with the sea trade left and, by the time that Napoleon's ships arrived there around the year 1800, Alexandria was little more than a small fishing village. Napoleon's visit created a new interest in the sea on the part of Egypt's rulers. Within twenty-five years, the city was once more a busy seaport as new canals were dug, linking the port with the Nile. With French assistance, warehouses, docks, and homes were built. By 1840, Alexandria's population had risen to 250,000. Today it is a city of more than six million and the danger of another tsunami like the one that arrived in 365 still remains.

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5

Antioch, Syria (now Antakya, Turkey), earthquake

526 AD

Antioch was located in what was called Syria,
at the time of the earthquake

Deadly earthquake with hundreds of thousands killed

Antioch, like several other locations in the eastern Mediterranean, had a history of repeated damage from earthquakes. It was probably damaged to a greater extent than most of its neighbors because of the multiple actions of four tectonic plates. The Anatolian Tectonic Plate beneath Antioch was moving north-westward under pressure from the Arabian Plate. These two were then influenced by the African Tectonic Plate as it subducted under the Eurasian Plate. In May of 526, in the early evening while people were in their homes, the worst of many earthquakes hit the city, demolishing it completely. Every building was destroyed. There were many aftershocks that added to the terror of the event, but the greatest devastation came the next day when a fire engulfed the entire city. A quarter of a million people perished in the course of all that took place.

Antioch was a critical frontier in the political and military world of the sixth century. Conflict between the Byzantine Roman Empire and Persia had frequently exploded into warfare and Antioch, at that time part of Syria, was the place that defined the boundary between the two. The earthquake of 526 was followed by aftershocks and, in the course of one of these, the Great Church was demolished. Thousands of lives were lost, largely those of the Christians who were there for a church assembly. Several major earthquakes hit again in later times. The 526 earthquake is singled out partly because of the enormous damage it caused, but also because of its significance for the Byzantine Roman Empire. Emperor Justin was about to hand over his authority to Justinian who had made it clear to all that he intended to extend the boundaries of the empire to what they were in the heyday of Roman power. Antioch was a key location for this purpose because of threats from Persia, so the emperor in Constantinople spent two thousand pounds of gold to rebuild it. Some years later, Emperor Justinian was reminded of the value of Antioch when the Persian King Khosran I sacked the city in 540.

The significance of Antioch to Rome dates from the Roman army's conquest of it in 64 BC. At that time, the city received all kinds of attention from Rome. Great temples, a forum, a theater, aqueducts, and baths were added. Constantine, after he became emperor in 305, added the golden-domed Great Church. The church was so much admired by the people that, when it finally caught fire and disintegrated, everyone decided that the earthquake was a punishment from God. The few survivors of the earthquake and fire described the catastrophe as the destruction of every building and every other thing that was standing. When the fire finally ended there was nothing left but the rubble and ashes on the ground. Not only in ancient times, as was the case here, but in the twentieth century too, great earthquakes were often followed by fires because the materials used for building and the open fires used for cooking made it easy for fires to spread as houses were toppled over. San Francisco in 1906 and Tokyo in 1923 both experienced far greater destruction from the fires that were triggered than happened from the earthquake alone. Saddest of all the survivors' experiences was the sight of looters who arrived from neighboring communities to steal what they could from bodies or buildings, using violence whenever any person tried to stop them.

Seleucia was the port of Antioch in Roman times and sometimes the capital of Syria. This port, less than twenty miles from Antioch, is mentioned in the Bible as the place from which Paul sailed on his missionary journeys. It carried the name of its founder, Seleucius and was the commercial port for Roman Antioch. Seleucia had a strong fortress and a naval shipyard. During the early stages of Christianity, Seleucia had the privileges of a free city. Its harbor was enlarged several times under different Roman emperors. Seleucius must have had a passion for building cities because there were eight other cities in Roman times named after him. Antioch had a population of about 500,000 in Roman times. Its great Greek buildings and theater along with the sacred grove of laurel and cypress earned for it a reputation of being devoted to pleasure. The city was often referred to as Antioch the Golden but, because of the frequency of its earthquakes, it often had to be rebuilt. One such earthquake, in 37, caused the Emperor Caligula to send two senators to report on the condition of the city. Another earthquake followed in the next reign and, in 115, during Trajan's sojourn there with his army, the whole site was convulsed in an earthquake, the landscape altered, and the emperor was forced to take shelter in the circus for several days.

The empire, following the acceptance of Christianity in the time of

Constantine, had a special interest in Antioch because of its ties to historic Christianity. By the end of the third century, estimates of the numbers of Christians were more than 100,000 and Antioch had become the seat of one of the four great Christian centers, the others being Rome, Constantinople, and Alexandria. One of the canonical Eastern Orthodox churches is still called the Antiochian Orthodox Church, even though it had moved its headquarters from Antioch to Damascus many centuries ago. Arrangements of this kind were not unusual; some popes of the Roman Catholic Church retained the title "Bishop of Rome" when they happened to reside in Avignon, France.

From the viewpoint of the beginnings of Christianity and its spread all across the Roman Empire in spite of severe persecution, Antioch was by far the most important location. For some time after the crucifixion of Jesus, his followers were dominantly Jewish converts and their life as a community was centered in Jerusalem. At one point, their teaching angered the non-Jewish authorities and a widespread murderous assault was launched against them. Surprisingly, the leader of these attacks was the same person who, later, would be their main advocate and teacher. His name was Paul. Large numbers of Christians left Jerusalem to escape the persecution and many of them reached Antioch. Paul pursued them and it was while he did so that he had an extraordinary experience of Jesus near Damascus. As a result of this experience Paul became an ardent Christian. He joined the Christians of Antioch and from there began his life work of traveling throughout the Roman Empire to share the Christian news about Jesus.

The name Christian had not been in use as a definition of Jesus' followers until they came to Antioch. It is an indication of the importance of this city that it gave posterity the name by which the followers of Christ would be known for all time. Paul traveled from one end of the Mediterranean to the other and finally ended his life in Rome. The final triumph of Christianity came with the conversion of Emperor Constantine in the fourth century and the adoption of Christianity as the official religion of the Roman Empire. Antioch, because of its strong relationship with the early spread of Christianity throughout the Roman Empire, became a key source of Christian beliefs, especially beliefs about interpreting the Bible. Other centers of theology had a variety of views, mainly symbolic or philosophical. Antioch, by contract, based its views on the historical context within which biblical narratives and teachings were recorded. The historical context then became its key to interpretation, a key that has become a norm in modern times.

Today Antioch, or Antakya as it is known, has a population of 125,000 and is a key trading center for the rich agricultural region in which it is situated on the southeastern coast of Turkey. For centuries it had been little more than a village and its present good health and popularity with tourists is due to French rule in the years between World War I and II. Remnants of the ancient city, mainly blocks of old marble on walls of streets, stand nearby on ancient ruins. France's main legacy from its years of occupation is a film palace and the outstanding contribution from earlier centuries is a seventeenth-century mosque. Some of the ancient walls on the higher ground above the present city have been preserved but they are not very accessible to tourists. A key attraction for every visitor is the collection of Roman mosaics that come from the heyday of the Roman Empire and are preserved in the Archeology Museum. Their color and detail are so clear that experts refer to them as the best available anywhere.

The plain around Antakya is littered with historical mementoes, mounds that cover buildings and people that were destroyed by warfare or earthquakes, and ruins of places that survived assaults. The old seaport of Seleucia, long abandoned because the harbor filled up with silt in the long stretches of time that saw no shipping activity of any kind, still holds fascinating artifacts. During Emperor Vespasian's reign, a tunnel was dug out of rock at sea level to provide water for Seleucia. Today a visitor can see this tunnel with its series of thirty-foot-high great halls. Even though a small irrigation canal was built through these halls in modern times, a visitor can still easily walk through them and see at first hand some of Rome's renowned construction handiwork. Antakya claims to have the oldest church in the world, the one named St. Peter's, not to be confused with the bigger church of the same name in Rome. The apostle Peter is said to have preached in this church. If true, that would date it back to a time before 100. This church is a cave complete with a reservoir of water and a tunnel to ensure escape during the period of Christian persecutions.

A thousand years later, soldiers of the Crusades, people from the Roman Catholic Church who took vows to restore to Christian ownership the lands that had been captured by Muslims, decorated this cave in Antioch in honor of its history. A small Catholic community still lives in Antakya. It celebrates mass in a nineteenth-century church on the city's main street. A famous temple of Apollo also stands in this place, surrounded by villas and gardens that were added by wealthy people. Additionally, there is a legend that Antony and Cleopatra spent time here. The Antioch games, a major event of Roman times, were held in Antioch for many years and they surpassed in popularity and importance their counterparts in Olympus. The ruins of several monasteries can be seen today on the hills surrounding the old city of Antioch, including Saint Simeon's, named after the saint who, in the fourth century, initiated the strange rite of people sitting on the tops of high pillars, often for long periods of time. At its later stages of popularity more than a hundred of these pillars were occupied.

The Roman Emperor Julian, who had grown up in Antioch, was particularly fond of returning to the city to spend time there. Late in the fourth century, when he went back once again to Antioch, he found Christians busy at work tearing down the Temple of Apollo in order to use its stones to build churches. He was furious and immediately arranged to have it rebuilt. Julian had come to the throne after Constantine, the man who restored freedom of worship to Christians and made Christianity the official religion of the empire, so he could not outwardly attack or criticize Christian activities. He was, however, opposed to Christian faith and always looked for opportunities to strengthen the older forms of Roman religions. On the day after he left Antioch and with the rebuilt Temple of Apollo in place, the Christians again demolished it. There is no record of Julian returning again to Antioch or confronting the Christians. There is, however, a record of the Crusaders arriving in Antioch a thousand years after Julian and, like Julian, leaving evidence of their sojourn.

The main destination of the Crusaders was Jerusalem, seen as the most sacred site of Christianity, one that they felt must, at all costs, be restored to Christian ownership. To reach that destination, they had to traverse a lot of territory, all of it occupied by Muslim enemies, so they found they had to build fortified centers along the way, places where they could rest and recuperate from the journey without fear of being attacked. The Crusaders had reason to fear, not because the Muslims were particularly ferocious, but because they had behaved so cruelly as they traveled. They plundered homes and mosques, killing everyone they encountered at these places. Even Constantinople, with all of its treasures from Roman times, was raided and everything thought to be of value was stolen. Many remnants of the castles and fortified sites that they established in Turkey and Syria can be seen today. Among them are the old walls of Antioch. To Crusaders, Antioch represented a site of enormous strategic advantage. It guarded access to the rich plain of what is now southern Turkey. The Crusaders attacked and conquered it in the eleventh century.

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6

Constantinople, Byzantine Empire, Black Death plague

542 AD

Constantinople, now Istanbul, Turkey

Bubonic Plague from Asia arrived via Africa at Constantinople in 542

In 542, Roman Emperor Justinian was actively rebuilding the empire from its new headquarters in Constantinople, often referred to as the Byzantine Empire since there was so much Greek influence there. The old western part with its center in Rome had been taken over by barbarians, vandals, and others. Through a series of military victories, Justinian's forces had been able to recapture much of Italy and had also been successful on other fronts. It was in the midst of these successes that Constantinople was ravaged by the first case of a Black Death pandemic. It reached Justinian's capital from Egypt, probably carried by rats in ships. Historians have estimated that close to half the population of Constantinople died from the plague during its four or five months of active infections. The number of soldiers left for Justinian's campaigns was completely inadequate so he had to step back from defending or further extending the historic frontiers.

Procopius, a historian living in Constantinople at the time, vividly described the plague and its effects. He pointed out that often, in the first day of infection, nothing very serious was evident but, on the second day, a bubonic swelling developed in the groin, armpits, or on the thighs and mental problems began to appear. Some went into a deep coma while others became delirious. Death came quickly to many while others lived for several days. When small black pustules appeared in the skin, the infected individual usually died within a day. Another symptom, vomiting blood, almost always led to death within a few hours. The physicians of that time tried a variety of cures but the results were always the same: again and again the cases that they fully expected to live died and the ones who seemed to the physicians to be hopeless lived on far beyond the period of the pandemic.

In the sixth century there was no significant understanding of bacteria and their role in the spread of diseases, and nothing was yet known anywhere about genes and their critical influence in determining who survived and who did not. These are the reasons for the perplexity experienced by the physicians when they tried their best to save the sick and the results were disappointing. It was the same centuries later when the same Black Death that overtook Constantinople in 542 swept over London in 1665. Many people in London, such as gravediggers, who were constantly exposed to infected bodies, stayed quite healthy while those who had just a single exposure to the infection died within two days. U.S. researchers who investigated this problem in the late 1990s solved the problem: those who had a particular gene, commonly known as Delta 32, did not catch the disease if they inherited this gene from both parents. If they received the gene from only one parent, they got sick but they recovered. The same gene in HIV patients is now known to be the reason for them escaping the consequences of that particular infection.

Procopius went on to describe the disease in Constantinople by showing how it affected pregnant women. Here, as in the general population, death came to both mother and baby but, in a few instances, either a mother died at the time of childbirth while the child survived or else a child died and the mother survived. It seems likely that in these rare cases the Delta 32 gene had been inherited from one parent. One common cause of death that seemed to have escaped the attention of Procopius was inflammation of the lungs, usually followed by spitting blood. Death followed quickly in these cases. Overall, the 542 pandemic ran its course over a time period of four or five months, a common sequence in other places at different times. At its peak, 10,000 died daily. The disposal of dead bodies overwhelmed the whole city. At first, friends and relatives attended to burials but very soon, with bodies being left unattended in streets and homes, huge pits were dug for mass disposal of the dead. Even these arrangements were inadequate so, with more and more bodies piling up, men removed the tops of the towers on the city walls and threw bodies into the spaces inside the wall.

The great leaders of the Roman Empire saw the whole inhabited world as their domain of responsibility, yet when Justinian became emperor there had not been any additions to the empire's traditional territory since its acme in the second and third centuries. A glance at a map of the empire in second century and then one in the sixth reveals the enormous amount of shrinking that had taken place in the intervening four hundred years.

Justinian was determined to change this condition and push back the existing frontiers to encompass as much as possible of the known world. The Greek city of Byzantium became the new Rome in the year 330. It was named Constantinople in honor of Emperor Constantine who established Christianity as the official religion of the Roman Empire. Justinian ruled this eastern empire from 527 to 565 and, in the first half of that period, he set about restoring the size and prestige of the former empire. In many ways his reign therefore represented a preservation of the Roman past.

There was an unbroken tradition in Roman law that had continued from the earliest days of the empire into the sixth century. Justinian felt that the preservation and renewal of these laws was as important as the recovery of former territory and he set about getting the work done. It was an immense task, one that was to last far beyond the life of the Byzantine Empire and serve in later centuries as the basis of European jurisprudence. The work was begun in 528 when Justinian appointed ten jurists to compile a new codification of the statute law and it was completed a year later. The next task was even bigger, the preparation of a summary of jurisprudence from the great Roman lawyers of the second and third centuries. This involved the reading of two thousand manuscript books, assessing the key matters of content, and reducing the total amount of material to one fifth of the original. All this took three years of hard work. Justinian had a reputation of being a very hard worker and he inspired these writers by his own example. His staff often used to find him busy at work in the middle of the night.

Once the work of codification and summary of jurisprudence had been completed, no further commentary on the law was permitted. The code and the summary, or digest as it was called, now represented the whole of the law. Any new legislative acts were referred to as novels; they usually dealt with issues in ecclesiastical and public affairs. One very long novel dealt with Christian marriage law. It was a sign of the times, particularly the changed times that accompanied the move of the empire's capital from Rome to Constantinople, that all of these novels were written in Greek, not Latin. Furthermore, Justinian knew that many Roman laws had never been popular in the Greek east so local preferences frequently replaced old Roman laws. Hellenic traditions affecting family, inheritance, and dowry, for example, appeared in the new legislation. In addition, the power of the father, traditional in old Roman thought, was now considerably weakened. Christian influences too appeared in much of the newer legislation. There was a desire to make law more humane, an emphasis that came from Justinian's interest in including the idea of a love of humanity, and it was expressed in laws protecting the weak against the strong, favoring the slave against the master, debtor against creditor, and wife against husband. These improvements may seem small today but they represented a huge advance from the days of the old Roman Empire.

Justinian's role in the Black Death pandemic needs to be examined because it was he who greatly extended the activities of the empire into Africa, the place that was the source of the Black Death. His first moves were directed at recapturing some of the lost lands of the west. His armies invaded the Vandal and other kingdoms, one after another, in a series of bitter wars from 540 onward, and in all of these he achieved considerable success. He made the Germanic kings servants of the eastern empire but there remained the difficult problem of religious purity. Justinian was devoted to the Nicene Creed, brought in by Constantine as the official religion of the empire, but the Germanic kings were practicing and preaching a form of Christianity considered heretical by the established church. The Vandals were most zealous and quick to seize orthodox churches in order to convert them into different places of worship. The Vandals were so few in number that they resorted to terror in order to control their subjects so their kingdom became a police state in which orthodox Christians were stripped of property rights, and frequently of freedom and even of life. When a delegation of orthodox Christians from Africa appealed to Justinian to fulfill his role as defender of the faith, he decided that the time had come to bring Africa back under the control of the empire.

The immediate incentive for attacking the hundred-year-old Vandal kingdom in Africa was soundly based. Their king, Hilderic, had fostered good relations with the orthodox Christians. Exiled bishops had been recalled and churches reopened, but in 530 he was deposed by his cousin Gelimer and, from his prison, Hilderic appealed to Justinian. Even so, Justinian was uncertain about taking action because an earlier expedition had led to disaster. Finally, after much deliberation, Justinian went ahead with the invasion of Africa, convinced that the restoration of true Christianity justified it. The expedition set sail in 533 under the command of Belisarius. The field army numbered 18,000 men, 10,000 of them infantry and 5,000 cavalry. There were also some others. In Sicily, Belisarius got the welcome news that Gelimer was unaware of the offensive and had sent 5,000 men and 120 ships under his brother Tata to put down a rebellion in Sardinia. The expedition from Constantinople landed in Tunisia, and the army marched along the coast toward Carthage while the fleet accompanied it offshore. Gelimer's reaction was to put Hilderic to death and then march out to resist the invasion. His tactics were poor, perhaps due to inadequate planning, and he was routed. Belisarius marched on and took possession of Carthage. Gelimer fled westward and joined his troops who had been recalled from Sardinia, but within a few months suffered another defeat near Carthage. Gerlimer hid for a time with local tribesmen but finally surrendered. Belisarius went back to Constantinople with his captives and booty and Justinian arranged a victory celebration for him when he arrived, somewhat like the old Roman celebrations that followed successful military campaigns. About two thousand of the captives were conscripted into the army of Justinian.

Quite apart from his military successes and defense of traditional Christianity, Justinian achieved fame because of his extensive building program. The outstanding illustration of his work, one that still survives in the Istanbul of today, is the Hagia Sophia. There was an earlier church on the site that would become Hagia Sophia's, built by Constantius in 360. He was the son of Emperor Constantine who had liberated the Christian faith from centuries of persecution. The earlier church was known as the Great Church. In 404, this church was destroyed by mobs and, later, in 415, rebuilt. It too fell victim to a rampaging mob of heretics in 532. The new emperor, Justinian, firm defender of orthodoxy, made short work of the howling heretics and ordered that construction begin on a brand new basilica. Construction work lasted from 532 to 537 and the new church was consecrated in 537. Architecturally the grand basilica represented a major revolution in church construction. It had a huge dome and this demanded new skills and new materials in order to support the weight of the dome. No one had ever previously attempted this. There were no steel beams available at this time so the dome had to be supported by massive pillars and walls. The church itself measured 260 by 270 feet, the dome rose 210 feet above the floor, and the overall diameter of the dome was 110 feet.

Some awareness of the danger of earthquakes was known at the time but everyone was convinced that the huge structures employed would meet any threat. They were wrong. Parts of the church and dome were destroyed subsequently in an earthquake and large buttresses had to be added to the supports. In 1204, Roman Catholic crusaders attacked and sacked Constantinople and Hagia Sophia, leaving behind a lasting legacy of bitterness among Eastern Christians. For more that 1,000 years Holy Wisdom had served as the cathedral church of the Patriarch of Constantinople as well as the church of the Byzantine court, but that function came to an end in 1453, when the Ottoman Turkish Sultan seized the Imperial City and converted Hagia Sophia into his mosque. Today, Justinian's dreams of restoring the greatness of the old Roman Empire are long forgotten but the magnificent Church of the Holy Wisdom, which is the interpretation of the words Hagia Sophia, is still admired. It is a tourist attraction because it dominates the skyline of the modern city. Such was its stability over the centuries that, during an earthquake in Constantinople in 1999, the safest place for people was considered to be the Hagia Sophia. It is the mother church of all Eastern Christians of the Byzantine liturgical tradition both the Orthodox and the Greek Catholic.

The reign of Justinian proved to be a major factor in all of the history of late antiquity. Paganism finally lost out and the Nicene Creed that Constantine had established in the fourth century was almost universally recognized. From a military viewpoint, it marked the last time that the Roman Empire could go on the offensive with any hope of success. Africa and many other areas had been recovered. When Justinian died, the frontiers he had secured were still intact but it was the degree of restoration of the old empire that he had won back and the accompanying greatly expanded trade with the rest of the known world that led to the pandemic which destroyed so much of Constantinople and cut short all further military campaigns. Justinian had not created the disease, but he created the pandemic, which followed the movements of men and goods in Justinian's greatly expanded empire. Without the empire and its huge shipments of grain and cloth from Africa, it is difficult to imagine how the First Pandemic could ever have hit Constantinople at such an early date.

Istanbul (Turkish: İstanbul) is Turkey's largest city, and its cultural and economic center. It is located on the Bosphorus Strait, and encompasses the natural harbor known as the Golden Horn (Turkish: Haliç) in the northwest of the country. Istanbul extends both on the European (Thrace) and on the Asian (Anatolia) side of the Bosphorus and is, thereby, the only metropolis in the world which is on two continents. Its 2000 Census population was 8,803,468 (city proper) and 10,018,735 (province), making it, by some counts, one of the largest cities in Europe. The census bureau estimate for July 20, 2005, is 11,322,000 for Istanbul province, which is generally considered as the metropolitan area, making it one of the twenty largest metropolitan areas in the world. Istanbul is located at 41° N 28° E, and is the capital of Istanbul Province. Istanbul, formerly known as Constantinople, had been the popular name of the city for five centuries already, a name which became official in 1930. Due to its three-thousand-year old history, it is considered as one of the oldest still existing cities of the world. Istanbul has been chosen as the European Capital of Culture for 2010. Istanbul is sometimes called the "City on Seven Hills" because the historic peninsula, the oldest part, was built on seven hills, and is also represented with seven mosques at the top of each hill.

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7

Corinth, Greece, earthquake

856 AD
Corinth, Greece

Corinth, a city well acquainted with earthquakes because of its many underground geological fault lines, experienced an earthquake of magnitude 8 or more that almost totally destroyed the city in 856

Corinth, a busy and successful seaport in Greece and once part of the Byzantine Roman Empire, was no stranger to earthquakes. It stood amid a series of fault lines and the conjunctions of several tectonic plates or platelets so, like Iran and several other eastern Mediterranean places, Corinth frequently experienced earthquakes. The speed with which these tectonic plates moved far beneath its surface was greater that almost anywhere else. One subducting plate moved at three quarters of an inch per year. In geological terms that is very fast. Today that movement still continues at the same rate and we have the advantage of GPS technology to confirm the rate. In 856, Corinth experienced its worst of many earthquakes, one that is now recognized as having a strength greater than 8 on the Richter Scale. The city was almost totally destroyed and 45,000 people lost their lives.

Ancient Corinth, the original Corinth, founded more than three thousand years ago, was the richest port and the largest city in ancient Greece. Strategically located guarding the narrow isthmus that connects the Peloponnesus (as southern Greece is called) to the mainland, it was a powerful commercial center. The four-mile-wide Isthmus of Corinth was always a problem because Corinth was on the west side of it. Thus ships arriving through the Gulf of Corinth from Italy and other places west had to turn back through the Gulf and take the long journey around Peloponnesus in order to reach Athens. Yet Athens was less than fifty miles from Corinth. If only they had a canal across the isthmus the journey would be so much easier. Ships could continue their voyage past Corinth for the short journey to Athens. Some sailors were so anxious to overcome the hazard of the isthmus that they would drag their ships across it rather than contend with the long sea voyage. Ships were very much smaller in these times so they could do this. In addition there were the dangers of encountering pirates at sea and every sailor wanted to avoid that type of encounter.

As early as 67, Emperor Nero saw the advantages of having a canal dug across the isthmus. He lifted the first sod with a golden trowel, then instructed six thousand Jewish slaves he had brought from Palestine to get on with the work. There is no record of anything significant having been done by Nero's slaves. It was not until 1893 that the canal was finally dug and the ship voyage from Corinth to Athens was shortened by two hundred miles. The present site of Corinth (Korinthos on maps) with a population of 50,000 is quite close to the site of the ancient one. It is a port and a major transportation center on the Gulf of Corinth trading in olives, tobacco, raisins, and wine. Founded in 1858 after the destruction of Old Corinth by an earthquake, it was rebuilt after another earthquake in 1928 and was formerly known as New Corinth. Old Corinth, just southwest of modern Corinth, is now a village. It is strategically situated on the Isthmus of Corinth and protected by the fortifications on a two-thousand-foot-high limestone mountain above the city. Almost all of the pillars that held up the temples of ancient Corinth have collapsed under successive earthquakes over the past two thousand years.

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8

Damghan, Persia, earthquake

December 22, 856
Damghan in the north central part of what is now Iran

An earthquake of magnitude 8 hit and destroyed the city of Damghan, Iran, in 856 AD. Both the city of Damghan and many areas around it were destroyed

On December 22, 856, an earthquake of magnitude 8 struck the city of Damghan, at that time the capital of the area we now know as Iran. While the earthquake was centered on Damghan and destroyed most of that city, damage to neighboring areas extended east and west over a two hundred mile stretch of countryside. Every village in this area was destroyed. One third of the town of Bustam, about fifty miles east of Damghan, collapsed. In mountain areas close to the center of the earthquake the surface of the ground parted in several places. Overall, 200,000 people lost their lives. The memory of the event was so vivid that, two generations later, detailed memories of all that had happened were still being recounted.

Iran has always been known as a place of earthquakes because of its location along fault lines and between two major tectonic plates that are always colliding. In earlier times, news of earthquakes in this remote region east of Mesopotamia was almost nonexistent. Not until the early Islamic Period, after 622, was it possible to locate reliable records of events. Of the significant earthquakes reported after 622 and before 922, Damghan was the most powerful. There were about forty others within this period with magnitudes ranging from 5 to 7. At this early stage of scientific thinking, explanations for earthquakes among the more educated Muslims were based on Aristotle's thinking, a sort of philosophy of nature based on mathematics or on orderly patterns observed in nature. Unfortunately, earthquakes are anything but orderly. We know their causes but not their timing. For the vast majority of people in 856, earthquakes were viewed with awe and their origins attributed to the actions of a supernatural power.

Even in modern times, this theological interpretation of earthquakes is a common view. One group regards them as punishment from their god for bad behavior. Another sees them as omens of contemporary political events; that is, they indicate what is about to happen in a particular country. This view is so common in China today that the government of that country delayed for three years the detailed reporting on an earthquake that came in 1976. In the case of Iran, there was a fairly large earthquake in that country on the sixteenth of January 1979, in which several hundred people were killed. That particular day happened to be the one on which Shaw Pahlavi departed from Iran, leaving the government of the country in the hands of the theological leaders who replaced him. To many people in the country, the earthquake was evidence of the behavior of their god in rearranging the nation's government. With our present knowledge of the causes and outcomes of earthquakes, Iranian patterns can be identified across time and space, some because of local records and traditions seen to be repeating every thousand or even every five thousand years.

The Eurasian and Arabian tectonic plates converge at an average rate of a little over one and a half inches every year. Iran is in the middle all of this activity and its numerous fault lines bear the evidence. Across a line that stretches east and west for more than six hundred miles strike-slip and reverse faults are the places where plate movements are expressed. In earlier times, as in the Damghan earthquake, most of the country consisted of small farming settlements in which homes were built of simple mud-walls, a type of construction that easily collapses when an earthquake strikes. Some commentators have suggested that people built simple inexpensive homes because they knew that there would be new earthquakes and they would lose whatever they built. In places like these ancient Iranian ones, most of the deaths in an earthquake are caused by the collapse of homes. As a result, it often happens that huge numbers of deaths are reported from developing countries, where buildings are incapable of withstanding even low magnitude earthquakes; while developed countries report fewer deaths when hit with similar magnitude earthquakes.

Much of the history of homes in Iran is typical of conditions in other developing nations, so a closer examination of how single homes and clusters of buildings are constructed in Iran is worthwhile. In addition, their failure until very recent times to make buildings earthquake resistant is also typical of many other countries. In December of 2003, the ancient Iranian city of Bam was destroyed in an earthquake. It was clear in reports from the British Broadcasting Corporation (BBC) that failed buildings were the main cause of the large number of deaths. According to the BBC, Bam experienced a strong earthquake at four in the morning when most of the residents were in bed. One-third of its population of 200,000 was either killed or seriously injured. Most of the buildings, including two of the city's hospitals, were destroyed. The BBC's reporter told of intense scenes of grief as survivors stood beside corpses wrapped in blankets or buried beneath rubble. This story in all probability was very much like the one that was recounted in Damghan twelve and a half centuries ago.

Homes built a thousand years ago and those built today in most rural areas are built of dried mud or adobe bricks, rarely with a type of clay that gives significant strength to the building. Where timber is available, beams can be installed for the support of flat roofs in spite of the fact that the kind of timber available is often warped or weak from repeated use in previous constructions. Typically, a flat roof is very heavy. It consists of some kind of boarding on which two feet of earth is laid. A flat roof is always preferred because it provides a cool place in which to sleep during the hot summer months and can also be used for drying crops. In mountain villages, a common sight in a country that has one third of its land area higher than ten thousand feet above sea level, houses are built with stones and held in place with a clay mortar. Where slopes are steep the roof of one house becomes the ground floor and outdoors of the next home above it. On lower elevations homes are built close together with very little space between them. When a home is damaged, the repair work rarely tries to make the place stronger and, therefore, better able to withstand the next earthquake.

The concept of making buildings as earthquake resistant as possible was unknown until recently. Heavy rainfall still destroys hundreds of homes in the course of a few hours. The idea of changing both the appear-

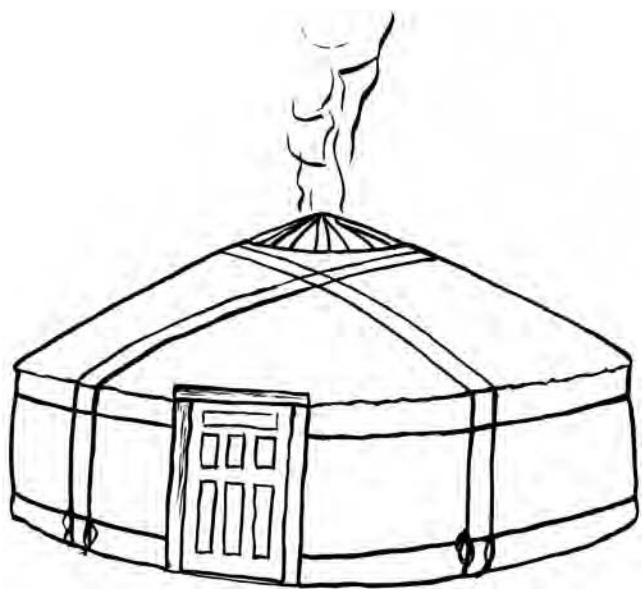

Figure 6 An Asian yurt, the safest type of dwelling in Iran during ancient earthquakes.

ance and shape of a home to make it better able to resist an earthquake began to appear for the first time in the second half of the twentieth century. There is one group of Iranians who have no need to make their homes earthquake resistant—the nomadic tribes who need homes that can be dismantled and remounted in a short time as they move from place to place. Their homes are yurts and they are perfect examples of earthquake resistant homes. These structures are dome-shaped, circular, tents made of collapsible walls of willow poles, known as yurts. The roof of a yurt is domed and both roof and walls are covered with a kind of felt made from animal wool. Dried grass and strips of leather are used for holding the structure together. In summer, the felt sides are rolled up to admit air and, in winter, extra sheets of felt are added to the outside for warmth. The whole structure can be taken apart and reassembled in an hour, a vital feature for nomadic life. A yurt can provide a comfortable home for at least fifty years.

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9

Aleppo, Syria, earthquake

1138 AD

Aleppo (modern name Halab)

The earthquake destroyed a vast area around Aleppo and killed 230,000

In 1138, a deadly earthquake destroyed the city of Aleppo and the area around it. This city is set in a nest of fault lines and earthquakes have always been a feature of life. A large earthquake of intensity greater than 7 hit the coastal area immediately south of Aleppo five hundred years earlier. Its impact was felt over a large part of the eastern Mediterranean and it was accompanied by a tsunami. The East Anatolian Fault line passes through Aleppo and, as it moves, it gives rise to a series of earthquakes over time. Additional disruptions come from the westward movement of the area as a whole under pressure from the Arabian Tectonic Plate. The earthquake of 1138 completely destroyed a vast area in and around Aleppo, now called Halab, and jolted places two hundred miles from the city. The death toll was 230,000, making it one of the five deadliest earthquakes in recorded history. There were several small aftershocks and, twenty years later, another very strong earthquake.

Aleppo has been settled for more than three thousand years. Initially it was the territory of the Hittites, then the land of the Assyrian and Persian empires for almost a thousand years until the Greek Empire of Alexander the Great captured it. The Romans were the next owners of this part of the Middle East and, after them, Arab and Ottoman masters until the fall of the latter in 1923. The key location of Aleppo on trade routes between Europe and Africa and Asia always made it a target of invaders. Around the year 1100, the city came under siege from the Crusaders on two occasions but they failed to capture it. The Mongol armies swept over it in the second half of the thirteenth century, destroying everything as effectively as any earthquake might do. Today the city is a large, modern, urban center of two to three million people, the second biggest city of Syria next to Damascus. It stands on the same site as it occupied for thousands of years; thus its rich history lies hidden beneath many buildings.

Aleppo is in a location that is extremely hot in summer but its elevation of more than a thousand feet above the surrounding plain, coupled with prevailing strong breezes, have always kept summer high temperatures below 110 degrees. Its modern name, Halab, is based on an ancient word for milk and traditions trace this name to the time of Abraham who, it is said, stopped here for a time on his journey to the Promised Land and grazed his cows in the area around the city. The traditional routes along the valleys of the Euphrates and Tigris and down the eastern Mediterranean coast make that a feasible story. Today, this ancient link with the Bible is reflected in a large Christian population in Aleppo, about 30 percent of the total, probably the largest concentration in any Middle East country, appropriately identified by the street called "Narrow." Another link with the Christian past is found in the Citadel mound. This place was a medieval castle, partially an imitation of the Crusader castles that were built all over the Middle East at that time. The crusaders brought with them the castle-building technology of Western Europe and in the years after they left the Middle East their technology is visible in the castles they abandoned. The castle in Aleppo is an excellent example of their work.

In addition to Christians, Aleppo had also from the very earliest times housed a big Jewish population. Their great synagogue held an ancient codex, now known as the Aleppo Codex, and it was dated in recent times as belonging to the ninth century. It somehow survived the catastrophes of the intervening centuries and is now housed in Jerusalem. There are other buildings too that define both its history and Aleppo's present place within Syria. A cathedral that was built in Roman times under the auspices of Saint Helena, mother of Constantine the Great is regarded as the burial place of John the Baptist's father. It was rebuilt in recent times. During the Crusades, when the invaders pillaged the surrounding countryside, the city's chief judge converted Saint Helena's cathedral into a mosque. Subsequently, it became a religious school. Aleppo's physical location defined its role through the centuries. It was a trading center. It maintained that role for a very long time, until Europeans began to use the Cape route to India and later the shorter route through the Suez Canal and Red Sea.

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10

Shaanxi, China, earthquake

1556 AD

In the Province of Shaanxi, China

The light loess soils of Northwest China are easily shaken by an earthquake. In 1556, a huge population lived there in underground homes and many were killed by this, the world's deadliest earthquake

The Shaanxi earthquake of 1556 was the deadliest ever experienced anywhere in the world. It happened in the northern interior of China not far from the city of Xi'an. It measured more than 8 on our scale of earthquake strength, damaged parts of ten neighboring provinces in addition to the Shaanxi one, and was so strong that half of China felt its impact. Aftershocks continued intermittently for six months. An area extending 250 miles outward from the epicenter was completely destroyed. Most of the population at that time lived in caves inside the loess cliffs. Loess is a relatively light type of soil and it disintegrated under the earthquake's pressure and shaking with the result that 830,000 people were killed.

In 1989, the Science Press of Beijing, with help from UNESCO, published a summary of the history of Chinese earthquakes. Its description of the 1556 one tells of mountains and rivers changing places and roads being completely destroyed. In several places earth movements pushed the surface up sufficiently to form new hills. At the same time, these same areas had sections that collapsed to form new valleys. Streams and gullies appeared in new locations. Overall, huts, official houses, temples, and city walls generally collapsed suddenly. Numerous valuable monuments were destroyed beyond repair. The important Small Goose Pagoda in Xi'an withstood the shaking but its height dropped by about six feet. The report from Beijing dealt with earthquakes of all kinds. It covered the long his-

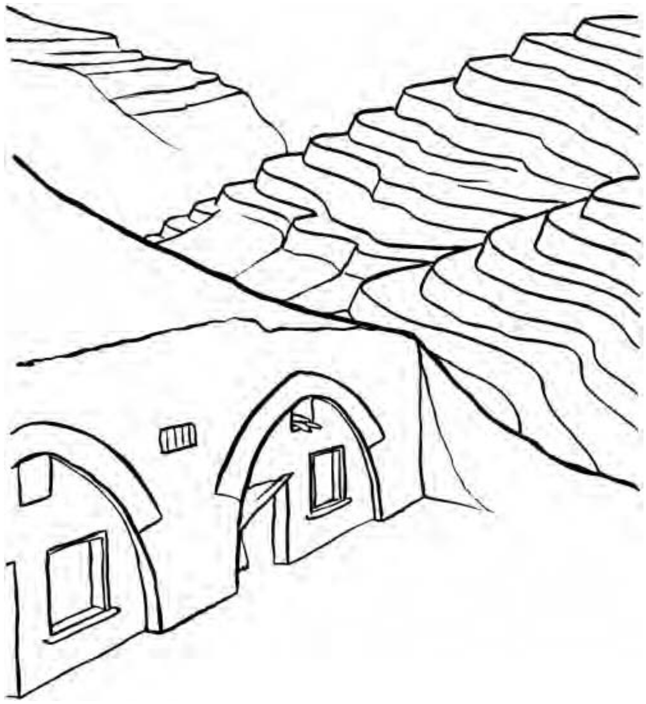

Figure 7 Loess homes beneath terraced farms in China's oldest agricultural area; the site of the world's deadliest earthquake.

tory of China and demonstrated for the first time the constant threat that the nation always had to face. Ten earthquakes like the 1556 one were listed, each of magnitude 8 or more, and of these the largest cluster appeared in areas close to the city of Xi'an.

Provinces historically experiencing earthquakes of magnitude eight or more:

1303, Shaanxi
1556, Shaanxi
1604, Fujian
1654, Gansu
1668, Taucheng
1679, Hebei
1695, Shaanxi
1739, Yinchuan
1833, Yunnan
1879, Gansu
1976, Hebei

The Loess region is of great historic importance to the Chinese. It is the cradle of civilization for the country. In ancient times it was the meeting zone between the nomadic herders of the Mongolian and central Asian lands and the more settled farming communities of what would one day become China. It was on the margins of these loess areas that the great trading cities and capitals of empire first formed. Xi'an is one of the best known of these. Today it is a city of the same size as Chicago. In the 1930s and 1940s, fully aware of its historical significance to China, Mao Zedong and the Chinese Communist Party set up their headquarters here and made preparations for their conquest of China which happened in 1949. Today, some two hundred million people live in or near the loess lands with almost one quarter of them living in cave housing. The importance of this part of China is seen in the Great Wall of China, built to protect the high concentrations of people to the south of it from the marauding tribes to its north. The Mongol armies of eight hundred years ago were the strongest of these.

Loess is wind-born silt that has settled out over many thousands of years, frequently to a depth of three hundred feet in provinces in and around Shaanxi. Much of this loess accumulated in the aftermath of the last ice age as winds from the Mongolian Plateau picked up and transported tiny particles of rock from the barren land surfaces left by the ice. It has a yellowish to light brown color and has no structure of layering like sedimentary rocks. As a result, it breaks away easily whenever it is cut away by stream action, leaving high cliffs alongside the stream. These cliffs provide ready access for excavating cliff-side homes and people have taken advantage of this opportunity for thousands of years both in China and in parts of Central Europe. Caves provided warmth in winter and cool conditions in summer. The climate of Shaanxi is semi-arid with an annual rainfall of twenty inches. However, this amount of rain in some years may fall in a single day and in loess territory that can be catastrophic because the soil is easily eroded and washed away. Its lack of layering means it has no natural cohesion. Frequent landslides occur with heavy rain and they cause considerable loss of life.

The Hwanghe, or Yellow River as it is often named because of the load of yellow loess particles that it always carries, cut its channel over time through these mountains of loess. In its upper reaches, because of the interior location, occasional bursts of rain are experienced in the warmer months of summer and the river overflows the levees that hold the flow of water to its main channel. Farms get destroyed when this happens. The usual reaction in past times was to have thousands of workers rebuild the levees by painstaking hard manual work. It is very difficult to predict these overflows because of the large volume of yellow silt that the river carries. A buildup of this silt at a turning point in the river can quickly become cumulative as the silt slows down the flow of water, thus speeding up the rate at which silt is deposited.

Loess is an excellent parent material for the formation of rich dark soils so these soils coupled with plentiful supplies of water from the river gave rise to the earliest agricultural settlements in the country. Grains and cotton were grown there thousands of years ago and a variety of domestic animals were reared. These natural advantages gave rise to a high population density even in prehistoric times. Loess is a major factor in agriculture all over the world, not only in China. It is particularly well suited to the cultivation of grains. The wheat fields of the Ukraine, and those of Argentina and the U.S. are outstanding examples of the value of loess-based soils. Knowing how easily the Yellow River can erode loess, Chinese authorities have terraced steep slopes and planted trees on the flat areas thus created. The trees tend to hold the soil in place during heavy rain.

In order to gain greater control of the problems associated with loess, research was undertaken by the Chinese government in the last quarter of the twentieth century. Engineers from China and Europe studied bedrock geology, quaternary sediments, geomorphology, landslide distribution, land use, and geotechnical properties of loess soil. Their findings made possible a much higher density of population and industrial installations in provinces like Shaanxi. A new problem arose as increasing numbers of people came to live and work there. As modern life impacted the traditional ways of Shaanxi, many workers, especially younger people, insisted on leaving the underground caves and building new homes above ground. In the new economy in which they were involved, these people had the financial resources to make changes. There had always been problems of dampness and darkness in the loess caves, especially in the ones that had to be excavated vertically into flat areas in contrast to those that had been dug into cliff faces. Former generations had no choice but to accept these limitations and even today there are millions who still live in the cave dwellings.

The 1556 Shaanxi earthquake was not the worst disaster in Chinese history. Millions have died from time to time when flooding destroyed their farms and they starved because there was no emergency aid from government sources. The Yellow River has sometimes been called the pride of China and sometimes its sorrow. Over the thousands of years past, it changed its course completely five times and its levees collapsed as many as 1,500 times. The yellow loess is carried along by the river and wherever there is an obstacle in the streambed it builds up and builds up over time until it overtops the levee and floods the adjacent farms. One and a half billion tons of loess in the form of silt is deposited annually near its mouth by the Yellow River. Often people tried to prevent the flooding that occurs by building small dams on the river but this only accelerates the problem of buildup. The 1887 flood, which is described elsewhere, killed more than a million people. In 1938, as China was being invaded by Japanese troops, the government of that time broke the levees in order to stop the advance of the soldiers. In the flooding that followed, 700,000 died. Even in modern times authorities seem unable to cope with the buildup of silt behind dams.

In the 1950s, in order to prevent flooding and at the same time generate electricity, Chinese engineers built a gigantic concrete dam, assuming that the silt, being of a fine texture, would flow through the turbines rather than create a buildup behind the dam. They were wrong. The same old problem reappeared. The plan was to have a lake of almost 100 billion units of water. Within two years, 20 percent of this amount had been lost to silting and gradually over the following eight years the total amount of water in the dam shrunk to seven units. The plan was scrapped. Alongside these problems of silting and flooding there is uncertainty about rainfall as has already been mentioned. In 2006, for instance, Beijing and its surrounding area had a serious shortage of rainfall and, at the same time, experienced recurring sandstorms. Attempts were made to seed a few clouds by sending tiny sticks of iodide high into the sky. A small amount of rain was obtained by this method.

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11

Arequipa, Peru, volcanic eruption

February 19, 1600
Southern Peru

A volcanic eruption of VEI strength 6 from a 13,000-foot-high mountain near Arequipa

On February 19, 1600, South America's biggest volcanic eruption in all of recorded human history occurred in a mountain close to Arequipa, a city in southern Peru. Its VEI was 6, the same as Krakatau's, and the type of eruption was also the same as Krakatau's, a Plinian one. By that term we mean that such an eruption sends ash, smoke, and fragments of volcanic rock with terrific force high into the atmosphere, frequently as high as twenty-five miles. Places within fifteen miles of the Arequipa volcano were devastated. The neighboring states of Chile and Bolivia received thick layers of ash, as did Lima, the capital and largest city of Peru. Later, ruins revealed the details of the communities that had been smothered by ash and rock fragments, just as Pompeii had been by a similar event in the year 79. The name Plinian was given to this type of eruption in honor of Pliny the Elder, the famous Roman who was killed when Mount Vesuvius erupted, killing him and most of the people of Pompeii.

Drainage, lakes, and transportation routes were all affected because of the huge amount of material that fell on them. In addition to the human losses, the loss of farmland, vineyards, crops, livestock, and water supplies completely disrupted the economy of the area. There were no international trading links, and no manufacturing or similar occupations to which people could turn in 1600 for their survival. They depended totally on what they could obtain from the ground. Fortunately, recovery was undertaken immediately. Arequipa was rebuilt and within a few years farming activities were close to pre-eruption standards, largely the result of life being very simple. In recent times, mainly through examining underground evidence of past climates, scientists have come to see that the impact of Arequipa was far greater than local records from 1600 would suggest. It affected countries all over the world. A few scientists said that it contributed to a worldwide cooling that occurred in the summer of the year 1601, the coldest summer within the past five hundred years.

The eruption was preceded by a series of earthquakes and explosions as magma made its way upward toward the surface. The volcanic mountain that was about to explode stood more than 13,000 feet high within the upper reaches of a broad valley. It had three vents high above the valley through which gas, smoke, and pumice was about to escape. Each one of the three was huge, about 300 feet deep and over 250 feet in diameter. The setting of the mountain was equally impressive, a valley that had been carved out of an ancient volcano's side and summit, a horseshoe-shaped amphitheater that looked like a glacial cirque. It is clear from the evidence that is being uncovered at the present time that the area around Arequipa experienced numerous volcanic eruptions over the past few millions of years. In the case of the 1600 eruption, tremors were felt long before February 19. By February 15, these movements increased in both number and intensity, and this condition was maintained right up to the night of February 18. On the fateful day of the eruption there was an explosion like the noise of a cannon, followed by a big fire that scared everyone. Within an hour of the explosion, the whole surrounding region became dark as large volumes of ash and other volcanic materials fell back to earth through the atmosphere. There was little change in this continuous flow of dark material until the eruption ended on the second of April. The following list summarizes the sequence of events.

February 15	Regular earthquakes begin
February 18	9 P.M.: Earthquakes increase in strength
	10 P.M.: People awakened by the strength of the earthquakes
February 19	Midday: two major quakes of intensity 11 (MM scale)
	5 P.M.: Eruption began, pumice and ash falls
	6 P.M.: Whole region dark with explosions every few seconds
February 20	Explosions and ash continue all day
	2 P.M.: All day was like midnight
	10 inches of sand and ash fall on Arequipa
	Eruption and earthquakes continue all day
February 28	A major earthquake
March 5	Ash fall finally stops
April 2	Atmosphere finally cleared

A flow of heavy, hot, pyroclastic material began to appear soon after the eruption. It formed new rivers as it traveled, disrupting the natural flow of water as well as the dams that had been built on the River Tambo. It was in the neighborhood of this river that most people lived. As volcanic material fell back from the sky and was added to the surface flow, the combined mass of material rolled down the steep slopes beneath the mountain and further disrupted everything on the surface. Fire and the weight of falling material did most of the damage. Today, geologists examining the scene of the 1600 eruption are finding plenty of evidence of the event. Thick layers of ash and pumice can be seen all over the area west of the River Tambo and the city of Arequipa. It is easy to see why most of the one thousand people of the region were killed. There is a record of the experiences of a hundred people who lived in one village. It tells of stones falling from the sky with many people and animals being killed, without giving them a chance to escape. Chaos and fear had gripped everybody; they hugged one another as hot ashes were falling and burning their homes.

The people were understandably terrified by the event, mainly because of ignorance and fears over the causes of volcanic eruptions. No one knew anything about tectonic plates in 1600. Records tell of Indians praying and casting magic spells because they felt that the church was unable to do anything about the eruption. Some local people prayed on their knees all day as one of their number played a doleful lament and asked for mercy. Fear drove people to walk around their community in a sort of dazed state. Churches kept their doors open all the time. Implicit in all of these reactions was the assumption that God was responsible for what happened and, since this particular event was troublesome and harmful, he must have done it as a punishment for bad behavior. To make matters worse, the local Spanish priest had warned his people at the time of the first small earthquakes that a hit from heaven was going to come to punish them for their sins. It was a similar story more than a hundred years later when Lisbon experienced a powerful earthquake on All Saints Day. Large numbers of people were in their churches when the earthquake struck. Lisbon was a very religious city and they were convinced that the earthquake was a punishment from God.

The warning from the priest was a particularly troubling factor for the social life of the community. The conquest of the area by the Spaniards, in the previous century, had brought to this village all that was best in the world. While it came by force of arms it nevertheless represented many things that were an improvement over their former lifestyle. Arequipa and its surrounding communities had been a traditional Indian village until the Incas captured it and made it the supply center for its capital of Cuzco nearby high in the mountains. Within a century of that development, the Spaniards arrived and took full control of the area. They immediately stopped the ancient practice of sacrificing humans and animals in order to appease the gods of the mountains but now, in 1600, the natives were in a helpless situation. The church could only threaten punishment. It could not stop the eruption. The mythology of the area told them that the devil was upset because they had abandoned sacrifices so he was going to punish them. Local wizards now persuaded them to find the nicest young girls, the best animals, and the prettiest flowers and sacrifice them. During the sacrifice the first burst came from the volcano and they were covered with ash.

There were reports from ships at sea experiencing ash falls, from as far as a thousand miles, just as there had been from Lima, in northern Peru, also a thousand miles away. However, most of the ash falls happened in Bolivia and Chile because the borders of all three countries are close to the site of the eruption. In the Pacific, offshore from Peru, sailors in a British pirate ship heard the explosions and thought they were about to be attacked by a Spanish warship. A merchant sailing south from Lima was caught in a storm of ash and pumice when his ship was off the coast two hundred miles west of Arequipa. The weight of ash dragged most of his boxes overboard. If we take the immediate communities in and around Arequipa for a distance of twelve miles outward from the city, it becomes clear that more than a thousand acres were covered with sufficient ash to make them unusable for many years. One factor that is rarely mentioned is the influence of rainfall on steep slopes when all the natural drainage channels have been dislocated. Rainfall is heavy on the west side of Peru's mountains and over the year or two following the eruption, without access to their natural channels, rainstorms washed away into the sea every movable thing on the sloping mountainside, including livestock, crops, and fish.

Volcanic eruptions along the west coast of Peru, as well as in other countries on that coast, are due to the accumulation of magma near the surface because of the subduction of the Nazca Plate beneath the continent of South America, disrupting both temperature and rock regimes deep below the surface. Peru experiences more earthquakes and volcanic eruptions than most of the countries on that coast. There are dozens of significant earthquakes every year, yet it seems that their familiarity with earthquakes and volcanic eruptions makes the people resilient, ready to start over when tragedy hits. It is an attitude similar to that found in Japan, another country well acquainted with earthquakes and volcanic eruptions. In 1784, Arequipa was hit with an earthquake that killed fifty people and destroyed almost all the buildings. Two others, in 1868 and 2001, did extensive damage. Despite the hazards, the city has grown rapidly through the years because it is located in a good agricultural area and it is strategically located for transportation. Arequipa's population has grown from about 20,000 at the end of the eighteenth century to 600,000 today, making it Peru's second biggest city.

The 1784 earthquake in Arequipa provided a better picture of the ways in which the Spanish overlords used local labor in the work of recovery. The records of the 1600 event do not tell us anything about relations be-

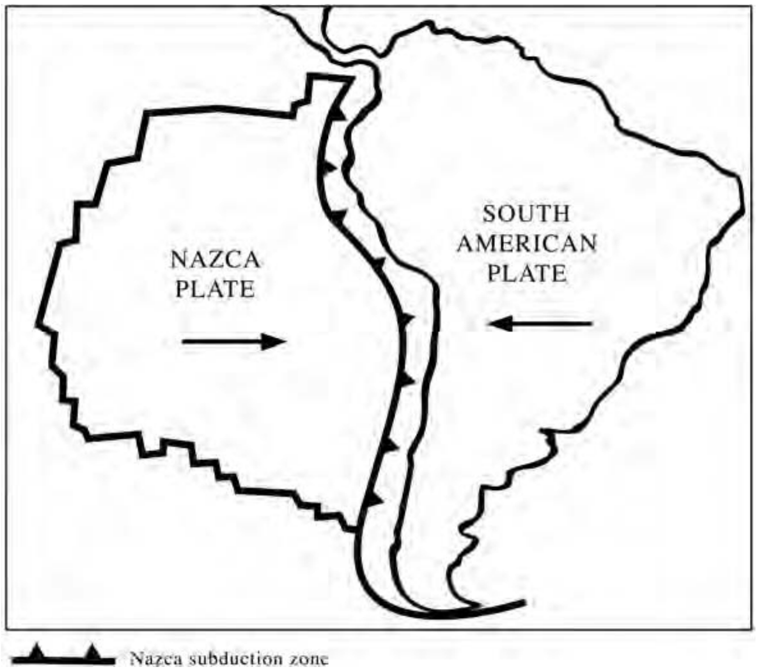

Figure 8 The eruption of Mt. Huaynaputina and many subsequent South American volcanic eruptions are linked to the subducting action of the Nazca Tectonic Plate.

tween the Spanish and the local people. In 1784 it is clear that forced labor was the method. Spanish royalty launched their conquest of South America in order to exploit its wealth, just as the British had done in America during the colonial period, and the Spanish would learn at a later time, just as the British did, that exploitation leads to revolution if the local people are not treated fairly. In 1784, the officer in charge arranged for a forced draft of six thousand Indians from neighboring areas to be brought to Arequipa to rebuild the city. There was little difficulty in arranging this as it was a common occurrence. An arrangement for ensuring adequate labor for the mines was a similar forced draft: every Indian community had to send one-seventh of their adult male population for a year to work in the mines. The low wages they were paid did not interfere seriously with the profits that had to be sent back to Spain, even after destructive earthquakes like this one in 1784 when the city was a much bigger place than in 1600.

Fortunately, recovery from the eruption in and around Arequipa did not take too long, perhaps because the area was not highly developed and the work of restoration consisted mainly of removing ash and other volcanic debris. During the eruption, ash had been falling so fast that the mayor of Arequipa gave orders to clear the roofs to protect them from collapsing. About three feet had fallen on the city by the time the eruption began to subside. For the cleanup the Spanish Commander commandeered six hundred natives and forty soldiers to clear the ground and rebuild the homes and public buildings. The work took a few years and Arequipa became known as the white city because of the volcanic stones used in construction; they were whitish in color and very hard, unlike pumice. It seems strange to use volcanic rock as the building material for a city destroyed by a volcanic eruption. Viticulture was a well-known traditional industry of the area and a particular tragedy was the loss of grape crops as a result of the ash fall. Seventeen years after the eruption, a visitor noted that very little development of agriculture had occurred since the eruption and no evidence anywhere of a revival of viticulture.

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12

London, England, Black Death plague

1665 AD

In the main built-up part of London, England

The Asian Bubonic Plague, known as the Black Death, hits London

No one knows why the bubonic plague, or Black Death as it came to be known in England, broke out in eastern Siberia in the 1300s and spread westward. There was very little knowledge, at that time, of the ways by which diseases are carried from place to place, so many of the efforts to get rid of them were ineffective. In later years it was discovered that infected fleas were the carriers. They passed on the disease to rats and when the rats died the fleas attacked humans. In 1347, a ship sailing from a Black Sea port to Messina in Italy, arrived at its destination with every person on board dead. It appears that the last to die were able to get the ship into port before they died. The port authorities in Italy, as soon as they saw what happened, had the ship carried out of the harbor, but their action was too late to stop the spread of the disease. Most of the people of Messina were already infected and, from this city, the disease spread quickly across Europe and across the English Channel, reaching London a year later, in 1348, where it killed close to half of the city's people. Within the following three centuries London suffered several different epidemics but these and even the experience of 1348 were relatively benign compared with the violence of the outbreak of Black Death that swept across London in 1665.

The name by which the bubonic plague came to be known was related to the formation of black boils in the armpits, neck, and groin of infected people, which were caused by dried blood accumulating under the skin after internal bleeding. People first experienced the bacterium of Black

Figure 9 The plague in 1665. The plague victims are being collected and loaded on a cart.

Death as chills, fever, vomiting, and diarrhea. Frequently, the disease spread to the lungs and almost always in these cases the victims died soon afterward. The name pneumonic plague was given to these cases. In all victims the disease spread easily from person to person through the air and, in the vast majority of instances, death ensued. London's population in 1665 was half a million; it was the biggest city in Europe. The first victim of the Black Death was diagnosed late in 1664 but it was in May of the following year that significant numbers of infections were being observed. By June, in the wake of a heat wave, more than seven thousand lives were being claimed by the Black Death every week. Those who could leave the city as the wave of death swept over it did so. The king and his retinue left. So did many of the clergy and nobility. The biggest surprise and the one that everyone condemned was the departure of the president of the Royal College of Physicians. All who were unable to leave the city, the vast majority, had to cope as best they could.

The usual practice of burying the dead in what was known as consecrated ground; that is to say, the cemetery on the grounds of the church, had to be abandoned as the number of dead mounted. Plague pits came into use to cope with the problem. As many as 100,000 lives were lost before winter killed the fleas and the epidemic began to taper off. The peak total of deaths came late in September, 1665, an interesting parallel with the time frame of the 1918 flu pandemic which lasted for a similar stretch of time. Presumably, those who are afflicted with such diseases develop antibodies after a time and fewer and fewer people then succumb. Doctors of the time could provide no explanation for the sickness, and most of them were afraid to offer treatment. In an attempt to keep from being infected, the few physicians who did risk exposure wore leather masks with glass eyes and a long beak filled with herbs and spices that were thought to ward off the illness. So terrified were the authorities that even if one person in a household showing plague-like symptoms a forty-day quarantine in the form of a red cross on the main door was imposed on the whole home. In many cases, it was a virtual death sentence for everyone living in the home because the black rat, the usual carrier of the disease, was an old inhabitant of London's homes. When these rats died from the disease the fleas used people as their hosts.

Daniel Defoe, who was a youngster in 1665, later wrote extensively of the effects of the Black Death. He described London as a city abandoned to despair, a place where every home and every street was a prison. One area near the center of the city that had no buildings on it became a mass grave where the dead were dumped unceremoniously and covered with loose soil. Every day, thousands of bodies were brought to this spot in what was described as dead carts. Farther out from the center of the city, as the disease spread, a burial pit was dug, forty by sixteen feet and twenty feet in depth, and this served as a mass grave. Defoe stressed the eerie silence everywhere. There was no traffic except for the dead carts. Anyone who risked going outside always walked in the middle of the street, at a distance from any building and as far away as possible from any other person. London's economic success, as evident in its huge population of half a million, led to overcrowding and neglect of hygiene, both conditions that encouraged the spread of diseases. Rat-infested slums that lacked running water added to the risk of infection. Paradoxically, the worst set of circumstances for those who showed initial symptoms was the five pest houses outside the city to which these people were sent. The unavoidable close contact with other patients made for easy transfer of the bacteria through breathing.

There have always been epidemics and outbreaks of sicknesses in London. This particular outbreak, the worst of all, had a predecessor in 1348, as has already been mentioned, which seemed to be the worst ever in its own time. A thousand years before the events of 1665 there was an earlier outburst of what must have been similar to the Black Death but was described differently at that time. Between the years 1550 and 1600 there were five severe attacks of Black Death, the last of which killed 30,000 Londoners. There were good reasons for these catastrophic experiences of diseases. Very little was known about public hygiene and open sewers were the norm. Homes were small and so tightly packed together that bacteria quickly moved around from person to person. Furthermore, London had for a long time been the center of national life and the place where there were opportunities in business and professional work. It had the biggest population of any English city. People kept arriving and living places became more and more crowded together in every part of the city.

There was a side effect from the frequency of diseases—the growth of what might be called healers. Charts were produced and circulated to show how the dates of saints or predictions about astrology related to the efficacy or otherwise for healing of different herbs. All kinds of superstitions were embraced, even the one about being cured if you touched the hand of a dead man. For centuries, the priests of the church were the doctors until the pope forbade them from drawing blood in any way. After that all kinds of lay doctors multiplied. Once a person managed to secure widespread publicity as a healer, large numbers of people accepted his cures without questioning them. The atmosphere of fear about new waves of disease was so great that the strangest type of cure was accepted. William Samson, a healer, practiced his art near the gates of Bartholomew's Hospital, a much-respected institution. Because of the location, his proposed remedies were readily accepted at the price he asked. Samson happened to be a bit of a psychiatrist and had evidence of people whom he claimed to have cured.

Before the Black Death had run its course an unexpected "cure" appeared in a rural setting in September of 1665. A tailor received a parcel of cloth from London that also contained some plague-infected fleas. Four days later the tailor was dead and, by the end of the month, five others died. Everyone had heard of the tragedy in London and panic set in after the deaths of the five. The whole community gathered together and arranged to have their village quarantined to prevent the disease spreading throughout the region. It seemed like suicide yet, a year later, when the first outsiders entered the village, they found that most of the residents were alive and healthy. How did so many live through the attack of a disease that had been consistently taking the lives of almost all those infected? It is here that two extraordinary stories from 1665 emerged, stories that affect life today. The first relates to Isaac Newton, the famous scientist who was studying at Cambridge when the Black Death began to reach that city. His mother took him home to northern England for two years and it was during that time of enforced isolation that he did most of the work on his Principia, meaning mathematical principles of natural philosophy, often regarded as one of the greatest scientific works of all time.

The second story relates to the survivors of Black Death. In London, as well as in the village where the tailor received the cloth with fleas, there were accounts of people who survived the Black Death in spite of close contact with family members who had been infected and died. Elizabeth Hancock was one of these. In 1665, she had buried her six children and her husband within a single week but never became ill. The village gravedigger who had close contact with hundreds of dead bodies also survived. Were these people somehow immune to the Black Death? In the last few years, as concern mounted over the possibility of a flu pandemic reaching North America, Dr. Stephen O'Brien of the National Institutes of Health in Washington, DC, decided to investigate the accounts of seventeenth century survival. He searched for descendants of the village where a number of infected people had clearly survived the disease. This was not easy as a dozen or so generations of families had successively spanned the long period of time. He finally succeeded and took their DNA record.

Dr. O'Brien had already been working with HIV patients and had discovered in 1996 that the modified form of a particular gene in these patients, one known as CCR5 and commonly described as Delta 32, prevents HIV from entering human cells and infecting the body. Based on this finding and convinced that the way in which Delta 32 protects the body from infection might apply to other diseases he took DNA samples from the surviving relatives of the lucky ones in 1665. As he examined them he made two startling discoveries based on both his work with HIV patients and the experiences of the surviving relatives. One copy of the mutation enables people to survive although they get very sick. Two copies, that is to say one gene from each of two parents, ensure that an individual will suffer no infection of any kind. Delta 32 has not been found in parts of Asia or Africa or other areas where bubonic plague or Black Death did not occur so this, for Dr. O'Brien, raised an interesting question: did some natural event create this mutation so that some would survive? It has been said that a destructive bacterium or virus does not want to destroy all of its hosts so that it can continue to infect others later. Was this what happened in the case of Delta 32?

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13

London, England, fire

September 2, 1666
In the central area of London, England

London was well acquainted with fires but the Great Fire was by far the worst London ever experienced

About two o'clock on Sunday morning, the second of September, 1666, an assistant to the king's baker, who lived with the baker and his family above the bake house, awoke to find his tiny room full of smoke. He alerted the rest of the household, told them of the loud crackling of burning timber from below, and urged them to escape immediately. Within minutes flames began to consume the steps leading to the upstairs so there was no way of escape in that direction. They all climbed into the attic above, squeezed through the narrow window that opened on to the roof, and scrambled along to the next house from which they could reach the ground and escape. Many others were less fortunate as flames jumped from house to house across the city. Before the end of the day the fire was out of control and all efforts were focused on rescuing people and taking them to a safe place.

London was well acquainted with fires at this time and this familiarity tended to make people indifferent to reports of fires. People waited too long in 1666 and, as a result, many lives that could have been saved were lost. It is easy to understand Londoners' indifference to fire alarms; they have been experiencing fires from their earliest days during the time of Roman occupation of the city in the first century. In his classic publication, *London, the Biography*, Peter Ackroyd gives a list of dates for the known fires that swept over some or all of London in the years before 1666: 60, 125, 764, 798, 852, 893, 961, 982, 1077, 1087, 1093, 1132, 1136, 1203, 1212, 1220, and 1227. There were other fires in the more than four hundred years between 1227 and 1666 but records for these were not well kept. The slow reaction to the 1666 fire was almost universal, partly because people thought it was just one more fire that would soon go out but also because, for a short time after the first house went up in flames, there was a time delay before the second house caught fire.

Furthermore, there were underlying environmental factors that would make this fire more destructive than all the previous ones. The month of August, 1666, had been exceptionally hot with almost no rain so the thatch and timber of the crowded buildings were the kind of tinder that would quickly ignite. Additionally, as the fire grew from its beginnings in a house near London Bridge, it was aided by a wind from the southeast that pushed the flames westward and northwestward toward the vast majority of the houses and public buildings that were occupied by the city's half million, probably Europe's most populated city at that time. The narrow streets, all that were needed four hundred years ago for horse-drawn wagons, made it easy for fires to jump to the other side of a street. The houses on either side were even more accessible as they formed a continuous line of buildings so each home caught fire from its contact with the next. Public officials were not allowed to pull down parts of houses that had caught fire because they would be held responsible for all the damages if the building did not completely burn down. Therefore, they had to wait until the whole building was destroyed by fire before intervening.

The first line of flames followed the lower elevations running alongside the Thames River, but bursts of fire appeared nearby as embers were blown ahead in all directions by the following wind. As parish churches became engulfed in fire and smoke their clerks made desperate efforts to recover the parish records and get them out of the buildings. Their priorities were clear: if you can rescue only one thing, make it the records, not the money. It was a clear indication of the speed at which the fire advanced that almost all churches rescued only their parish registers. The most troublesome loss of all on this first day was the destruction of the water conduit, a large lead pipe that carried water uphill to the center of the city. The wooden wheels that pumped the water from the river burst into flames as the fire reached them and the lead melted under the heat. As we will see in later accounts of both fires and earthquakes, it was the loss of water rather than the actual flames that caused the greatest amount of damage. That was true for the San Francisco earthquake and the subsequent fire in 1906 and in the Tokyo earthquake of 1923. In the case of London, no one would get access to water in any quantity for more than a year, a particularly dangerous condition for a city that had so recently survived the scourge of the Black Death and was very much aware of the risks of endemic diseases.

As the fire reached the various quays along the river it found plenty of incendiary resources in sheltered areas and on the waterfront. Stacks of timber, hay, straw, and coal, all standard commodities of trade at that time, were piled up, ready to be transferred to the barges that would take them downstream to where the sea-going ships lay at anchor. There were also smaller quantities of other tinder-dry commodities—barrels of lamp oil, tar, pitch, and tallow. The heat that resulted from all of these products catching fire boiled the beer in the hundreds of barrels that had been stored in the various breweries on the waterfront. The barrels burst their staves and the beer flowed away into the river. Even at this stage, in the early hours of Sunday morning, no general alarm had been given. Samuel Pepys, the writer from whom we received much of our information about the fire and who lived in London at this time, told of his lack of interest in the fire when it was first reported to him. At first, in the middle of the night, when one of his servants awoke him, he looked out of his window and seeing the fire so far away decided to go back to bed. He was about to do the same four or five hours later but changed his mind when told that over three hundred houses had been burned down within the previous four hours. His home was close to the Tower Bridge so he dressed quickly and found his way to a high point on the bridge where he could see the extent of the fire. In his own words as he looked around there was "an infinite great fire burning in all directions."

Pepys took a boat and moved upstream under the bridge to observe more closely the rapid advance of the fire along the banks of the river. No one tried to fight the fire in any way and this surprised him. All efforts were directed at getting valuables out of homes before they went up in flames. Any barge or boat on the river became a target on to which people threw their clothes and other larger possessions. They then found their way, as best they could, on to these same boats or barges to watch the sad spectacle of their houses being destroyed, wondering all the time about their future prospects. Pepys watched with horror as one of the great landmarks of the city, the church of St. Laurence, which had a steeple that soared above all other buildings in the city, burst into flames while the main line of the fire was still some distance away. He concluded for the first time that this was no ordinary fire like those that had come before it. Others too came to the same conclusion. Up to this moment most of the city's population had gone about their normal activities, attending church and offering prayers for the unfortunate people along the river who had lost their homes. Now, as St. Laurence's steeple came crashing down before the eyes of most Londoners, a state of near panic set in.

By afternoon of the first day the fire had reached Whitehall and Westminster Abbey and every department of government was under threat yet, at the Palace of Charles the Second, little was known of the extent of the fire. Pepys arrived at the palace at this time where he told all the staff about the things he had seen. A general alarm soon spread as far as the king and Pepys was called in to repeat his report. He used the opportunity to urge the king and the Duke of York, who happened to be at the palace, to give command that houses be pulled down ahead of the fire. This move had been avoided up to this time because of the liability risks. Now it was apparent that no alternative could stop the fire so the king instructed Pepys to go to the lord mayor of London and command him to spare no houses in order to stop the spread of the fire. Pepys found it hard to get to the lord mayor's place in the eastern part of the city. Every spare wagon had been commandeered by a few who were escaping with their possessions and the streets were clogged with people. The lord mayor threw up his hands in desperation when told of the king's command. "What can I do?" was all he said. He went on to explain to Pepys that no one would obey him and whenever he and one or two others began to pull down houses the fire overtook them before they could complete their work. He had started the demolition of buildings in the night and was tired from six hours of continuous work.

Monday, the third of September and the second day of the fire, was another warm day with the strong wind from the southeast still blowing. It had become even stronger during the night, so strong that ships in the English Channel had to take shelter on the French side. The glare of light reflected from the smoke clouds overhead had been visible all night as the fire continued to sweep westward over the great houses in and around Westminster and farther west in and beyond Chelsea. The world outside London slowly became aware of the tragedy. Often half-burnt newspapers would be carried by the wind up river as far as Eton. One writer described London's yellow smoke as the output of a giant furnace ascending to heaven, a smoke so great that it darkened the sun at midday. No one person was yet fully aware of the scale of the fire. There were no methods of communication that could inform them. Thus, on this second day of the fire, people were still arriving at friends' houses with their belongings not knowing until they arrived that their friends were busy gathering what they could take away with them before the fire struck. September the fourth, the fire's third day, saw the wind abating and the advance of the fire firmly stopped by an order from the king to use gunpowder to blow up houses in the path of the fire and thus create an effective break.

As the smoke cleared and people could see the desolate mass of ruined homes, stumps of chimneys, and broken towers, many of them left the city for good with no hope or wish ever to return. Most of London had been destroyed. The work of reconstruction would be enormous. One sad aspect of the fire was the behavior of some who had carts and coaches for hire and decided to charge exorbitant prices for carrying personal possessions out of the city. Survivors had no choice; they had to pay the price or forfeit their possessions. Only one-fifth of the city was untouched by the fire. The reconstruction had to be seen as the creation of a new city and, to their credit, Londoners accepted the challenge and got to work. All the city homes were rebuilt or replaced within five years. The new streets were wider and brick became the common building material instead of wood. For the first time in the history of the city and after the many fires

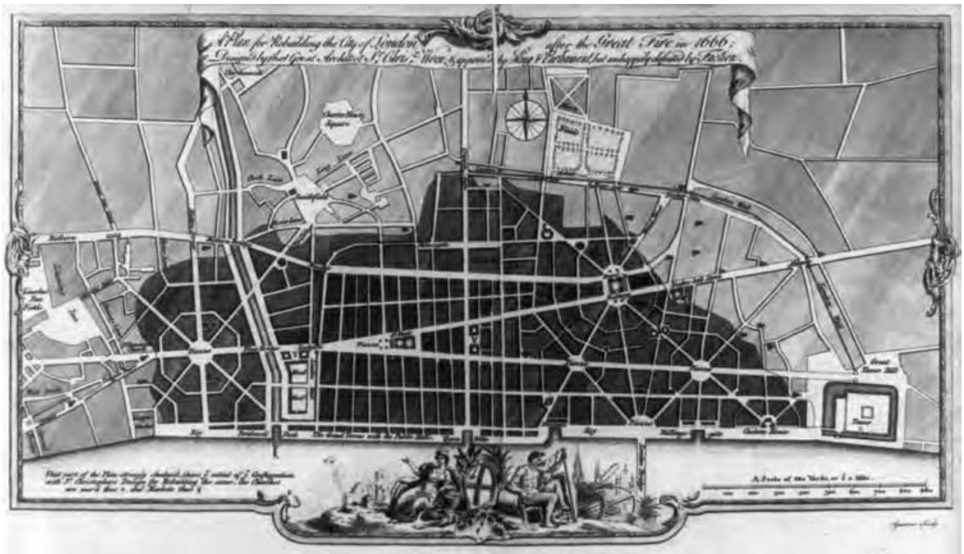

Figure 10 Christopher Wren's plan for rebuilding the city of London after the Great Fire in 1666.

that had assaulted it over that time, London now had a fire insurance plan in place. Never again would the possessions of hundreds of thousands of people be wiped out by a single fire.

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14

Port Royal, Jamaica, earthquake

June 7, 1692
Harbor of Kingston, Jamaica

Port Royal was a city on a sand spit in the harbor of Jamaica, Kingston. It was hit with an earthquake and tsunami and the whole city sank into the ocean

On June 7, 1692, Port Royal, Jamaica, experienced a powerful earthquake and a tsunami. Larger houses collapsed almost immediately and smaller ones slid off the land into the harbor as a widespread state of liquefaction dislocated their sandy foundations. Before the end of the day most of the city had disappeared beneath the waters of Kingston Harbor. Most of those who were left standing in the midst of all the destruction were swept into the sea by the tsunami. Two thousand were killed immediately and an additional two thousand died later from injuries or disease. The city's graveyard was a victim of the earthquake so the survivors, as they sought to recover some of their possessions, had to cope with a frightening scene. There were coffins and bodies from the graveyard floating around along with those who had just been killed. As they continued their search they had to fight against a group of thieves who were taking advantage of the chaotic situation.

Few people seeing modern day Port Royal, Jamaica, a small isolated fishing village at the tip of a sand spit that extends into Kingston Harbor for about eighteen miles, would ever think that it once played a major role in the politics of the Caribbean and England. All the evidence now lies beneath the water of Kingston Harbor. Port Royal is the only sunken city in the western hemisphere. Founded soon after the conquest of the island of Jamaica from the Spanish by an English invasion force in 1655, Port Royal went through a spectacular rise in wealth and influence. Just before the

Figure 11 Port Royal, the city that sank beneath the sea in 1692.

earthquake it was the largest English town in the New World, and the most affluent. Every visitor was impressed with the multistoried brick buildings, quite a contrast to other English colonial towns in the New World. It had a population of more than seven thousand and rivaled Boston in size and economic power, the only other city of comparable importance at that time.

The English turned Port Royal into a strategic military and naval base. Its location in the middle of the Caribbean made it ideal for trade. Trade, as well as loot, dominated the economy in those times. The European powers extracted wealth from their colonies and brought it back to Europe in ships. If a country happened to have a powerful naval force it was considered fair game to raid the ships of other countries and empty their cargos of gold and other valuables. England was one country that engaged in that kind of enterprise. During its heyday, Port Royal was laid out with broad unpaved streets, named after familiar streets in London, each lined with buildings ranging in height from one to four stories. There were several sidewalks lined with bricks and rents ran as high as the highest found anywhere in London, maybe because London was still recovering from a devastating fire and an equally destructive plague. Port Royal in 1692 occupied a space of more than fifty acres at the western tip if the sand spit that extended out from Kingston Harbor, and after the earthquake only twenty of those acres were still above water. It was a little different on parts of the spit nearer to shore. Their underlying foundations of coral, below a hundred feet of unconsolidated sand, seemed to be more solid. Those who started running toward the shore at the first indication of an earthquake were saved.

The tsunamis that caused so much trouble came from submarine landslides. The various movements in the faults around the harbor of Kingston occurred horizontally, as strike-slip actions. There were no vertical displacements. The powerful earthquake created spaces for these landslides and the five-foot tsunami that ensued, mainly inside the harbor area between the peninsula and the main part of the island, swept more than twenty vessels off their moorings and sunk them into the harbor. At the same time, Port Royal was overwhelmed by the same tsunami and most of it sank into deep water to remain submerged for more than two centuries, providing scientists today with a well-preserved record of an early settlement. A brass watch that was recovered in later years appeared to have stopped at 11:43 and archeologists wondered if that represented the exact time of the earthquake. For earthquakes like the one of 1692, the return period lies between two hundred and five hundred years. Hence, a repeat of a similar earthquake and tsunamis could occur at any time.

The experiences of those who were still standing after the disaster, mainly by holding on to a branch or pole, provide a useful description of liquefaction. They told of streets rising and falling like waves of the sea. They saw people disappear in the sand and later reappear as stronger waves washed over the streets and carried quantities of sand out to sea. Others that sank into the sand never reappeared. Experiences of this type have often been documented in other earthquakes. Similar events happened in San Francisco in 1906, in Massachusetts in 1755, and more recently in New Orleans in 2005. The reasons for these recurrences are easy to understand. Unconsolidated stretches of sand, especially these near the sea in major cities, are valuable and suitable sites for building. Either because they did not know of the dangers of liquefaction, or because they did know but were able to persuade authorities to give them permission, construction companies have built large subdivisions on such places, hoping that the next earthquake would not arrive soon. In far too many places it was a false hope.

As so often occurs, in the midst of tragedy, there are instances of unexpected courage and generosity. The slave of one master of a ship decided to jump overboard to save his master after he had been swept off his ship into the sea. The slave reached his master and brought him safely back to the ship but then, too exhausted to stay afloat, lost his own life. Slaves were still slaves in 1692 and they were valuable property for those who owned them. In the chaotic situation that followed the earthquake slave owners were afraid that they would either start a revolt or escape—neither happened.

Reconstruction of Port Royal was ultimately a big problem. It had so little land left that everyone wondered how it could continue to carry its former responsibilities. Kingston was not an acceptable alternative for several reasons: it had a high death rate because it was so unhealthy and it was not easily defended if attacked by land and sea simultaneously. Furthermore, since sailing ships were the only kind available in the late seventeenth century, Kingston was not accessible in windy weather. England decided to let both ports, Kingston and Port Royal, share responsibilities for all shipping.

In 1907, a submarine landslide occurred in almost the same location as the one that occurred in 1692. This new submarine landslide generated a tsunami that overwhelmed the peninsula where Port Royal had stood. The earthquake that gave rise to the tsunami caused enormous damage to places all along the shores of Jamaica. At one location, the sea was observed to withdraw as far as three hundred feet within three minutes after the earthquake and to return as a destructive eight-foot wave. The fact that only three minutes elapsed between earthquake and tsunami makes it clear that the landslide happened very close to shore. A pilot and crew of a ship witnessed the return to shore of the tsunami. They saw both the peninsula and the town of Kingston disappear from view for some time. Shortly afterward, seiches as high as eight feet were observed in Kingston Harbor. One thousand people died in the town of Kingston, mainly from falling buildings, and another thousand were injured. Approximately 90,000 were left homeless.

Nothing like seventeenth-century Port Royal remains in that location today. Visitors now see a fishing community of less than 2,000 along with an abandoned British Naval Base, now used by the Jamaican Coast Guard. Jamaica is an independent nation now so the marks of former British activities lie, for the most part, under the sea. The ships and houses that sank in 1692 now form part of a magnificent museum and a unique center for archeological research. On land and sea above all these, in the years since 1692, Jamaica has experienced many more disasters. There was a fire in 1703, completely destroying all that was left or had been rebuilt of the old city of Port Royal. Hurricanes hit it in 1722 and again in 1744 and on both occasions everything came down and had to be rebuilt. Two earthquakes came later, one in 1770 and one in 1907. The former destroyed the hospital and the latter a large part of the dockyard. Another fire, in 1815, did extensive damage to all the buildings, and a third earthquake destroyed the old fortifications.

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15

Cascadia earthquake

January 26, 1700
In and around Seattle

An earthquake, estimated at magnitude greater than 9, and accompanied with an equally powerful tsunami swept across the Pacific Northwest near Seattle

On the twenty-sixth of January 1700, a massive earthquake of magnitude greater than 9 shook the ocean floor west of Seattle. It occurred about one hundred miles off shore in the zone where the Juan de Fuca Tectonic Plate subducts beneath the North America Plate. A tsunami followed quickly because the distance from the epicenter to Seattle was small. A wall of water swept over the whole coastal area, destroying everything in its path. How do we know that these things happened? The only humans who lived in this area in 1700 were native people and they had no written records or indicators of time that could tell us. The answer lay in a series of events that began in the mid-1980s.

A nuclear power plant was being installed south of Seattle in the 1980s and the nuclear regulatory authorities wanted to know if there were any seismic concerns that ought to be taken into consideration. The initial response from geologists was that there was no record of big earthquakes in this area so a nuclear power plant would not be in danger, but the question that had been asked stimulated new questions that no one had previously asked. Geologists knew that, throughout historical time, there had not been any record of an earthquake of magnitude 8 or 9 at the Juan de Fuca site, yet all along the Pacific Coast of North and South America there were earthquakes of this magnitude in all the other regions. Is the Pacific Northwest unique? Do the gigantic Pacific and North American plates behave differently here than they do everywhere else? It was the remaining portion of an older Pacific spreading ridge, namely the Juan de Fuca Plate that caused the massive 1964 earthquake in Alaska, but that same plate is subducting beneath the Pacific Northwest. Why were there no big earthquakes there? These were the questions.

By the 1980s refinements in our knowledge of plate tectonics, particularly awareness of the much greater power in plates that are subducting when the distances from their spreading ridges are short as they were with the Juan de Fuca Ridge, persuaded scientists to search for evidence of past quakes in the Northwest. Perhaps, they speculated, there were powerful earthquakes in the past of which we know nothing because this part of the country has been settled for such a short time. Digging down beside a stream close to the coast, one geologist found layers of sand and mud below the surface. They extended downward for about six feet before coming to an abrupt stop at a junction with a layer of peat. As he dug down farther he found another layer of sand and mud below the peat. It was obvious

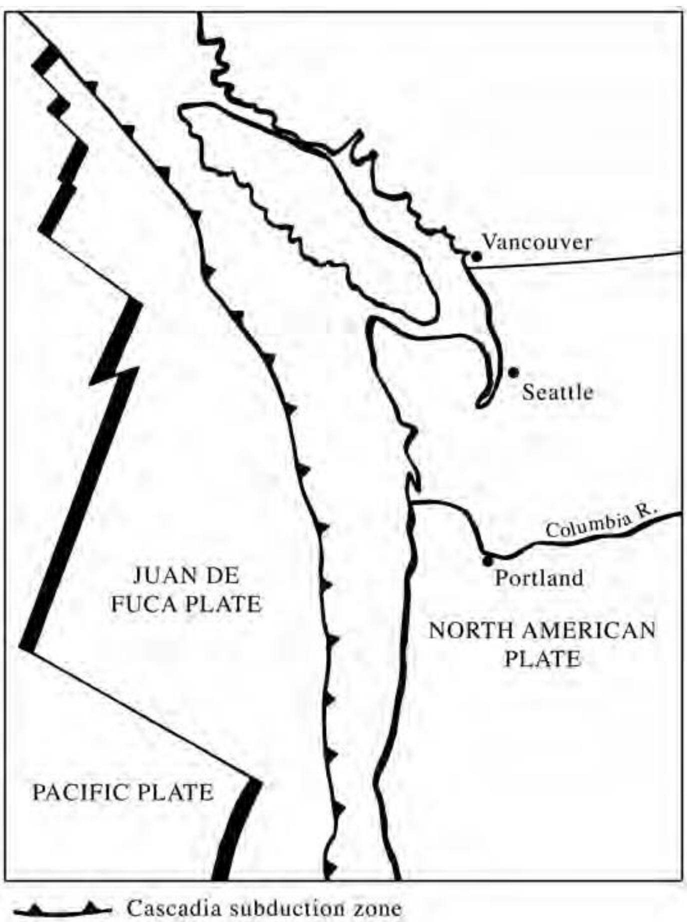

Figure 12 The massive Cascadia earthquake of 1700 was caused by the subducting action of the Juan de Fuca Tectonic Plate.

that this part of the coast had once been below high water, then above it, and then below it again before coming to its present state with topsoil in the uppermost eight inches. Furthermore, the sharp demarcation lines between peat and sand suggested that the changes from below to above water had been sudden, just the sort of thing known to be typical of subduction earthquakes.

If this was indeed the result of a former subduction earthquake there ought to be similar layers of mud and peat at the same depths all over the same place. Before long, evidence of such was found in abundance. In one place, a number of additional sets of layers were uncovered, suggesting that there might have been a succession of subduction quakes, separated by long periods of quiescence. As researchers moved farther and farther back from the coast, looking carefully at each location where layers of mud and peat were found, a very fine layer of sand on the peat seemed to become thinner and thinner the further you were from the coast. This is exactly what you would expect if a powerful tsunami had swept across the land following an earthquake. Samples of plant material and bits of wood from the top peat layer were collected and their age calculated using the carbon-14 technique. They were found to be approximately three hundred years old. At the same time, all sorts of additional data kept coming in, all confirming the original speculation that this region has always experienced massive subduction earthquakes, as many as thirteen over the past six thousand years, the last one being before there was any European settlement, about three hundred years ago.

It became clear that, in 1700, one of the world's largest earthquakes had hit the west coast of North America. The undersea Cascadia thrust fault ruptured along a six-hundred-mile length, from mid Vancouver Island to northern California in a great earthquake, producing tremendous shaking and a huge tsunami that swept across the Pacific. The Cascadia Fault is the boundary between two of the earth's tectonic plates: the smaller offshore Juan de Fuca Plate, formerly the Pacific Plate before the North American Plate had overtaken it, now the one that is sliding under the much larger North American Plate. This earthquake caused a shaking of the houses of the Cowichan people on Vancouver Island as we know from their stories. The shaking was so violent that people could not stand and so prolonged that it made them sick. On the west coast of Vancouver Island, the tsunami completely destroyed the winter village of the Pachena Bay people leaving no survivors. These events are recorded in the oral traditions of the First Nations people on Vancouver Island. The tsunami swept across the Pacific also causing destruction along the Pacific coast of Japan. It is the accurate descriptions of the tsunami and the accurate time keeping by the Japanese that allows us to confidently know the size and exact time of this great earthquake.

It was as geologists began to get firm data about the 1700 earthquake that they made contact with a Japanese seismologist who happened to be visiting North America and became interested in the Pacific Northwest.

This seismologist was well acquainted with subduction earthquakes and the tsunamis that so often accompanied them because they were common occurrences in his home country of Japan. He concluded that if one had occurred here about three hundred years ago it ought to be possible to prove that it had happened. Japan, being an older civilization, has records of earthquakes and tsunamis going back many hundreds of years. When he returned to his country he found that a powerful tsunami, of the kind that would be triggered by an earthquake of magnitude 9 or more, had struck Honshu, Japan's main island, exactly three hundred years ago and that it came from this part of North America. Knowing the speed of the tsunami he was able to say exactly when the earthquake took place. It was the twenty-sixth of January 1700.

A researcher from the Geological Survey of Japan, along with a team of scientists from the University of Tokyo, found Japanese records of tsunami occurrences along the country's eastern coastline between January 27 and 28, 1700. Careful analysis of these historic tsunami records indicated that several coastal villages were damaged. Accounts were recorded in different villages along Japan's coastline. Seawater was known to have covered land as if it had been high tide. Water went as far as the pine trees and returned to the ocean very fast. Reports indicated repeated waves of water coming in and going out as many as seven times before noon. Because the way the tide came in was so unusual, people were advised to move to higher ground. Some accounts tell of twenty houses being destroyed by waves ten feet high. Rice paddies were destroyed by these waves.

The long history of subduction activity is the key to the history of the Cascade Range of mountains that lie north and south of Seattle near the coast. These mountains are located approximately 170 miles from the coast. If we were to imagine a line descending directly downward into the earth from these mountains we would encounter the subducting ocean crust from the Juan de Fuca Plate at a depth of about seventy miles. Ocean crust from the Juan de Fuca ridges descends slowly so it has traveled some distance inland before it gets down to a depth of seventy miles. At that level the heat in the crust and in its associated water and other volatile material is high enough to create pockets of magma, which rise close to the surface. If a conduit permits any of this magma to break out on to the surface we have a volcanic eruption.

The Cascade Range is a series of stratovolcanoes; that is to say, volcanic mountains that are conical in shape because of the nature of the lava that built them over the past thousands of years. Other volcanoes, such as those in Hawaii, have a different shape because the lava that built them has a different chemical composition. The Cascades run from Mount Garibaldi north of the Canadian border all the way to Mount Lassen in northern California and each peak has its own unique history; some have a very violent past while others either took shape quietly or we do not know enough about their past. We will look briefly at some of these volcanic peaks, beginning at the south end at Mount Lassen. This mountain in northern California experienced a major eruption in 1915 with continuing action at different times over the following two years. The type of rock that erupted was mostly basalt, but in the explosive action accompanying the main event hot rocks were thrown on to its snow-covered sides, triggering major debris flows. In Lassen Volcanic National Park, which includes Mount Lassen and three smaller volcanic centers, the present-day geothermal system has a magma pool near enough to the surface to provide hot water. This system consists of a reservoir with a temperature of more than 400 degrees, underlain by a reservoir of hot water.

Crater Lake, farther to the north, in Oregon, is the remnant of a catastrophic eruption of what was once Mount Mazama, over 10,000 feet high. In that gigantic upheaval of 7,000 years ago, thousands of tons of matter were flung into the air in a pyroclastic flow that spread ash over large parts of eight states. It was an explosion that was probably ten times greater than the one that occurred later in Mount St. Helens. As often happens in an event of this magnitude, the summit of the mountain sank back into the now empty five-mile-wide inner magma chamber and went down below ground level. The empty caldera then filled with water to form the place we know as Crater Lake. Mount Baker has a summit rising to more than 9,000 feet. Apart from Mount St. Helens it is the most active volcano in Washington State. Steam and gas emissions from it were common during the 1970s. Glacier Peak is a volcanic mountain very similar to Mount Baker. Its height is more than 10,000 feet and, like Baker, its cone is less than one million years old. Mount Hood is the fourth highest peak. It has been active for more than twenty million years.

Mount Rainier is the highest mountain of the Cascades, towering more than 12,000 feet above sea level. It has the greatest concentration of glaciers of any mountain in the lower forty-eight. Like other peaks of the Cascades its growth occurred within the last million years but, within that period, all sorts of volcanic eruptions, landslides, and mudflows devastated the surrounding area. As recently as 1989 a gigantic rock avalanche crashed down on the north side of the mountain. Debris flows like this one give a great deal of concern to surrounding settlements. Glacial outburst floods originate when water stored at the base of glaciers is suddenly released, and floods of this kind have been launched from four of Mount Rainier's glaciers. The most prolific of the four is South Tahoma Glacier, which had fifteen of these outbursts between 1986 and 1992. These floods occur during periods of unusually hot weather in summer or early fall. Rainy weather can also be a trigger. I used the term debris flows in relation to these because the release of water triggers small landslides and picks up sediment on the way down. This flow of water, mud, and rocks at ground level then travels at about fourteen miles an hour, tearing up vegetation and damaging roads and facilities in Mount Rainier National Park.

Mount Rainier is receiving a lot of attention these days. Part of the concern relates to its rock structure, the presence of weak layers of rock high on the mountain, as well as its huge cap of snow and ice. These areas could collapse in even a small earthquake and disrupt life and industry in nearby Seattle. During the 1990s, Mount Rainier was selected by the United States Geological Service for intense study as one of three places that might cause major damage over the next decade or two. To emphasize the urgency of this study, it was pointed out that a fault line, known as the Seattle Fault, runs from a point near Mount Rainier to Seattle. Given the frequency of smaller earthquakes in and around Seattle, there is every justification for concentrated research efforts while, at the same time, keeping a close watch on the mountain's behavior.

We now know that a similar offshore event will happen sometime in the future and that it represents a considerable hazard to those who live in southwest British Columbia. However, because the fault is offshore, it is not the greatest earthquake hazard faced by major west coast cities. In the interval between great earthquakes, the tectonic plates become stuck together, yet continue to move toward each other. This causes tremendous strain and deformation of the earth's crust in the coastal region and causes ongoing earthquake activity. This is the situation that we are in now. Some onshore earthquakes can be quite large (there have been four magnitude 7+ earthquakes in the past 130 years in southwest British Columbia and northern Washington State). Because these inland earthquakes can be much closer to our urban areas and occur more frequently, they represent the greatest earthquake hazard. An inland magnitude 6.9 earthquake in 1995 in a similar geological setting beneath Kobe, Japan caused in excess of $200 billion damage.

At 9 P.M. on January 26, 1700 one of the world's largest earthquakes occurred along the west coast of North America. The undersea Cascadia thrust fault ruptured along a six-hundred-mile length, from mid-Vancouver Island to northern California in a great earthquake, producing tremendous shaking and a huge tsunami that swept across the Pacific. The Cascadia fault is the boundary between two of the earth's tectonic plates: the smaller offshore Juan de Fuca Plate that is sliding under the much larger North American Plate.

The shaking of the earthquake collapsed houses of the Cowichan people on Vancouver Island and caused numerous landslides. The earthquake also left unmistakable signatures in the geological record as the outer coastal regions subsided and drowned coastal marshlands and forests that were subsequently covered with younger sediments. The recognition of definitive signatures in the geological record tells us the January 26, 1700, event was not a unique event, but has repeated many times at irregular intervals of hundreds of years. Geological evidence indicates that thirteen great earthquakes have occurred in the last 6,000 years.

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16

Lisbon, Portugal, earthquake and tsunami

November 1, 1755
The main city of Lisbon

An offshore earthquake of magnitude 9, followed by a tsunami destroyed Lisbon, Portugal. The combination of the earthquake and the tsunami, especially with little understanding of the nature of tsunamis, caused almost universal destruction in Lisbon

On November 1, 1755, an earthquake of magnitude 9 hit Lisbon. Houses and shops in the lower part of the city, which had been built on unconsolidated ground, were completely wiped out and most of the parish churches were also destroyed. The shock of the day on which this happened was as strong as the event itself. November 1 is All Saints Day, a sacred occasion in a Catholic country like Portugal. In such a religious place the middle of the eighteenth century there were deeply held convictions about all the earth being an orderly creation guided by its Creator for the benefit of humanity. How could such a tragedy occur on All Saints Day and how could it happen when most people were in churches and where so many of them lost their lives? There was a sense of bewilderment all around. Those who were able to get out of buildings before they collapsed ran down toward the open areas near the sea, tragically unaware that a powerful tsunami was about to overwhelm the very area they thought was safe.

The city of Lisbon is a short distance inland from the Atlantic coast on the northern bank of the River Tagus. As people moved toward the mouth of the river close to the coast they noticed that the water's edge had moved away from the land, leaving a broad stretch of beach covered with all kinds

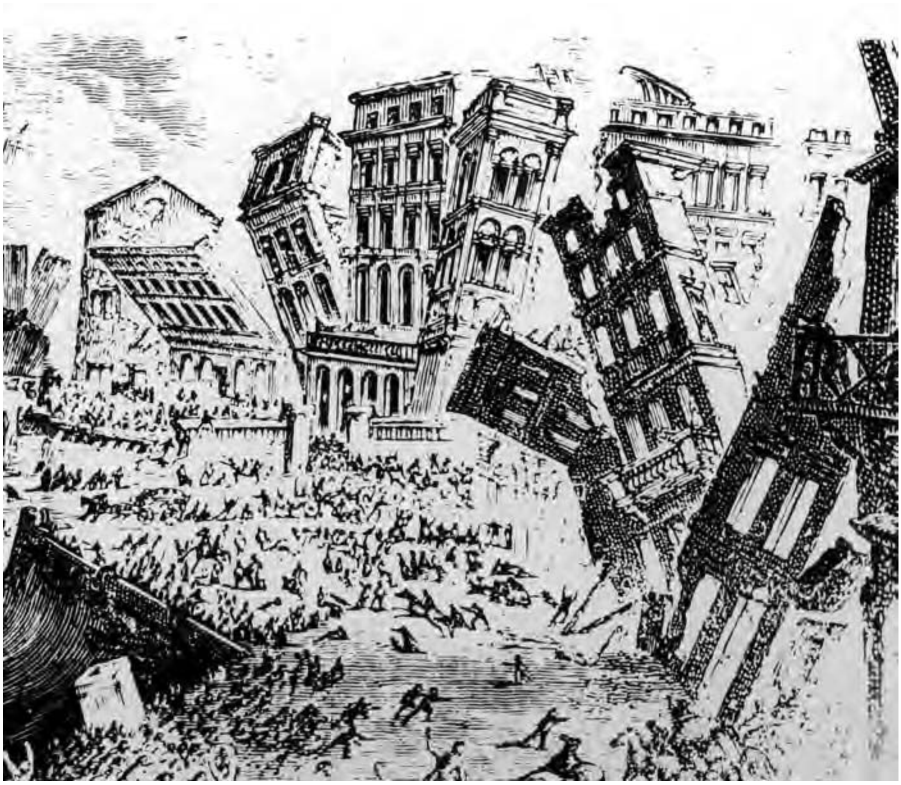

Figure 13 Lisbon earthquake. An accompanying quote is from Voltaire's *Candide:* "The seas rose boiling in the harbour and broke up all the craft harboured there; the city burst into flames, and ashes covered the streets and squares; the houses came crashing down, roofs piling up on foundations, and even foundations were smashed to pieces. Thirty thousand inhabitants of both sexes and all ages were crushed to death under the ruins."

of sea life. What they were unaware of is that the withdrawal of water from beaches is frequently the first action of tsunamis as they reach shore. There is a pause as tsunamis encounter shallow water and friction is experienced by one part of the advancing wave. The wave stalls, then, like a suction pump, it withdraws all the water in front of it and recedes back out to sea, only to return later with much greater strength. There was no understanding of tsunamis 250 years ago so no one was prepared for the wall of water that subsequently crashed on to the shore destroying everything in its path. The wave was forty feet high at first and increased in height as it made its way up the valley of the River Tagus.

The epicenter of the earthquake was located at sea about seventy miles southwest of Lisbon in a location where two tectonic plates meet, the Azores Plate and the Gibraltar Plate. Historically, those have frequently given rise to tsunamis, particularly if the quake's magnitude is greater than 9. Thus, the result of the earthquake was first of all huge damage to

Lisbon, but then lesser destruction up and down the coast as far south as North Africa and northwards to Britain and even Scandinavia. Along the French coast lakes and sea inlets were flooded. There were several phases to the tsunami. It was not just one wave that came in but rather a sequence over a period of time, so places continued to be hit at a distance over time. Lisbon was a city of 275,000 people in 1755 and first reports told of 20,000 buildings having been destroyed but this was just the beginning of troubles. As has so often happened in earthquakes fires break out and quite soon they are out of control. This was the case in Lisbon and the same thing happened more recently in San Francisco's earthquake of 1906 and Tokyo's of 1923.

Fires always get out of control very quickly after earthquakes for similar reasons, because they originate in numerous places at the same time. In Lisbon, candles in churches were knocked over and open fires in kitchens were also tipped over. Wood, cloth, and paper, all highly flammable materials, were everywhere available to assist any flame. To make matters worse, strong northeasterly winds sprang up around the city. Fires blazed on for a week, destroying all that was left standing from the destruction cause by the earthquake. All kinds of valuable collections of silks, spices, and goods were destroyed by the fire, as were some outstanding buildings such as the Opera House, just built in the year of the earthquake, and the Patriarchal Church and Royal Palace. The major libraries of the city lost more than 70,000 volumes. Of special interest to those who disliked the authoritarian rule of the church was the news that one of the buildings destroyed was the headquarters of the Inquisition, the branch of the church that was responsible for the persecution and torture of all who opposed the beliefs of the church.

At least 30,000 people lost their lives in the city of Lisbon and a general state of chaos followed the tsunamis and the fires that followed. The sad situation that emerged was an opportunity for scavengers and thieves. They began to search all over the ruins of the city, among the living as well as the dead, to find what they could. Their behavior, added to all the destruction, gave rise to what can only be described as mass hysteria among survivors. The need for some form of authority coupled with effective control over crime became urgent. The government of Portugal had collapsed as a result of the widespread destruction and there was no obvious source that could exercise control. The king decided to appoint one man, on a temporary basis, to take complete charge of all the affairs of the city. He was given absolute authority. He had to launch quickly into three immediate tasks: establish order, fight the fires, and bury the dead. To make it clear to all who might try to steal or profit from the high demand for food, this man arranged to have several gallows erected in the city. The bodies of more than thirty looters were soon found on these gallows, left there for the public to see.

Securing the approval of the church to bury the dead quickly was a difficult task, despite his authority. Where you were buried was seen to be as important as how you had lived because it affected your fortunes in the afterlife. Burial in a consecrated plot beside the church was essential because that would mean your beliefs and behavior had been approved by the church. Without that approval you were certainly destined for hell. However, there were neither enough priests nor sufficient time to arrange for each burial and the man in charge wanted to conduct a mass burial at sea to prevent the spread of disease. Bodies had already been ignored for some days. The greater good prevailed and all bodies were buried at sea. The next task was to arrange temporary housing for the homeless along with public kitchens and food distribution centers. Both Portuguese and foreign ships that happened to be in the harbor were ordered to unload their provisions and sell them at reduced prices.

One foreigner visiting Lisbon who happened to be on the fringes of the city in a place that was largely untouched by the earthquake decided to record his observations of the event. It was probably all he could do because everywhere around him there was a situation of panic. He noted a slight tremor in the ground around 9:30 in the morning and thought it must be the result of a passing wagon. The tremor lasted for about two minutes and was followed, after a short pause, by a violent shaking that made nearby houses split and crack. This much stronger shaking went on for what he felt was about ten minutes and was accompanied by a steady build up of dust in the air, latterly so heavy and dark there was no daylight. Suddenly, he noted, the dust settled down and the sun appeared. There was a short period of nothing happening before he felt a third and far greater shaking. He could see at a distance building after building collapsing. Once again the sun was obscured and he began to hear the cries of pain from all directions. Soon afterward he saw fires springing up here and there and he could see people running away from them. A wind had sprung up and no one was trying to cope with the flames. Every person was trying to save his or her own life. Fortunately, this foreigner's written record was preserved and later added to the official documentation.

About an eighth of the 275,000 people of Lisbon had perished along with its buildings. The fires raged on for five days and Lisbon, one of the largest cities in Europe, famed for its architecture, was reduced to ashes. Architectural treasures from the days of Moorish occupation were lost. The city's opera house, built earlier in the same year as the earthquake, had gone. The cathedral and all the major churches were ruined and the Royal Palace was no longer habitable. The city's hospital was overtaken by fire and its destruction added significantly to the total loss of life. The total value of property losses was estimated to be $100 million. This earthquake was the first in all history to be subjected to very close scientific investigation. The same man who had been given absolute authority to bring order and provisions after the earthquake arranged for a questionnaire to be sent to every parish in all of Portugal asking them for all the information they could provide as to the time and duration of the shocks and aftershocks, how high the sea waves came, and how many people had been killed. This record was kept in Portugal's national archives and it has been a very valuable source of information for succeeding generations on the whole subject of earthquakes and their effects. Also included in this record were the notes from the foreign observer.

The work of restoration began quickly. Debris was cleared from the city within a year and by the end of that year the various branches of government were in place. Fortunately, the new prime minister decided to take account of the information that had been collected from all the areas affected by the earthquake and use it as a guide in the design of what would be a new city. There were many aspects of the old city that both contributed to earthquake destruction and hindered escape when tragedy struck. The new prime minister was determined to correct these weaknesses of design and, as a result of the work he did, he became known in history as the father of seismology. One improvement he introduced seems very simple to us today but was revolutionary in 1755. It was to make streets wider and remove curves. This one change would enable people to escape quickly from a collapsed building without having to cope with the debris that so often filled the older streets. In addition, fires could not jump easily from one side of a street to the other so they would not get out of control as quickly as they formerly had. Even in modern times, as was seen in Japan in the aftermath of the 1923 earthquake, a simple idea like this is not always implemented. Instead, in Japan, streets were left in the older narrow format.

To ensure against the collapse of buildings in an earthquake, the new prime minister did several things. First, he arranged to have models of buildings drawn to scale and then arranged for army units to parade backwards and forwards with their horses around the models to find out if their weights and activities affected the models in any way. As the design of new buildings progressed he finally settled on a new kind of structure consisting of a flexible wooden skeleton around which masonry walls would be built. The idea was that the flexible skeleton would be firmly anchored in order to hold the masonry walls in place during an earthquake. At the same time, the masonry would protect the wood from catching fire. This was perhaps the first occasion when a building design was carefully related to the effects of the earthquake. It may have been the first anti-earthquake building system ever designed. Such systems became fixed law for Portugal and guided Lisbon's new city plan. There were two other valuable initiatives that the prime minister added: he included the details about earthquake experience that had been collected and made them part of the overall plan for the city and added, in some detail, all that was known about the behavior of animals before and during earthquakes. Today we are well aware of the warning signals we get from all forms of life with regard to earthquakes but this was probably the first time they were given serious consideration.

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17

Massachusetts offshore earthquake

November 18, 1755
Two hundred miles off the coast of Massachusetts

An earthquake of magnitude 8 occurred offshore from Gloucester and damaged coastal areas; it was the largest earthquake experienced in Massachusetts up to that time

On November 18, 1755, a magnitude 8 earthquake, centered offshore two hundred miles east of Gloucester, severely damaged areas onshore. Heaviest damage occurred around Gloucester. It was the largest earthquake experienced in Massachusetts up to that time. Shaking was strongest all along the coastal areas southwards toward and around Boston. Within the city of Boston there was considerable damage. As many as 1,600 chimneys were knocked down and the brick walls and roofs of several buildings collapsed. Stone fences were thrown down throughout the countryside, particularly on a line extending from Boston to Montreal, reminiscent of an earlier earthquake around Montreal in the previous century which destroyed several stone chimneys in Boston.

Earth movements took place west and south of Boston; new springs formed, and old springs dried up. Cracks opened in the earth and water and fine sand issued from some of the ground cracks. The impact of the earthquake was felt in Halifax and Montreal in Canada, in Chesapeake Bay in Maryland, and on a ship that was at the epicenter. There, above the epicenter, the shock was felt so strongly that those on-board believed the ship had run aground. There were several aftershocks. An area of reclaimed land near the wharfs in Boston was damaged to a greater extent than anywhere else. It may have been one of the first examples of liquefaction, that is to say a ground surface changing to a mixture of water and mud during an earthquake, a problem that appeared later where buildings had been erected on unconsolidated sediments.

This earthquake may also be the first record of a tsunami in the U.S., now a familiar story in subsequent records of major earthquakes, especially the powerful 1964 earthquake in Alaska. In other countries, as we know from the devastating tsunami of 2004 in Sumatra, Indonesia, tsunamis have often been experienced. The Lisbon earthquake of the same year as the one in Massachusetts was one of the most powerful tsunamis ever known up to that time. This 1755 earthquake off Gloucester affected other vessels near the epicenter and left a few vessels aground in the Leeeward Islands, more than a thousand miles away to the south. In that area the typical tsunami effect of water being drawn back from the harbor was observed—fish were left on the banks along with anchored vessels and then, a short time afterward, a larger wave that was six feet higher than normal swept ashore.

The Gloucester earthquake, often referred to by the name "Cape Ann," was interpreted in the popular mind as a judgment from God for bad behavior. There were similar interpretations in other locations, at different times, including the United States today, despite our present understanding of the causes of earthquakes. In the case of the Gloucester quake there were additional reasons for attributing causation to the direct action of God. Widespread religious revivals had been taking place throughout New England under the leadership of Jonathan Edwards and they carried warnings of the imminent judgment of God against all who did not repent. Historians have identified a consistent theme in all the published sermons of that time, namely that the ground had shaken because of the moral imbalance in human behavior. In some southern states the influence of earthquakes on religious behavior was dramatically expressed in the increase of people attending Methodist churches. From 1811 to 1812, the dates of the Madrid quakes, their numbers jumped by 50 percent. For the prior decade this denomination's numbers had changed very little.

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18

Bengal, India, famine

1770 AD

Northeast India, in the area now known as Bangladesh

British administration failed to prepare for times of inadequate rainfall so, when crops failed in 1770, no food supplies were available for the peasant farmers. Ultimately, the mass starvation of Indian peasants resulted from poor government administration

In the summer of 1770, the northeast of India, a region we now recognize as Assam Bihar and Bangladesh, experienced a famine that affected the entire area. By the end of that year ten million of the residents had died from starvation. The explanation given by the ruling authorities was that the tragedy was due to natural causes, but a closer examination of the circumstances associated with the sudden loss of rice, the principal food of the native people, revealed that the tragedy was due to two things: first, ignorance of rice agriculture on the part of the ruling authorities and, second, removal of the basic necessities of life by the same rulers in order to export or sell the rice and make a profit for the British government. At this time in its history Britain had no clear policy for its relations with colonial subjects other than to maximize its exploitation of local natural resources.

The East India Company was the ruling power in India at the time of the famine. Its work in that country dated from 1600 when the British government gave it the right to capture and control as much of India as they wished. Gradually they expanded their territory until they were the effective if not the official government of the whole country. Numerous trading posts were established along the east and west coasts and a large number of people came from Britain to look after these trading posts. The largest ones were in Calcutta, Bombay, and Madras. A successful military campaign in Bengal by the British leader Robert Clive in the year 1757, in which the local emperor was defeated, gave the East India Company complete control over the best and most extensive agricultural land in all of India. Plentiful supplies of water from the Brahmaputra and other rivers coupled with extensive tracts of flat, rich, alluvial soils enabled this part of India to sustain a high density of population. Summers were hot, ideally suited to rice cultivation. In addition, every summer brought the monsoon rains, high levels of rainfall that ensured adequate supplies of water for the paddy fields.

If the two causes of the tragedy are examined in more detail, the way that events unfolded become clear. The monsoon rains were always the key to successful cultivation of rice in Bengal. They arrived in onshore winds from the sea early in the hot summer months and they persisted into the fall when a reverse, cold, dry flow of air from the continental interior took their place. These gigantic movements of wind systems affected a much wider area than Bengal and it often happened that climatic changes in more distant places delayed the arrival of the summer rains, even causing an almost total absence of rain in some years. Two years before the famine, one of these monsoon anomalies began to appear. In 1768 there was a partial shortfall of rain. As a result, there was a reduction in the amount of rice harvested and in the following year there was even less rain and therefore a correspondingly smaller harvest. By September of 1769 there was a severe drought, and alarming reports were coming in of rural hunger. Early in 1770, reports of widespread starvation began to arrive at the East India Company Headquarters and they were followed by news of a rapid increase in the number of deaths.

In the midst of the developing tragedy, local authorities maintained a strict control over agricultural output. Their income depended on either the sale of the rice they demanded from the local small farmers or on the taxes they levied on the people producing the rice. The people, however, who decided who would benefit from the harvested rice were unfamiliar with rice farming. They knew almost nothing about the vicissitudes of the monsoon rains and they were equally ignorant of local customs, including the traditional ways of dealing with years of drought. It was normal practice among the people of this area to have some rice in reserve because they knew that on occasion they would experience the kind of situation that developed in 1768 and 1769. Thus, they had a reserve of rice to cope with bad years. The British rulers made no arrangements for some rice to be kept for emergencies. Worse still, they prevented the local residents from having such a traditional reserve. As conditions worsened in the early months of 1770 and the death toll mounted the only response from the local authorities was that a natural disaster had occurred and nothing could be done about it.

It is even more astonishing that the leaders of the East India Company, educated people who had come from England where humanitarian concerns for neighbors in distress was almost instinctive, could be so indifferent to the suffering that was taking place all around them. Instead of reducing demand on the harvest of 1769 and using all of it to provide emergency food supplies for the starving residents, they went in the opposite direction and increased the demand on available supplies of rice while continuing to increase the tax on the harvested rice. All the authorities cared about was the need to demonstrate to the British government that they made a profit year by year. If natural conditions reduced the harvest then, in their minds, the obvious thing to do was increase the tax on people so that the profits would remain at a high level. That is what happened. From the beginning of their control in Bengal, the Company had raised land taxes and trade tariffs up to half of the value of the agricultural produce. In 1770, with millions already dead from starvation, it raised these taxes and tariffs by 10 percent so that their profits would remain high.

Famine was everywhere in 1770. Peasants tried to sell their possessions, even the ploughs and bullocks that they would need for their survival in the future. The price of rice, their staple diet, kept going up, and soon nothing that they could sell would pay for enough food. Children were sold to anyone who would buy them and some of them ended up as slaves in European and Indian households. Conditions deteriorated to levels of desperation that give rise to cannibalism and, at the same time, to an increasing spread of disease. At first the starvation and rate of death was in the rural areas, where the population as a whole depended on the rice crop. Then, as out-migrations accelerated, most people headed for the capital of Calcutta in the hope of finding relief there. There was little for them there and soon the streets of that city were full of dead bodies. One or two members of the East India Company were so moved by the horror of the situation that they left the country and went back to England. Later they recounted the events that had made such an indelible mark on their memories. They had seen human corpses mangled by hungry dogs and by jackals and vultures. When the situation became too great a danger to public health the Company employed a hundred men to pick up the dead bodies and throw them into the River Ganges.

As a result of the famine, large rural areas were depopulated and allowed to revert to natural jungle. Many cultivated lands were completely abandoned. Bengal, formerly the richest part of the nation, became destitute and the East India Company was no longer able to maintain its formerly profitable status. The British Government appointed a governor-general to take charge and replace the Company. The famine had taken the lives of ten million peasants, about one-third of the total population of Bengal. The total may have been much higher; there had never been a census of the population and only the painstaking work of researchers in later years made it possible to confirm that the death toll was at least as high as ten million. The famine ended as quickly as it had begun. By the end of the year 1770 substantial rainfall ensured a plentiful harvest. The whole desperately tragic event needs to be placed in the context of previous and subsequent famines in India. Altogether there were about twenty-five substantial famines in different parts of the country during the period of British rule, some in the far south and several in areas west of Bengal. Estimates for the total loss of life in all of these exceeded thirty million. None of them was as catastrophic as the 1770 famine.

Famines were still present even in the final years before the country secured its independence from Britain in 1947. The last serious famine came in 1943, in the middle of World War II. Japanese forces had captured large areas of the south and the south east of Asia and they were advancing through Burma, at that time the largest exporter of rice in that part of the world. The British had encouraged the development of rice cultivation in Burma and, by 1940, was purchasing 15 percent of all India's needs of rice from that country. Bengal, because it was so close to Burma, depended to a greater extent on Burma's rice. About one person in every four of Bengal's population relied on imports of rice from Burma. If anything happened to that source there would be another famine. True to its former neglect of retaining resources to cope with possible emergencies, the British once again had nothing in reserve. What military authorities did do, and what proved to be more disastrous than anyone imagined, was to introduce emergency measures all across the Bengal area. Large areas of rice cultivation near the Burmese border were destroyed in order to slow down the advance of Japanese armies, depriving the area of all local food resources in the process. At the same time, almost all the rice available was transferred to other parts of India and other theatres of war. The residents of Bengal were told that they had to cope with less rice because so many of their agricultural areas had been destroyed.

In October of 1942, the whole east coast of Bengal was hit by a powerful tropical cyclone and areas of land as far as forty miles inland were flooded. The fall crops of rice were washed away and lost. Small quantities of what was already a reduced harvest, the part of the harvest that always had to be retained as seed for planting in the months of winter that followed, had to be consumed for food. As the hot weather of 1943 appeared and there was nothing to eat because nothing had been sown in the winter growing season, famine appeared and before the year was out four million had died. The military authorities had made no provision for food emergencies. Furthermore, all the military commanders in that region were concentrating on the war and gave little attention to domestic issues. The government of India tried to get help to the stricken areas but no one seemed to care in far away Britain at a time when World War II was at a peak of activity. Subsequent records of rice production for the year 1943 revealed that there was enough available to prevent starvation if only the military commanders had chosen to divert supplies of rice to the impoverished peasants.

In the late 1990s, Indian author Amartya Sen was awarded a Nobel Prize in economics for his studies of the Bengal and other famines in India. His conclusions were a damning indictment of British administration in India. He showed that rice production in India during the years 1941–1943 were pretty much normal and were sufficient to provide food for everyone. The totals, year by year, varied only slightly from the normal: 1940, eight million tons, 1941, seven million, 1942, nine million, and 1943, eight million tons. Sen was convinced that the 1943 famine was caused, not by a shortage of rice, but by the removal of supplies from the stricken areas to meet the needs of fighting troops. His thesis went on to show that, while malnutrition and hunger remained a common condition in India, no major famine occurred in fifty years following independence. Yet, in those years, 1951–2001, the total population grew from 360 million to more than a billion. By contrast, in one fifty-year period of British rule, 1891–1941, the population only grew from 287 million to 389 million. Sen selected the fifty years from 1951 because the immediate aftermath of independence led to considerable strife and disruption of agriculture.

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19

Connecticut earthquake

May 16, 1791

Along the lower reaches of the Connecticut River

The earthquake in 1791 was Connecticut's biggest earthquake up to that time. The earthquake hit east of New Haven and did extensive damage in the East Haddam Region of the Connecticut River

On May 16, 1791, along the lower reaches of the Connecticut River, east of New Haven, the state experienced its biggest earthquake up to that time. The felt intensity was 7 as based on the Modified Mercalli Scale, a measure that is similar to the Richter Scale but different in that it takes account of the effect of an earthquake rather than its power at source. In many older records of earthquakes all we have are accounts of the damage that was done. From these we can estimate its intensity on the Modified Mercalli Scale. The area affected by this earthquake is in and around East Haddam. It has a history of frequent earthquakes extending back to earliest settlement times.

The East Haddam region on the Connecticut River is known in Indian lore as a place of noises, presumably the noises of earthquakes. The first reported earthquake began on May 16 with two heavy shocks in quick succession. Stone walls were shaken down, tops of chimneys were knocked off, and latched doors were thrown open. A fissure several meters long formed in the ground. In a short time, thirty lighter shocks and more than one hundred other aftershocks continued during the night. Both the earthquake of May 16 and the many aftershocks were heard in Boston, Massachusetts, and in New York City.

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20

New Madrid, Missouri, earthquakes

1811 and 1812

In and near New Madrid, a community close to where the states of Missouri, Arkansas, Kentucky, and Tennessee meet

The New Madrid earthquakes of 1811 and 1812 were the most powerful to hit contiguous United States in its history. The intra-plate quakes of 1811 and 1812 were accompanied by numerous aftershocks and both the main shocks and those that followed were felt over most of the continental United States

The first of the 1811 and 1812 New Madrid earthquakes occurred on the sixteenth of December 1811. Its magnitude was 7.2. The second quake hit the same area on the fifth of February 1812. Its magnitude was 7.4. In between there were numerous aftershocks. Both earthquakes were centered on a part of the Mississippi embayment close to where the states of Missouri, Arkansas, Kentucky, and Tennessee meet. The ensuing destruction was similar and widespread for both events; buildings collapsed, trees toppled, and the Mississippi River changed course. What could be called mini-tsunamis appeared on the river as fissures opened and closed below the surface. The shock waves rang church bells in Washington, D.C., and they were felt from Indiana to Massachusetts. Fortunately, there were few people living in the area at the time so, in spite of the great intensity of the earthquakes, the loss of life was very small.

On the basis of the size of the area damaged and the extent to which awareness of the events was felt across the continent, the New Madrid earthquakes can be considered the most powerful to have hit the United

Figure 14 New Madrid earthquakes, 1811 and 1812. Trees tilted by the New Madrid earthquake at the Chickasaw Bluffs on the east side of Reelfoot Lake, Tennessee. Note the twist of trees into an upright position. 1904.

States since Europeans first settled here. An area of more than 200,000 square miles showed evidence of significant damage by these earthquakes and one million square miles experienced shaking that was strong enough to alarm the general population. This last-mentioned area can be compared with the effects of more recent events. It was more than twice the size of the area affected by the 1964 Alaska earthquake and ten times larger than that of the San Francisco earthquake of 1906. The complex physiographic changes that occurred on the Mississippi River within the earthquake areas were extensive. An uplift of land thirty miles long and fifteen miles wide raised the river's valley by as much as thirty feet.

The first effects of the earthquakes on those who lived in and around New Madrid were the sounds of timbers groaning, creaking, and cracking, of furniture being thrown around, and of chimneys crashing down. People got out of their homes as quickly as they could in order to avoid the falling debris. The log cabin was the most common type of building in the area, a structure that is well able to withstand earthquakes, yet one that did not stand up in this instance because of the extensive ground movements.

Earth waves similar to those experienced in water kept moving across the surface, bending trees and opening up deep cracks in the ground. Landslides, one after another, swept down from the steeper bluffs and hillsides and, simultaneously, large areas of land were uplifted. Water emerged from below through the cracks. On the river huge waves overwhelmed a number of boats. Others were thrown on to land high above the level of the water and the returning waves took back with them trees and other debris, rather like the actions of a tsunami. Whole islands in the river disappeared.

Aftershocks for both events were numerous and unusual when compared with those of other earthquakes. After the December event, these lesser shocks were almost continuous but with lesser intensities over time, then came two weeks of quiescence followed by several days in which the ground was in a state of constant tremor. Records of the aftershocks were kept locally and it seems that they continued in patterns similar to those of 1811 and early 1812 for about two years. In spite of the great intensity and widespread damage associated with these earthquakes, few lives were lost because the density of population at that time, in that area, was very low. One life was lost in New Madrid through falling buildings. Several drowned when they were thrown into the river as a result of landslides, and several boatmen drowned when their boats sank. A number of canoes had also been abandoned and it was concluded that their owners had drowned.

The most seriously affected areas were characterized by raised and sunken land with the former marked by fissures, sand blows, and landslides. These areas extended from Cairo in Illinois to Memphis in Tennessee, a distance of 150 miles, and southeastward from Crowleys Ridge, past Memphis for a distance of fifty miles. The extent to which the quakes were felt has already been identified in terms of area. It helps to put place names to that statistic: the shocks were felt from Canada all the way to New Orleans and from Montana to Boston. People in Washington, D.C., were frightened badly because the shock in that part of the Appalachians was more acute than in places closer to the coast. This difference was later related to a connection between the Appalachian system and the epicenter of the New Madrid earthquakes.

Precise locations of the epicenters of the New Madrid earthquakes of 1811 and 1812 are now known. The fault zone is one hundred twenty miles long and the epicenters show a northeast-southwest trend. Another series of events like those in the nineteenth century would be felt from Denver to New York City and damage buildings in eight states. Tennessee and the other three states bordering this earthquake zone would be devastated. Today there are more than fourteen million people living within the area that was devastated by the New Madrid earthquakes. Some comparisons can be made with the San Francisco quake of 1906, about which we know much more and the total population affected there was four million. Furthermore, because of the nature of the earth's crust in the central parts of the United States, the physical size of the area affected by any earthquake is much bigger. Geologists are always working on assessing the frequency rate of large earthquakes; that is to say, the average number of years between each big event. When they succeed preparations can be made to cope with the next occurrence.

The pressures that cause the massive tectonic plates to move will also cause them to rip apart because of the spherical shape of the earth's surface and therefore the differential rates of motion of the ocean crust as it moves away from the spreading ridges. The North American continent is therefore impacted on its east coast at different rates and so internal stresses are created. Studies of the New Madrid zone show that earthquakes like those in 1811 and 1812 did occur in the past. Exactly when and how consistently are the questions that researchers want to answer. Sand deposits and liquefaction are often useful in dating the past, for example, these two remnants of past earthquakes can be located quite easily today to show that powerful earthquakes hit New Madrid in 1811 and 1812. Charles Lyell, the British scientist who pioneered new developments in the field of geology and was Charles Darwin's mentor, visited New Madrid shortly after the nineteenth-century earthquakes and discovered that the native Indians had valuable information in their legends about past events.

Other geologists have followed up on the possibility of dating past events by examining the sites of ancient Indian settlements. It is known that native Indians used sandy areas for cooking, leaving on these places after they moved elsewhere fragments of their cooking utensils and charcoal residues. Archeologists can date items of pottery by their form and size; they can also date carbon or charcoal by the radiocarbon method. From evidence of this kind we now know that a major earthquake occurred in the New Madrid area sometime between 1180 and 1400. It was powerful enough to cause liquefaction. Evidence of much earlier earthquakes was also found, one of them being dated several thousand years ago. Large gaps of this kind between successive events are of little value for predicting future earthquakes so the search goes on. One alternative method employed by geologists involved examining earth fissures from the past, the same types of cracks in the surface that were seen in 1812, and looking for deposits of different material in them. By carbon dating these alien materials in the cracks they were able to locate one big earthquake somewhere between 780 and 1000 and another between 1260 and 1650. By interpolating from these it is now possible to come up with a rate of occurrence of 400–500 years.

If the 400–500 frequency rate were to be true for the future, Memphis, the nearest big city to New Madrid, need not expect a huge earthquake for another two hundred years. However, there are other considerations that illustrate the difficulty of being precise when it comes to predicting earthquakes. For one thing, the New Madrid area has been hit with more than twenty-four earthquakes since 1812, all of them events that did substantial damage. On national maps of the United States, New Madrid is shown as having a greater chance of being hit with an earthquake than any other place east of the Rocky Mountains. There is, additionally, one other variable affecting the time of the next earthquake. It has been found in several countries where the average rates of recurrence of earthquakes are known that sometimes the sequence is interrupted by a cluster of earthquakes. That was experienced in Australia when a series of five major earthquakes hit an interior area within a period of twenty years.

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21

West Ventura, California, earthquake

December 12, 1812

Epicenter of the quake was offshore, west of Santa Barbara

An earthquake of magnitude 7.1 struck western Ventura, including Santa Barbara. Extensive damage was done to the lightly-constructed Catholic missions in and around Santa Barbara

On December 21, 1812, one of the largest earthquakes in Californian history struck the western part of Ventura, including Santa Barbara. It had a magnitude of 7.1 and its epicenter was offshore, probable in the Santa Barbara Channel. Extensive destruction occurred in the lightly constructed buildings of the various Catholic missions. Three missions suffered the greatest damage—Santa Ynez, Santa Barbara, and Purisima. The experiences of Santa Ynez were typical of all three. One of the new homes next to the church was torn down and the upper interior walls along with the tiles on the roofs of all the adjacent houses were knocked down. Reports of a tsunami were persistent despite the rarity of such in the history of Californian earthquakes. Liquefaction was widespread along the coast. The effect of so much damage persuaded the Catholic authorities to remove most of their stations from the coastal areas to places farther inland.

The reports of sea waves were extensive, the only descriptions possible at that time for what we now call tsunamis, and it is highly likely that they occurred despite the absence of any reports of deaths from them. A Spanish ship at anchor thirty-eight miles offshore was substantially damaged at the time of the earthquake. People living at the Rancheria Mission where damage was minimal decided to move half a mile away from the coast because the waves threatened to flood them since they had already flooded two areas of Santa Barbara. At the Santa Barbara Presidio there were reports of the sea having changed its natural condition because the whole mission appeared to settle, presumably a reference to the land sinking because everyone ran away for fear of being engulfed by the sea. Another of the many scattered reports that were later recovered from the local archives told of an earthquake so violent that the sea receded and then rose up like a mountain. This account bears the marks of authenticity because it is exactly what would have happened, as we know from our present knowledge of plate tectonics, if indeed a tsunami had accompanied the earthquake.

An earthquake of magnitude 6.9 hit this same area thirteen days earlier but the epicenter was in a very different location, one hundred miles east of Santa Barbara, at Wrightwood, near the San Andreas Fault. This earthquake affected a wide area, reaching westward to damage some of the same places that were destroyed by the later one. It destroyed the church at Mission Santa Barbara, and caused major damage at Mission La Purisma Concepcion, near present-day Lompoc, causing that site to be abandoned, and a new Mission Purisma to be built several miles farther north. This earlier earthquake is often referred to as the San Juan Capistrano earthquake because it was responsible for the death of forty Native Americans who were attending mass at Mission San Juan Capistrano when the earthquake struck. The mortar in the church walls failed and the church collapsed. It had been poorly constructed. Damage was also reported at Mission San Gabriel and even as far away as San Diego and San Fernando.

Most of the overall damage was due to the December 21 quake but often, because both quakes sometimes hit the same place, we get explanations like the following of the additional damage done to a place that had already been hit by the December 8 quake. The damage at Mission La Purisima Concepcion on December 21 was extraordinary and horrifying. The earthquake completely ruined the church. It destroyed several statues and paintings, and ruined most of the art work. The ecclesiastical vestments were not damaged since they were in drawers. Some of the buildings were flattened to the ground while others may have been usable after repairs. The possessions and furnishings of the mission also suffered. Some were smashed, others broken, and all were damaged. The inclement weather with its copious rain did not allow people time to dig out or to repair roofs. The original mission was on the edge of a marsh and on sloping ground, which probably contributed to the extensive damage. Aftershocks caused considerable concern at Mission Santa Barbara. They were almost continuous at times. One person reported counting thirty on a given night and, in daytime, they arrived every fifteen minutes. All of this served to paralyze the community and delay restorative work. Priests were even afraid to conduct services because of the condition of the buildings.

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22

Tambora, Indonesia, volcanic eruption

April 5, 1815
On Mount Tambora in the eastern part of Indonesia

The earth's biggest eruption within historic times hit Indonesia in 1815. This eruption had a VEI of 7 and it not only devastated Indonesia but also changed climates all over the world for years

The area we now know as Indonesia experienced earth's two most powerful volcanic eruptions. The first, Toba, the biggest within the last two million years, had a VEI of 8 and was located in western Sumatra. It erupted 74,000 years ago. The second was Tambora, which had a VEI of 7 and was located east of Java. Tambora erupted in April of 1815 and was the biggest in all of recorded human history. It is likely that the tsunami of 2004, also in Indonesia, will go down in history as the most destructive tsunami ever experienced. Thus, Indonesia has come to be known as the locale of the world's most deadly earthquakes and eruptions. When Tambora erupted, two million tons of debris rose upwards to a height of twenty-eight miles. The heavier parts fell back to earth but the lighter particles stayed aloft, circling the earth and blocking out much of the sunlight. Temperatures dropped in every country of the world and many people subsequently referred to the year 1816 as the one without a summer.

Some sense of the immensity of this event can be gleaned from the dimensions of the mountain before and after the eruption. It was approximately thirteen thousand feet high before and nine thousand afterward and this loss of four thousand feet of height occurred in a mountain that was thirty-eight miles wide at its base. The total weight of the material that rose into the atmosphere was ten times greater than that of Krakatau in 1883 and one hundred times more than the amount ejected from Mount St. Helens in 1980. The sound of the explosion was heard in Western Sumatra, a thousand miles away. The heavier fragments of lava fell back into the ocean and the combination of heat and impact with the water created mini eruptions from which the finer quantities of dust were added to the already darkened atmosphere. The actual volume of ash produced by these secondary was ten times greater than the amount generated by the original eruption. For years, the average amount of sunshine reaching the earth was reduced. More than ninety thousand were killed by the eruption, most of them indirectly through the starvation and disease that followed as everything around them was obliterated. The mountain itself continued to burn for three months before finally coming to rest.

The local devastation in places within a hundred miles of the eruption is well illustrated in the experiences of the villagers of Bima, a small community at the eastern end of Sumbawa, the island on which Tambora previously stood. For several days following the eruption they were shaken day and night by the ongoing explosions that followed the main eruption. A dense ash cloud in the atmosphere above Bima completely shut out the sun for four days, similar to Vesuvius when the people there also experienced total darkness at midday. The weight of fallen ash was too much for most of the homes and they collapsed. At the same time, throughout the early hours following the eruption, tsunamis flooded the village just as they had done elsewhere on the Island of Sumbawa. Later, government officials found innumerable numbers of corpses of people and animals on the ground around Bima or floating nearby on the sea. In different places around the world the impact of Tambora was not as dramatic as it was in Bima but nonetheless enormously destructive.

Reports from northern Europe described the harvests for the year that followed as being so poor that starvation was common among poorer families. The industrial revolution was still young and most people were still totally dependent on what they could wrest from the soil. Many were reduced to eating rats. Grain prices rose four-fold in that part of the world and, when other countries tried to be capitalize on the shortage, the price of grain on the international market rose extremely high. France suffered more than other countries of Western Europe because it had been involved in Napoleonic wars right up to the year 1815 and the whole social life of the country had been severely strained from the stresses of warfare. In the year 1816, farmers were afraid to take their produce to market because of the dangers of being robbed by hungry people along the way. Government troops had to be called in frequently to protect these farmers. In the United States, farmers in New England had so many crop failures over such large areas that many of them migrated westward to Ohio and elsewhere.

All over Indonesia, in addition to the immediate destructive effects of the eruption, masses of ash, rock particles, and sulfur dioxide gas were deposited everywhere and they continued to give trouble year after year for some time. Sulfur dioxide is a poisonous gas used in the manufacture of sulfuric acid, a highly toxic substance. An invisible gas, the presence of sulfuric acid in the air created complications for the digestive system of both humans and animals and many died as a result. Lack of rain was another consequence of the disaster. Since all vegetation was destroyed, transpiration activity stopped. Normally new soil forms quickly in tropical areas that experience volcanic eruptions and the eruptions contribute to much of the tropical rainfall that comes frequently in latitudes such as those in Indonesia. Accordingly, population there is always dense and crops can be grown two or three times a year in such soil. However, it took several years before Indonesia was able to grow crops of the kind and quality needed to feed its huge population.

The collection of thousands of islands that we now call the nation of Indonesia always had a fascination for the people of Europe, largely the result of the value of spices in centuries past. Marco Polo was the first to acquaint the West with what was then called the Spice Islands. That was about eight hundred years ago but it was considerably later when the importance of spices appeared. By the middle of the nineteenth century and after considerable success in both farming and stock rearing, Europeans were faced with the problem of preserving meat in winter. Animals were slaughtered in the fall to reduce the cost of feeding them and the meat was then salted away in iceboxes to preserve it for six or more months. The taste of salted meat after all that time was, to say the least, not very attractive and Europeans discovered that one specific item from the Spice Islands, pepper, was the thing that would profoundly enhance its flavor. Trade in pepper between Indonesia and Europe became a top priority. So great was the value of this commodity that a single peppercorn was considered to be worth its weight in gold and this became evident in the rules governing stevedores at European ports. Whenever they had to handle peppercorn shipments from Indonesia their pockets were sewn up to minimize theft.

The island chain that is Indonesia extends in a curved form for more than 4,000 miles. Closely following the islands on their south side but deep below sea level stands the tectonic boundary between the Indo-Australian Tectonic Plate and the Eurasian one. The Indo-Australian Plate is moving northeastward beneath and at a slightly faster rate than the movement of the larger Eurasian Plate and this subduction is the main cause of the numerous volcanic eruptions and earthquakes we hear about from Indonesia. Within the overall picture of these two huge tectonic plates, there are smaller components of each that can at times be extraordinarily destructive. The gigantic earthquake of 2004 off the coast of Sumatra was caused by the Indian portion of the Indo-Australian Plate subducting under the Burma portion of the Eurasian Plate and creating one of the most powerful earthquakes of all time. The tsunami that accompanied this event and radiated outward from the entire 750 miles of plate that had been displaced is also likely to go down in history as the most destructive. It was literally an earth-shattering wave and it took several minutes for the displacement to be completed.

The island on which Tambora stood is more than two hundred miles north of the tectonic boundary. The magma that rises from below this boundary has to travel upward about one hundred miles from that boundary and from far below it to reach the summit of Tambora and cause the eruption. It is the work of geologists to trace as completely as they can both the source of the magma and its age. Only by doing this can information be found on the past history of volcanic activity as big as Tambora's and thereby be able to predict when another one might occur. The sea floor is the top of the outermost solid layer of the earth's surface, known as the crust, often several miles thick. Below the crust is where the magma exists and there have weaknesses or fault lines in that crust if the magma is going to rise to the surface. One such fault line stretches northwestward for 150 miles from the Island of Sumba across the tectonic boundary to the Island of Sumbawa, the site of Tambora.

It was through breaks in this fault line that magma built up over the centuries. Geologists did not know very much about either tectonic plates or subduction at the time of Tambora's eruption and it was about 150 years later that the secrets of earth's mosaic of tectonic plates became known. Ever since that time geologists have been busy making use of this new knowledge to trace the history of earthquakes and volcanic eruptions.

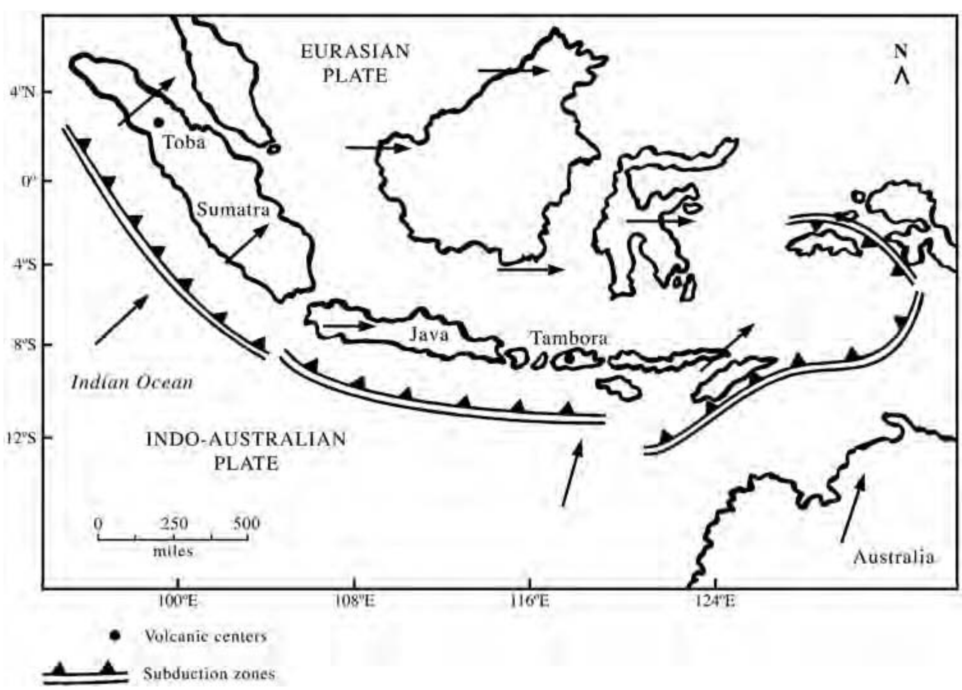

Figure 15 Locations for two of Indonesia's most powerful eruptions.

The age of the oldest lava on the site of Tambora is about 50,000 years and the youngest are the layers of ash and rock that were deposited on Indonesia in 1815. Beneath these deposits are some older rocks, about 5,000 years old. This discovery, while inconclusive, gave geologists at least one clue to the likelihood of another Tambora-type eruption arriving soon. If the time difference between the 1815 event and the one that came before it is 5,000 years, then one possibility is that there will not be another one before another 5,000 years.

More work needs to be done by geologists on the history of eruptions in this part of Indonesia in order to obtain the average time between these destructive events over the millions of years through which they have occurred. Only when armed with data of that kind can we estimate the future with some degree of accuracy. The final phase of the 1815 event seems to have begun three years earlier. Reports from local observers tell of noisy steam eruptions, sometimes followed by dark clouds of volcanic ash, happening from time to time between 1812 and 1815. These things were the result of hot magma encountering moisture as it rose within the mountain. Overall, in the course of the three years, there was a two-inch layer of ash on the sides of the volcano and on the ground.

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23

Natchez, Mississippi, tornado

May 7, 1840

Natchez, a city on the lower Mississippi River

Natchez was almost totally destroyed by a mile-wide tornado and 317 lives were lost

Shortly after noon on May 7, 1840, a mile-wide tornado slammed into Natchez, Mississippi, a city on the Mississippi River, about 150 miles north of New Orleans. The storm was loaded with all kinds of debris it had picked up along its path. No one expected it and no one was warned of its approach even though the sounds of its destruction farther down the river could be heard in Natchez. Unlike the present time, there was no national weather service to alert people to an approaching storm and there were none of the things that individuals could have used to warn others, two-way radios, telephones, or cell phones. As the tornado struck Natchez, banks, homes, stores, steamboats, and other vessels were completely destroyed. Houses burst open. Three hundred and seventeen lost their lives. It was the second most deadly tornado in U.S. history.

About an hour before it struck Natchez, a thunderstorm with driving rain had formed in an area about twenty miles to the south and moments later a tornado began to form out of that same storm. The tornado gathered strength as it moved northward along the Mississippi valley. The United States gets about 1,000 significant tornadoes every year, more than the total number experienced by all other countries combined. Only one in every hundred is as powerful as Natchez. At the present time, in sharp contrast to 1840, few are killers. We now have the ability to identify the kind of weather that is likely to lead to a tornado and we can trace the paths of these twisters so that those in their paths can take shelter. Forecasting, detection, communications, and raised public awareness of the danger, all help to minimize the number of fatalities. The U.S. Weather Service in 1840 was only able to report on what was visible and measurable locally in terms of wind speed, temperature, and humidity. There was no system of communication that could relay these data quickly enough to provide a warning to those who were in the tornado's path.

As the tornado tracked northeast, heading for Natchez, people took advantage of the cooling rain to sit out in their porches, or to walk about even in the rain because the rain provided a cooler atmosphere than the usual hot dry conditions. Many were preparing to eat, fully aware of the dangers that any thunderstorm would present but unaware that this particular storm was much more than a thunderstorm. At the very moment that the tornado struck, the dinner bells in large hotels had rung and most citizens were sitting at their tables. It is difficult for us today to appreciate the scene in Natchez in the year 1840. This was pre-Civil War America and there were two social classes of humanity living and working in the plantations and in the home—ordinary Americans and slaves. There is no reference to the deaths of slaves in the various newspapers apart from one sentence in one paper, saying that hundreds of slaves died. They died in their homes or at work in the plantations. It is quite clear from the details of life on the river, and the large number of deaths that occurred there, that the vast majority of the 317 deaths occurred among the merchants who were transporting goods on their flatboats. The hundreds of slaves who died were considered property losses.

The approaching tornado raced up the river from a point seven miles south of Natchez. As it traveled it stripped the forest from both sides of the river. Those on the river were the first to hear what must have been a thunderous roar from the river as it churned with massive waves and whitecaps. Up and down the river on either side of Natchez scores of vessels, steamboats, flatboats, and skiffs, were crowded together in great numbers, including many itinerant boatmen who traded everything from furs to liquor. Flatboats and people were tossed into the air like toys and, as they came down, they were drowned. The volume of debris as well as the tumultuous state of the water made it impossible for anyone to be rescued. One or two survived because they were thrown on to the land. As the tornado swept northwards, the central and northern parts of the town were demolished. Survivors described the air as being black, filled with spinning pieces of walls, roofs, and chimneys and with large timbers flying through the air as if shot by a catapult. Beneath the ruins lay the crushed bodies of many strangers. There were many escapes and many heartrending scenes. A woman named Mrs. Alexander was rescued from the ruins of the Steam Boat Hotel. She was seriously injured and was holding on to two dead children.

The destruction of the flat boats was an immense blow to the economy of the area. At least sixty of them were lost. It was impossible to calculate the total value of the boats and their contents. The steamboat *Hinds*, with most of her crew, went to the bottom, and the *Prairie* from St. Louis was so much wrecked as to be unfit for use. The steamer *St. Lawrence*, at the upper cotton press, was a total wreck. It was difficult to tell how widespread the ruin had been. Reports of major damage came in from plantations twenty miles away in the state of Louisiana. Looking back from today's vantage point, these losses were all the more unfortunate because there were none of the aids with which we are now familiar: Red Cross, National Guard, presidential disaster decree, and mobilization of doctors and emergency personnel from other places. The townsfolk did the best they could and, as always in these earlier days, the unexpected was attributed to the deliberate action of God. One newspaper described the whole scene as the voice of the Almighty and hence prudence should dictate reverence rather than execration. Total costs of the disaster were estimated at 1.3 million dollars at the 1840 value of money.

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24

Fort Tejon, California, earthquake

January 9, 1857
Fort Tejon, about thirty miles south of Bakersfield

California's most powerful earthquake ever struck Fort Tejon, a place near the San Andreas Fault. The quake's epicenter was some distance north of Fort Tejon and the scar it left alongside the San Andreas Fault was two hundred miles long

On January 9, 1857, California's greatest ever earthquake struck the central part of the state near the San Andreas Fault. It left a surface scar of more than two hundred miles along the line of the fault and caused a horizontal displacement as large as thirty feet. Its magnitude was 7.9. The Owens Valley Earthquake and the great San Francisco event of 1906 make up, with Fort Tejon, California's three biggest historical earthquakes. The 1906 San Francisco guake was 7.8 and that in Owens Valley was 7.4. The epicenter of the 1857 event was not at Fort Tejon but rather about sixty miles farther north but, because Fort Tejon was a well-known place in a thinly populated area, the earthquake was named after it. The earthquake itself caused one fatality, evidence of the low density of population. If we compare San Francisco in 1906 with Fort Tejon in 1857, the break in the San Andreas Fault was longer in the former but the maximum and average displacements were larger in the latter.

The effects of the quake were quite dramatic, even frightening. Were the Fort Tejon shock to happen today in the context of present population, the damage would run into billions of dollars, and the loss of life would be substantial. In 1857, the population density was extremely low and native people were the principal residents. When the earthquake actual hit strong shaking ensued, which lasted from one to three minutes. Property loss was heavy at Fort Tejon as five buildings were severely damaged and several others sustained moderate damage. Trees were uprooted and fish were thrown out of Tulare Lake. Ground fissures appeared in the beds of several rivers and evidence of liquefaction was found between Stockton and Sacramento. Additionally, there were two significant aftershocks within a week of the main event. Ground openings and fissures were reported from Sacramento to the delta of the Colorado River and changes in the flows of rivers occurred in several locations. In Los Angeles, a city of 4,000 people at that time, minor damage was done to homes.

The San Andreas Fault extends for more than eight hundred miles from the northern Californian coast to the Gulf of California. It is at the heart of almost all California's earthquakes. Interaction between the North American and Pacific plates along this fault takes place within an elongate zone, broadening from sixty miles at its north end to three times that width in southern California. The fault is close to the east side of this zone in the south and it gradually migrates across the zone, lying on the west edge at its northern end. The constant interaction between the Pacific and the North American tectonic plates takes place in opposite directions along this fault, with the Pacific Plate moving northwards and the North American Plate moving southwards, but these movements are not always smooth. Many factors interfere with their movements, including the presence of subsidiary faults, different types of rock, and the differential rates of plate movements because they are moving on the globe, a curved, not a flat surface. Much of the energy expended is, therefore, unable to do its work of moving the tectonic plate forward. It gets stored elastically, that is to say under pressure, in the upper crust of California's bedrock, close to the fault. From time to time the fault slips, the stored energy is released, and an earthquake occurs.

California in 1857 was thinly populated with Europeans, except for the two dominant settlements, San Francisco and Sacramento. The first big gold rush of the many that would happen later in the nineteenth century—in the Klondike, Australia and South Africa—had created a feverish scramble among people everywhere to get to California and be the first finder of the mother lode, the place with the biggest gold nuggets. There were no roads or trains across the United States and the gold seekers had to find their way either across land near Panama or by sea around Cape Horn. In this year of 1857, the gold rush was in its ninth year of diggings and things were beginning to slow down. There was less and less gold to be found but, in the few years of frantic efforts to strike it rich, San Francisco had become a big city, the only big city west of the Rockies. Its population was 53,000 and the only other city, Sacramento, the state capital, had a population of 12,000. It was fortunate for us today, as we seek to understand better the huge earthquake of 1857, that there were newspaper descriptions and other reports of the event published in these two cities at the time and we can examine these accounts today. San Francisco had six newspapers at the time and Sacraments had five.

Most of these records deal with human reactions and damage to buildings, all of which were either of adobe or brick construction. In either case, in a frontier location like this, the masonry used would be weak so that minor shocks could be very destructive. From Marysville, fifty miles north of Sacramento, all the way to the southern border of the state and eastward as far as Las Vegas some level of shock was experienced. The main area affected, however, while still large, is limited to a hundred-mile stretch of territory from 34 degrees north to 36.5 degrees north. Shocks of strength 7 on the Modified Mercalli Scale were experienced everywhere within this area. Typical newspaper accounts of the shocks experienced were as follows: we all ran outside as our building cracked because we saw that others had collapsed. It was difficult to remain in a standing position. We saw men being physically thrown down by the force of the earthquake. Reports by those who were close to the epicenter of the quake described homes collapsing and trees being knocked down. Everywhere, people were afraid. They did not have our present knowledge of earthquakes so, understandably, they had no idea what might happen next.

The intensity experienced in Los Angeles, at that time a pueblo in the location we know today as downtown, was described as moderate. People were frightened but the only damage to buildings was the cracking of walls. It was a similar level of shock in San Bernardino and Santa Barbara. From data such as these it is reasonable to conclude that a repeat of the 1857 earthquake today would not cause serious damage to low-rise buildings in Los Angeles. There were many mild aftershocks to this momentous earthquake of 1857 but among them two seemed to have been sufficiently strong to attract the attention of several newspapers. One occurred on the evening of the day of the main shock. The second one arrived a week later. Both were described as severe but there was no record of damage. The duration of each of these two strong aftershocks was short, much less than the timing of the main shock, and they continued for three minutes in San Bernardino and two minutes in Fort Tejon.

The close link between the 1857 and 1906 earthquakes, coupled with the growing body of research findings on previous powerful quakes along the San Andreas Fault, has given rise to calculations and possible predictions about the future. When might another magnitude 8 earthquake occur here? That question has occupied the minds of many geologists. One of the first pointers to an answer came with investigations of past quakes. One geologist used evidences of past displacements on the fault, deformations of the crust, and distances between the two tectonic plates that move on opposite sides of the fault to propose a timetable for the future. His calculations were based on a time period of twenty million years so many of his colleagues treated his estimates as very-long-predictions; that is to say, estimates that might prove to be statistically good but incapable of giving much guidance for the immediate future. His prediction was that another large earthquake would occur at intervals of from fifty to two hundred years. Another researcher, Kerry E. Sieh of the California Institute of Technology, focused his investigations in one place, the same area affected by the 1857 quake, and examined the earth's crust vertically rather than horizontally as was done by the geologist who considered the past twenty million years.

Sieh discovered evidence of at least nine earthquakes over the past 1,400 years. Later, as he continued his investigations, he expanded the number to twelve. Based on these findings that cover a relatively short time, geologically speaking, he concluded that the average recurrence interval would be between 140 and 150 years. His work was carried out in the mid 1970s and many scientists commented on his findings in later years. In 1985, for example, two geologists wrote a major article on predicting future San Andreas earthquakes in the journal *Scientific American*. They noted that the time interval from the 1857 earthquake was 128 years at the time of their writing and added that this figure was alarmingly close to Sieh's estimate for a recurrence. More than twenty years after the publication of their article, the San Andreas Fault still awaits its next magnitude 8 event. These two attempts, one looking back twenty million years and the other 1,400 years, are a useful reminder of the great difficulties in predicting earthquakes. Nevertheless, the attempts continue and, as mentioned in the introduction, they have expanded in China and Japan to observations of the behavior of wildlife just prior to earthquakes.

Sieh's findings were incorporated into the prediction that the Geological Survey was asked to provide to the National Security Council. Preparations have to be made in anticipation of future earthquakes even if there is no certainty about specific dates. These preparations take account of all kinds of data in the hope that they will, one day, be able to anticipate a catastrophic earthquake. Experts know, just to add another item of information to what they already have, that strain accumulates on the San Andreas Fault at a rate of a little more than an inch a year. Thus, if one were to calculate the strain since 1857, it would amount to twelve and a half feet by the year 2007. Deductions from such data as well as from the earlier ones are not reliable. Even when the recurrence rate of a major event in the San Andreas Fault is known, activities in other domains may disrupt our calculations. Slight changes in the earth's rotation or in its normal distance from the sun can change the behavior of the tectonic plates that are a vital causal factor in California's earthquakes. The massive Indonesian earthquake of December, 2004, was sufficiently powerful to do what had never before been observed in human history. It slowed down for a fraction of a second the earth's rate of rotation.

The value of knowing when the next earthquake may strike becomes more and more important with the passage of time. There are so many elements of our total environment that human society can now control, and so much technology with which we can do what is needed, that the quest for answers to earthquake prediction must be pursued. In 1857, the total population of California was not much more than 10,000, perhaps not even as great as that. In the early years of the present century its population is thirty-five million and growing at a rate that is above the national average. It added fifteen million since 1970. Today, a single county may be the custodian of most of the nation's wealth. Santa Clara County suffered heavy damage in the 1906 earthquake; today it is the principal home to the nation's supplies of semi-conductors. Urbanization has added its own urgency to the demand for earthquake prediction. Most of the state's people live in cities and San Francisco is now a huge urban agglomeration, not just a single city as it was in 1906. There are estimates of casualties if a magnitude 8 quake should hit the San Andreas Fault within the next decade. They vary according to the time of day that such an event occurred. At two in the morning it would be over 13,000 and proportionately less at various other times of day.

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25

Calcutta, India, cyclone

October 5, 1864
Calcutta, India

Cyclones from the Bay of Bengal in the northeast of India frequently cause extensive damage. This cyclone took 60,000 lives and flooded the entire city of Calcutta

On October 5, 1864 most of the city of Calcutta, India, was flooded and destroyed by a cyclone. Sixty thousand people were killed at once and many thousands of others died later from the sicknesses and diseases that followed. The cyclone crossed the east coast of India south of the Hooghly River, one of the streams that constitute the delta of the River Ganges, shortly after 10 A.M. As the cyclone entered the narrowing waterway the water level rose until it became a towering forty-foot-high wall. Its height had been raised to a maximum by the arrival of high tide before noon on the same day. Everything was washed away in its path as the water swept inland. In the months that followed, the city, the surrounding area, and the harbor had to be rebuilt.

Different parts of the world have different names and different definitions for the storms they experience. In Asia, a storm with speeds less than 39 mph is called a tropical depression. If the circulating speed is above 39 mph it is named a storm and, if above 73 mph, it is classified as a cyclone. The meteorological conditions in India are very different from the Caribbean. Winds are stronger, rainfall is heavier, and preparations for weather extremes were almost non-existent in the nineteenth century. Hence, there are records of huge losses of life and widespread damage to buildings from that period of history. Even today, as was seen when the Indonesian tsunami of 2004 struck India, many lives can be lost if preparations for coping with disasters are inadequate. A comparison of the Caribbean and

Southeast United States storm environment with that of India helps to explain why India's storms are enormously destructive.

The first thing to note is the temperature difference. India lies south of the Tropic of Cancer while the Southeast United States is north of this line so water temperatures are generally higher in the waters around India. The winds, therefore, are able to carry greater volumes of water vapor at any given time and bring high levels of rain if they are moved over land. In the areas around Calcutta, especially in the mountainous regions north of it, the highest rainfall records in the world are found. Cherrapunji is a community 300 miles northeast of Calcutta and 4,000 feet in elevation, in the country of Bangladesh. It holds the world record for being the wettest place anywhere. Its average annual rainfall is 450 inches but many years have totals far beyond that figure. Calcutta's rainfall is much less than Cherrapunji, even though it experiences the same winds, because its elevation is close to sea level. The second thing to note is the huge expanse of the Indian Ocean compared with the Caribbean and the equally massive extent of the landmass north of India. The air masses that build up over these areas are larger and denser than we find over either the Caribbean or the United States and, hence, their winds are stronger when storms or cyclones form.

In October of 1737, the coastal area of the Bay of Bengal north and south of Calcutta was hit by a cyclone. Numerous ships in the waterways of the Ganges delta were destroyed and many thousands of Indians lost their lives. It was a similar story twenty-five years after the 1864 cyclone, and with similar devastating outcomes. This part of India will always be at risk as the huge air masses that move over it create storms and cyclones. At the same time, the benefits of the monsoon rains they bring are felt and welcomed all over India as they have sustained a human population of a billion. These seasonal winds, blowing toward the land of India from May to October, and blowing in the opposite direction for the rest of the year, bring large volumes of rain. Indian farmers depend on them for their livelihood and if they are delayed for any reason, and sometimes this happens due to unusual behavior of air masses, the result can be disastrous. Many of the accounts of famines in India are related to a major delay in the arrival of the monsoon rains. For various reasons, often because forests were cut down, the ground does not preserve much of the water that comes in the wet season. Even in Cherrapunji there is an inadequate amount of water in the dry season and the people have had to travel great distances, on foot, to find clean drinkable water.

In addition to their unfamiliarity with India's physical environment, British colonial officers had to cope with the limited knowledge of meteorology when they had to cope with cyclones. Temperature and pressure measurements and reports from ships at sea constituted almost all of their available data and the ships at sea in 1864 were often sailing ships. Powerful cyclones could completely destroy both ships and their cargoes so captains were always eager to detect approaching storms and report their findings to shore by wireless telegraph. One vessel, the *Proserpine*, was caught in the1864 Calcutta storm as it made its way out of port and found itself in the spiral winds of the cyclone almost two hundred miles from its center. Within an hour of entering the storm area, the captain of the *Proserpine* discovered that the winds were too strong for his ship, even though it was a steamboat, so he just let it be carried along under the force of the winds. Three hours later he noted that the winds had greatly increased in strength, perhaps because his ship had been drawn further into the storm area. The ship began to roll violently and the engine-room started filling with water.

Over the following six hours every member of the ship's crew was busy pumping out water. At the same time, everything that could possibly be spared was thrown overboard in order to make the ship as light as possible and so minimize its resistance to the waves that swept over it. In the hold there was a quantity of wooden beams, part of the cargo, and they too would have been thrown overboard if they had been lighter. As the ship lurched backwards and forwards the cargo of beams also moved and the captain was afraid that they would make a hole in the ship's hull. Twenty-four hours after their first encounter with the storm, the *Proserpine* entered calmer water beyond the storm. It had barely managed to stay afloat. Everyone was exhausted after all the hours of pumping out water and they could imagine conditions in and around Calcutta when such a powerful cyclone would reach land. That scene of devastation has already been described.

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26

Kau, Hawaii, earthquake

April 3, 1868
The epicenter was on the south coast of Hawaii, known as the Big Island

An earthquake of magnitude 7.9, the biggest ever, hit the island of Hawaii. The earthquake caused enormous damage in Hawaii Island and was felt three hundred miles away

Every year thousands of earthquakes hit the state of Hawaii, the vast majority of them occurring on the biggest and youngest of all the islands that form the state, The island of Hawaii, known as the Big Island. On the third of April 1868, this island experienced Hawaii's biggest earthquake ever, magnitude 7.9, which caused damage all across the hundred-mile-long island. Its epicenter was in the district of Kau on the south coast, on the southeast flank of Mauna Loa, a volcano that rises more than 27,000 feet into the air, higher than Mount Everest if you count its height from the ocean floor where it begins. The earthquake, which could be heard more than three hundred miles away on the Island of Kauai, caused a mudflow, a rare aspect of Hawaii's many earthquakes, an occurrence that killed thirty-one villagers. It also caused coastal subsidence west of the epicenter and created a tsunami that flooded several villages in Kau and drowned forty-six people.

All along the south coast of Hawaii the earthquake knocked wooden homes off their foundations and, in the villages where straw was the main building material, it tore homes to shreds. Even the more substantial structures of stone were demolished. In the community of Hilo, some distance away on the east coast of the island, every building was damaged. Farther north, almost a hundred miles from the epicenter, in the Kohala Mountains, there were ground waves rising as high as two feet that made it almost impossible for people to stand. Ground fissures of varying depths extended from Pahala to the Kilauea Crater, a total distance of twenty-five miles. Landslides were common all over the island and there was subsidence on the southwest coast to depths of six feet. Much of the destruction was a direct result of the tsunami in which water at times rose as high as forty-five feet. Its impact was also felt beyond the Big Island, on Maui, Lanai, Oahu, and Kauai.

The state of Hawaii is a chain of volcanic islands near the center of the Pacific Ocean. Every part of the state has a volcanic origin. The following is a list of the eight main islands, in descending order of size: Hawaii, Maui, Oahu, Kauai, Molokai, Lanai, Niihau, and Kahoolawe. These eight constitute 90 percent of all the land area of the state but there are numerous smaller islands. There are also many very large islands but they are farther west and are below sea level. The name of the island of Hawaii is a bit of a problem because references to it in books and news reports are often confused with the whole state. It is not only the biggest island; it is more than twice the size of all the other islands combined and it contains the biggest volcano in the state in terms of total mass, Mauna Loa. Because of its location at the eastern end of the state, Hawaii is the youngest volcanic island and therefore the one where most volcanic activity is taking place. The reason for the greatest volcanic activity being at the eastern end of the state is because the hot spot, that is to say the opening down below in the crust of the earth, is directly below the Big Island.

Big Island has five volcanic mountains, approximately twenty miles apart, separated from one another by saddles formed from past lava flows. As the newest island it has none of the coral reefs that are common on the far western, much older islands, and little of its coast has yet been affected by erosion. Maui, Molokai, Lanai, and Kahoolawe, which were once probably a single volcanic peak, are all now separated by distances averaging eight miles and by shallow waters usually three thousand feet deep. Oahu, third in size, is the location of the state capital, Pearl Harbor, The East-West Center, and the well-known tourist attractions of Diamond Head and Waikiki Beach. Kauai and Niihau stand apart from other islands. They are at considerable distances from their nearest neighbors and the water in between is quite deep compared with most of the other islands.

The whole of the state of Hawaii is part of a large volcanic mountain range, most of which is beneath the sea, the islands forming the state being the youngest and, therefore, the highest and most visible parts. The whole mountain chain was formed by what some call a hot spot beneath Big Island in the earth's mantle. This hot spot does not move relative to motions on the surface of the earth and for the past few million years it has been underneath the Big Island. Hence, the frequencies of earthquakes and volcanic eruptions are more frequent here than anywhere else. The Pacific Tectonic Plate on which all the islands stand does move very slowly from east to west. As it moves it takes all the islands with it so the ones we see today as the farthest west are the coldest and least active because they are farthest away from the hot spot. The Pacific Plate moves northwards and then northwestwards, first at a rate of about three inches a year, then four inches, and this has gone on for the past seventy million years. Mama, magma from areas seventy miles below sea level erupted continually at the location of the hot spot, creating, over time, the volcanic mountains that constitute the state.

The history of the Pacific Plate's movements is told in the evolution of the Hawaiian-Emperor Chain, a dogleg series of volcanic mountains stretching thousands of miles across the North Pacific from Hawaii to the Kurile Trench, a subduction zone close to the Kamchatka Peninsula. It also provides a concrete illustration of sea floor spreading. The dogleg section, the change of direction when the Pacific Plate switched from moving northward and took a northwesterly course, was caused by collisions between the Indian subcontinent and the Eurasian land mass forty million years ago. Volcanic mountains in the chain that would now be counted as are older than seventy million years were carried down into the Kurile subduction zone. This series of volcanic peaks consists of more than one hundred individual volcanoes, most of them are below the sea. Their ages are progressively older and their heights lower as they move away from the hot spot. The history of any one of these volcanoes can now be better understood because a new one, Loihi, presently under active study, is developing under the sea twenty miles to the east of the Big Island. Its peak is still less than a mile below sea level.

The heights of some of these volcanoes can readily be overlooked because so much of them is below sea level. Take the two highest, for example, Mauna Kea and Mauna Loa, and note that they stand, like all the others, on an undersea platform that rises far above the general level of the seafloor. A single contour line representing one and a half miles of depth can be drawn to encompass all of Kauai, Oahu, Maui, and Big Island. Even this measurement does not reach far enough. The average depth of the ocean floor in this part of the Pacific is approximately three miles. The identification of a hot spot anywhere on the surface of the globe provides one location that is fixed with respect to the earth's mantle. This is very valuable because all else is relative. All the plates are moving and have no fixed reference to the interior of the earth. It's the same with mid-ocean ridges, oceans, and continents. These hot spots are found in a number of places all round the world but their behavior over time is difficult to track if they occur on land. It is a much easier task when the spot is in the ocean so the Hawaiian-Emperor Chain is an ideal model for studying the historical process.

Over the long seventy million years that we can trace this chain before the oldest of the volcanoes disappears beneath the Asian continent at Kamchatka, we can see a clear pattern developing for each individual volcano. First, as the Pacific Plate moves westward and volcanic eruptions decrease, the rock that formed the mountain gets cooler and cooler and therefore heavier. This increasingly heavy mass then presses down on the seafloor and pushes it downward. At the same time, erosive forces go to work on the top of the peak, first rain and wind, then ocean waves, until it is almost flat. The end result is a series of underwater volcanic mountains, each the same height above the seafloor, but with the flat top of each progressively deeper and deeper below sea level. The ocean floor had sunk but each mountain ended up as a similar landform.

Because of their universal and multi-faceted influence over conditions in the state of Hawaii, we need to be aware of the evolution of a typical Hawaiian volcano before examining its effects in daily life. Although the final appearance and size of a volcano will be unique, each one in the chain evolved and is evolving through the same sequence of stages. First comes the eruption of small quantities of lava deep in the ocean over the hot spot, gradually increasing in quantity until it reaches a peak about half a million years later, after which the amounts decline. Several million years may pass before eruptive activity finally ends and the volcano becomes extinct.

The volcano's life begins deep down below the ocean surface as submarine eruptions build a steep-sided, small mountain with a shallow caldera. As the young volcano grows, small landslides cut into its steep slopes, scarring them. This first phase lasts about 200,000 years but produces only a small part of the final mass. An increase in the frequency and volume of eruptions marks the second phase along with changes in the composition of the basaltic lava. This is Loihi's present stage of development and, before it is completed, Loihi will be close to the surface of the ocean and explosive, ash-generating eruptions will become common as lava mixes with water.

The third phase is when the volcano has grown to more than two thousand feet above sea level and explosive eruptions begin to taper off. Lava flows are now low in volume and continue intermittently for several hundred thousand years. The type of lava emitted is shaped by the slope of the ground and the physical properties of the erupted basalt, and is most commonly basalt. Lava that flows into the ocean shatters into sand and gravel-size fragments and these blanket the submarine slopes. During all three phases, the summit caldera repeatedly collapses, fills up, then collapses again. By the end of half a million years, more than 90 percent of the volcano's mass has been accumulated and it looks like a warrior's shield, hence it has come to be known as a shield volcano.

Weathering and erosion now take their toll of the high, steep-side mountain. The side of the mountain that is closest to the sea and therefore not supported as well as the landward side slips readily toward the ocean, creating large faults and causing major earthquakes. Occasionally there are catastrophic landslides. Recently, vast fields of debris, some of it in large blocks, have been discovered all around the major islands. These submarine deposits suggest that major landslides must have occurred every 150,000 years on the average. Over time, deep canyons cut into the flanks, often along faults previously created by landslides.

At the same time, the volcano's enormous weight pushes the underlying lithosphere downward. Mauna Loa, for example, the world's biggest volcano, has a volume of more than one and a half million cubic feet. Under these conditions the volcano begins to sink and as this happens fringing coral reefs grow at the shoreline with sediments from the reefs accumulating in lagoons. In some Hawaiian islands, remnants of these ancient reefs can be seen. During times of global cooling when polar ice caps grew and sea levels dropped the volcanic shorelines remained at the same level for long periods of time, allowing numerous large reefs to grow.

Beneath Mauna Loa, because of its enormous weight, the ocean crust is depressed approximately 1,500 feet, forming a hollow known as the Hawaiian Deep. In the adjacent waters the seafloor rises by about the same amount to form the Hawaiian Arch. Kilauea is 250,000 years ahead of Loihi in its evolution. It rose above the surface of the ocean 200,000 years ago and within the following 100,000 years had grown to a height of 2,000 feet above sea level. One of the interesting comparisons between Loihi and Kilauea is that both have three main areas of volcanic activity: the summit and two flanking rift zones. Though widely separated in time it seems that their patterns of growth take similar paths.

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27

Chicago, Illinois, fire

October 8, 1871
In the barn of a farmer in the city center

A bigger fire, compared with all the previous ones, broke out in the center of the city of Chicago. Inability of firemen to get to the fire quickly gave the flames a quick start from which, aided by a brisk wind, they were able to push the fire beyond the control of the fire department

This fire began in the barn of a farmer near the center of the city in the evening of October 8, 1871. There was considerable delay in responding to the fire. The alarm was not sounded for more than an hour and then the firemen were sent at first to the wrong place. These factors allowed the fire to make a quick start. Additionally, weekends seem to be favorite times for tragedies of this kind. It was on a weekend, early Sunday morning, that the great fire of London of 1666 broke out and it was also on a weekend that the tragic Coconut Grove Club fire in Boston occurred, killing five hundred of the people who had packed into that club for the evening of November 28, 1942. There was an additional troubling factor affecting the Chicago fire: weeks of extremely dry weather had caused a rash of fires. Daily the city's fire bell kept ringing every three or four hours. Firemen were completely exhausted by the time the big fire broke out on October 8.

Chicago, the windy city, unfortunately lived up to its reputation on this occasion. Soon after the start of the fire a strong wind began to blow from the southwest. This was the trigger that accelerated the conflagration, pushing it beyond control within a couple of hours. The wind rose to 60 mph, flaming bits of debris were blown from one building to another, and soon large numbers of people were running toward Lake Michigan's

Figure 16 A view from the west side of the great fire at Chicago October 9, 1871.

beaches for safety. The reality that firemen had to face was that Chicago was a city almost entirely constructed with wood and all of this wood had become as dry as tinder in three months of drought since early July. Less than three inches of rain had fallen in those months. Wood was the universal raw material for homes and streets at that time and writers often referred to Chicago as being all wood. The arrival of blacktop was still a long way ahead in time. Walkways, paths, and even streets, were made of wood planks. There were hundreds of miles of wood in Chicago and every home and almost every building was a wooden structure.

The city in 1871 had become the national center for the meat packing industry and so the entire ground area in the newly opened stockyards were paved with wooden blocks to prevent damage to the feet of cattle, sheep, and hogs. The ships in the Chicago River were made of wood and so were the bridges that spanned it. There were wooden fences and wooden barns and outbuildings, wooden stables behind the wealthier homes and even among the large buildings of the city most of them were built of wood. The poorer residential homes stood next to lumber and coal yards, paint sheds, furniture factories, and other buildings of an industrial kind that were filled with flammable goods, so they constituted a fire trap in the given situation. That situation included widespread neglect of such fire and safety regulations that were in place. The considerations with which we are familiar today were absent in these early days of burgeoning western cities. Nowadays, the cost of a fire in a major city is so great that strict controls and high penalties for neglect are installed in all vulnerable sites.

By the time the fire eased, which would be eighteen hours later, there was a huge population of homeless people. Late on Monday evening, that is almost a day and a half after its inception, the fire burned itself out. Flames had swept over more than 2,000 acres of land and destroyed an estimated $200 million worth of property. The worst feature of all was that the areas that had been destroyed were the ones that the city could least afford to lose. The center of the city's commercial, cultural, and civic life was destroyed. As so often happened in situations of this kind, it was hard to control looters. The authorities did what they could and the military units that were drawn in to control the situation were given orders to shoot at sight anybody who was looting. However, that did not seem to inhibit the amount of looting. There was a national and international outpouring of charitable contributions and a remarkable amount of work was accomplished in a short period of time for the many who were homeless. Reconstructing the city was a big task. Eighteen thousand buildings had been destroyed, three hundred had died, and there were a hundred thousand people without homes.

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28

Owens Valley, California, earthquake

March 26, 1872

Lone Pine was a small community two hundred miles north of Los Angeles and close to the Nevada border

The town of Lone Pine, California, was hit with an earthquake of magnitude 7.4. This earthquake destroyed a seventy-mile fault line and killed twenty-seven. Although one of the largest quakes in California's history the death toll was small because there were few people living here in 1872

The town of Lone Pine, California, two hundred miles north of Los Angeles and fifty miles west of the Nevada border, was virtually leveled when the entire seventy-mile length of the Owens Valley fault ruptured on March 26, 1872. It was one of the largest earthquakes in United States history with a magnitude of 7.4. There were fewer than three hundred people in Lone Pine. Twenty-seven of them were killed and fifty-six others suffered cuts and bruises. All the adobe homes were destroyed. The event was felt throughout most of California and Nevada, and as far as Salt Lake City, Utah. Adobe and brick buildings sustained the brunt of the damage. Minor damage also occurred two hundred and fifty miles away in the San Joaquin and Sacramento Valleys on the western side of the Sierra Nevada. In Yosemite Valley one hundred and fifty miles to the north the earthquake triggered a landslide.

As severe as the ground shaking must have been, it was noted that no one would have been killed or hurt if the houses had been made of wood. The characteristic log homes of early settlement always provided good protection against earthquakes. Numerous depressions and uplifts occurred in and around Lone Pine as would be expected from an event that displaced the Owens Valley fault horizontally by as much as twenty feet. In one location, an area two hundred and fifty feet long sank twenty-five feet while a neighboring stretch of land of comparable size rose by twenty feet. Many comparisons have been drawn between the Owens Valley earthquake and the great San Andrea earthquakes of 1857, the Fort Tejon earthquake, and 1906, the Great San Francisco event. The extent of the land area shaken by each of these three events is comparable, as are the maximum fault displacements. All of them can be classified as great on the basis of the lengths of the ruptures that occurred in the faults but their seismic magnitudes are all much smaller than, for instance, the Alaska earthquake of 1964.

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29

Bangladesh cyclone

October 31, 1876
Southern coastal area of what is now Bangladesh

A cyclone in the area we now know as Bangladesh destroyed the city of Chittagong. At least 200,000 people in Chittagong and its surrounding area died as a result of the cyclone

On October 31, 1876, the community of Chittagong, in a part of India that is now in the nation of Bangladesh, experienced a powerful cyclone that swept inland up the River Meghna, part of the Ganges River's delta. As the surge of water moved upstream into the shallower and narrower stretches of the river it rose in height until it became a monstrous wall of ocean water, thirty to forty feet high. Bangladesh, on the eastern part of the Bay of Bengal, experiences cyclones twice a year, in October and in May. These two months represent the turning points of the monsoon winds. In May they begin to move on shore and in October they move southward from the cold air mass in the north to dominate the atmosphere of India for almost six months. It seems that these turning points, because they represent for a time a mixing of the two contrasting wind systems, trigger the cyclones. The impact of this cyclone in 1876 was devastating in every way. A hundred thousand persons drowned and another hundred thousand perished from diseases or famine.

There is, initially, an accumulation of water in the various small sea inlets along the coast as the cyclone pushes water toward the land. This is a slow process because the Bay of Bengal is quite shallow for a distance of several miles outward from the land. Other factors too, in addition to the depth of the ocean, determine the rate at which water accumulates. A spring tide, a higher than normal level of tidal water, if it were to coincide with the arrival of a cyclone, would greatly increase the breadth of destruction because tidal waters influence the entire shore. This coincidence occurred several times in the recent past, in 1970, 1981, and 1991, fortunately with less loss of life, presumably because disaster preparedness was greater than in 1876. The wind strength of the cyclone and the angle of impact with the shore are two other factors influencing the amount of destruction.

Bangladesh seems to have received more of the types of cyclones that result in high death rates than has any other country in South or Southeast Asia. One statement that gives support to this claim is based on a list of deaths from cyclones that occurred only in those countries and in those cyclones in which there were more than 5,000 deaths. The data reveals that Bangladesh featured in more than half of the countries listed. One physical factor in the environment of Bangladesh may be a contributing cause. The country's overall low elevation makes it easy for relatively small storms to transform its coastal area into a vast sea. With regard to the future, scientists have debated the implications of global warming with respect to the nature of cyclones in the Bay of Bengal. The only tentative conclusions arrived at to date are that sea temperatures will increase and these cyclones, as a result, will likely be more intense and therefore more destructive.

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30

Marshfield, Missouri, tornado

April 18, 1880
Marshfield, Missouri

A fast-moving category 4 tornado swept through downtown Marshfield, Missouri. Most of its buildings were destroyed

A massive category 4 tornado left little standing after it had swept through downtown Marshfield, Missouri, on April 18, 1880. It arrived from northeast of Springfield. Seven people were killed in that city as it passed through and ninety-two lost their lives in Marshfield. This was one of the worst natural disasters to strike a small town anywhere in the country, at least up to 1880. All but fifteen buildings in Marshfield, a community of 1,100 people, were destroyed. Memories remain strong when a small community suffers such a large degree of destruction and some of these memories were recalled many years later. They provide a vivid picture of the nature of a tornado and the suddenness in both forming into a vortex and traveling at high speed across the ground.

One man recalled that the day of the tornado was warm and without any wind, an ideal day for young people to be out of doors playing. This is what he remembers doing. It was a Sunday and nothing changed in the appearance of the sky from three in the afternoon to five. From 5 P.M. to 6 P.M. everything seemed to happen. First came the darkening of the sky by a series of black clouds that looked like smoke coming from one of the old coal-fired steam engines. Then almost immediately one could see a mass of these same clouds coming in their direction. This man remembered the reaction of his father at this stage. He had recognized the signs of a tornado and without a moment's delay began to run toward the one place that was known to be a safe refuge in a tornado, the courthouse. As he ran he pushed or dragged every member of the family with him. Family members remember the fear that was evident as they ran.

In the short space of time between identifying an approaching tornado and running the hundred yards to the courthouse, the air and ground all around had filled up with all kinds of debris. Anyone who was still outside could only hold on to anything that seemed firm and hope for the best. The wind was a howling, greater than 100 mph force, sweeping away anything and anyone in its path. Those who remembered noted how quickly it was all over. So quickly, in fact, that no one wanted to leave the courthouse for some time. When they did leave it was to witness their demolished homes, and cope with the horror of dead and injured neighbors.

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31

Georgia/South Carolina hurricane

August 1881

The hurricane made landfall at Ossabaw Island

A category 2 hurricane struck the coastal and interior areas of Georgia and South Carolina. Damage was greatest in Georgia where the majority of those killed had lived

In August of 1881, a category 2 hurricane struck the coastal and interior areas of South Carolina and Georgia, in and around Savannah. The hurricane made landfall on Ossabaw Island so it has been named Georgia/South Carolina rather than South Carolina/Georgia to indicate the dominance of damage in Georgia where most of the seven hundred people who were killed by the hurricane had lived. This particular storm was somewhat overlooked in records of the time, probably because it was limited in its lateral coverage. However, very low pressures were recorded in Savannah at the hurricane's peak and one instrument for measuring wind speed was blown away at 80 mph. Based on modern storm surge predictions, a category 2 storm that made landfall at the time of high tide would have inundated large portions of Isle of Hope. The Georgia/South Carolina storm was an example of the worst possible outcome from a category 2 event. After landfall it turned sharply toward the west and died out over northwestern Mississippi on August 29.

Hurricanes that strike Georgia and the Carolinas usually originate in the Atlantic Ocean east of the Bahamas. Many hurricanes that track north of the Greater Antilles eventually threaten this portion of the southeastern United States. Periodically, storms in the eastern Gulf of Mexico pass over the Florida peninsula and move up the Atlantic coast toward the Carolinas. Cold fronts that sit over the subtropical waters off the southeast coast have, on occasion, formed into hurricanes. Many of the largest and most intense tropical cyclones that strike the southeastern United States have long tracks covering thousands of miles. Numerous powerful hurricanes reached the Carolinas in the decades after 1881. Georgia, however, despite its earlier experience of several powerful hurricanes prior to 1881, has been largely free of major hurricanes for most of the twentieth century.

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32

Haiphong, Vietnam, typhoon

September 15, 1881
Haiphong, Vietnam

A monstrous typhoon struck Haiphong, Vietnam, killing 300,000. Haiphong, poorly prepared in 1881 for typhoons, was devastated

Haiphong, Vietnam, in the Gulf of Tonkin, lies directly in one of the most frequently used paths for those Pacific typhoons that originate in and around the Philippines and reach the Asian mainland through the Gulf of Tonkin. The typhoon that arrived on September 15, 1881, was very powerful and it devastated Haiphong and the surrounding coastal area. Three hundred thousand died. Little is known of the social and environmental conditions there at that time. It seems that no protective barriers were in place to protect people against a typhoon. Even today it is often difficult to protect people and buildings. Admiral William Halsey, commanding the U.S. Fleet during World War II, discovered something of the power of these storms when he found his ships caught in one. Seven hundred and eighty men were killed, three destroyers sunk, and more than a hundred aircraft lost. The storm had been more destructive than many of his encounters with enemy fleets.

Long before the typhoon of 1881, the Japanese, like Admiral Halsey, discovered the power of typhoons. In 1281, a Mongol fleet attempted to invade Japan but the ships were destroyed by a typhoon. The event was immortalized in the Japanese word "kamikaze," meaning divine wind, and later in the suicides of the kamikaze pilots of World War II. Haiphong, Vietnam, is located in the delta of the Red River, approximately sixty miles from Hanoi, the Vietnamese capital. Haiphong is the main seaport for the northern region of the country and has, for centuries, been one of Vietnam's principal trading centers. Earlier in the nineteenth century, when Vietnam became a colony of France, the city was France's main naval base in Indochina. After

World War II, when Vietnam attempted to regain its independence, Haiphong was the site of the first military action undertaken by the French. Later, during the Vietnam War of the mid-twentieth century, Haiphong was subjected to heavy bombing by the United States due to its status as country's major port. After the war, the city was built up as a major industrial center and years later, early in the morning of September 27, 2005, Haiphong was struck once again by a strong Pacific typhoon.

Aware that the 2005 typhoon was approaching, preparations were made on the previous day to provide shelter from the storm by moving 2,000 people to areas away from the coast and giving them supplies of food and water that would suffice for several days. Dikes near the coast, built some years earlier to minimize the effects of storm surges of water, were already in place. The typhoon began as a tropical storm in the Philippine Sea east of the Philippines on the twentieth of September, 2005 but, as it passed over Luzon and moved into the warm waters of the South China Sea, it became a typhoon. The typhoon crossed over Hainan Island on the twenty-fifth of September and reached the coast of Vietnam early on the twenty-seventh with sustained winds of 100 mph. Chinese and Vietnamese authorities had been watching the approach of this typhoon with much concern and it turned out to be the worst typhoon they had experienced in several decades as its winds caused widespread flooding and destruction along the coast. Ultimately, the 2005 typhoon caused more than 150 deaths, almost half of them in Haiphong, before it moved on westward into China.

Vietnam's deputy prime minister, accompanied by representatives of various government departments, spent most of September 27 on tours of the city assessing the damage. They discovered that the Maritime Search and Rescue Center was rendered helpless as a major dike protecting it had collapsed under the typhoon. The Center's inability to rescue the people overwhelmed by storm surge may account for the high death toll. Elsewhere on the coast and throughout the city the deputy prime minister and his representatives encountered a scene of almost complete destruction. Within a few days, the government of Vietnam issued a worldwide appeal for help, asking for the equivalent of US$1 million in cash, goods, or on-site help. The appeal said that five thousand families, involving 25,000 people, needed both immediate and long-term care, the latter for at least twelve months. The government added that it had already contributed from its disaster emergency fund one quarter of the amount requested in order to begin the restoration work.

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33

Krakatau, Indonesia, volcanic eruption

August 27, 1883

Krakatau was seen before the eruption as a small group of islands with the main part towering high above the others in the ocean between the islands of Java and Sumatra

The main part of Krakatau stood 6,000 feet above sea level before the eruption; afterward it was below sea level

In the course of the nineteenth century, Indonesia was struck by two of the most powerful volcanic eruptions it had experienced in the past 10,000 years—Tambora in 1815, in the eastern part of the country, and Krakatau in 1883, farther west between Java and Sumatra. Krakatau had one tenth of Tambora's power but, nevertheless. was sufficiently destructive to profoundly affect places all over the world. Following tremors and minor explosions during the previous night there was one massive outburst of pyroclastic material that rose more than six miles into the upper atmosphere on the morning of the twenty-seventh and at the same time swept across Indonesia, darkening the sky for as far as one could see. The explosion was followed by several tsunamis ranging in height from 40 to 120 feet. Most of the 36,000 who died were victims of the tsunami.

The Krakatau Islands in the Sunda Strait were the above sea level portions of a single volcano that had erupted more than once over the previous million years. Just before its last phase of activity, many centuries before 1883, Krakatau was a mountain that stood 6,000 feet above sea level. When it erupted in 1883 the entire top of the mountain and much of the portion below sea level disappeared and in their place was a huge four mile-wide crater, known as a caldera. The caldera was mostly below sea level and all that remained visible of Krakatau after the event in 1883 were the four Krakatau Islands, composed of the higher parts of the caldera. At the time of the 1883 eruption, because the eruption originated below sea level and was so massive, the noises of pyroclastic material mixing with water were the most powerful and long lasting experiences of all who witnessed the event. For thousands of miles from Sunda Strait, in places as far away as Australia, the sounds of explosions were heard, and in countries all over the world the atmospheric shock caused by the eruption were registered in their barometers.

Some estimate of the power of the explosion on August 27 can be seen in reports from the time. The place we now know as Indonesia was a European colonial territory in 1883, mainly a Dutch possession and to a lesser extent a British one. A Dutch warship was close to the site at the time of the eruption. As a result, the ship was carried inland for more than a mile and was left there at an elevation of thirty feet above sea level. Extensive damage was done both on land and in the sea. Towns on both sides of the Sunda Strait were completely destroyed; blocks of coral, some as heavy as 600 tons, were torn away from their locations and left on shore; and more than 5,000 boats were sunk. In Australia, four hours after the eruption, a thousand-foot-high tsunami reached almost one mile inland. On the eastern coast of India, in Calcutta, three hundred riverboats were sunk by the tsunami and, still further away at the southern tip of

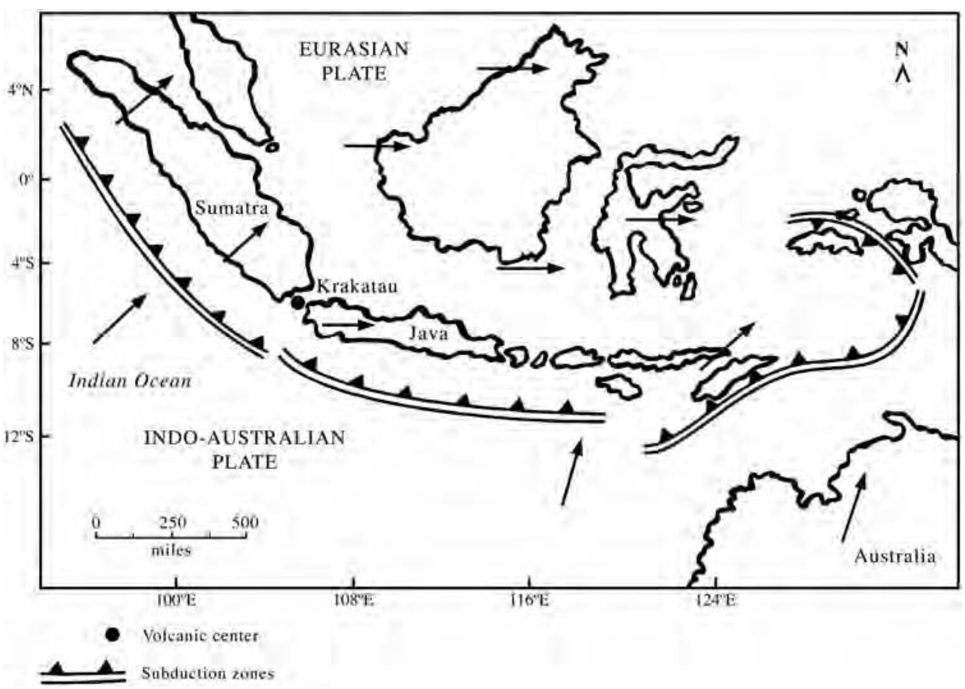

Figure 17 The site of the Krakatau eruption.

Figure 18 Krakatau is located in the Sunda Strait, between Sumatra and Java. It is famous for its devastating 1883 eruption, one of the largest in history. This drawing shows the ash cloud from the 1883 eruption.

Africa and in the North Island of New Zealand, there were some minor repercussions from this powerful wave of water from Indonesia.

The volume of material that was ejected from Krakatau on August 27 was not understood for many years, not until extensive measurements were taken in and around the Krakatau Islands about one hundred years later. Altogether six cubic miles of materials of different kinds had been thrown out by the eruption and most of that material came back to earth or sea in areas quite close to their source. So heavy was the deposit on the north side that two new islands were formed just below sea level. Coastlines were extended on both sides of Sunda Strait and the ocean around Krakatau was shallower as a result of the deposits. All of these events together gave rise to the two events that were vividly remembered by the people who lived there at the time: the explosive noises of magma and rocks at temperatures of more than 700 degrees entering water, and the tsunamis that were created by the huge displacement of water. The caldera that remained had a diameter of four miles and it was more than two hundred feet below sea level.

Fortunately for us today, detailed records of the events of 1883 were sent back to Europe soon after the eruption by the Dutch and British colonial authorities in Indonesia. Alexander Cameron, the British Consul in Batavia, now the city of Jakarta, wrote a letter to the British Prime Minister, William Gladstone, five days after the volcanic eruption. In the letter, Cameron identified what had happened as one of the greatest calamities of the century. Uppermost in his report were two things: the loud noises that were identical to artillery shells exploding, and the darkness that covered the area around him. He described the latter as a thick cloud of grey ashes that gradually reduced light from twilight conditions to total darkness by midday as the cloud moved eastward. Cameron's report went on to describe the tsunamis that followed the eruption and affected the neighboring shores of Java and Sumatra, stressing their height and speed. Details of the damage caused and the numbers of lives lost were still unknown as his report was being written because all forms of communication had been interrupted.

Others also recorded their observations. A representative of Lloyd's of London Insurance Company who was based in Batavia reported to his head office in London that all methods of communication, including roads, had been destroyed, and that the principal peak in the Krakatau Islands—which was almost 3,000 feet high—was no longer there. Other observations came from a harbor pilot whose home was in Anjer on the shore of Java and whose work was to guide ships through the Sunda Strait. The pilot was walking on the beach near his home on the afternoon of August 27 because hot volcanic fragments had been dropping from the sky all day and he was afraid that they would set his home on fire if the thatch on the roof were to be ignited. As he stood on the beach he saw a dark, black object moving toward the shore, something he had never seen before in his many years on the ocean. As the object approached he could see that it was a high wall of water. This was the first of several tsunamis that would, over the following twelve hours, cause the deaths of almost all of the 36,000 who lost their lives.

The deadly tsunamis made the Krakatau eruption different from other events of this kind elsewhere in the world. Approximately 10 percent of the world's peoples live close to volcanic sites that are either active now or potentially active in the lifetime of those living nearby. Volcanic eruptions occur somewhere in the world every year yet, over the past two centuries during which there are records of close to a hundred tsunamis that were created by volcanic eruptions, not one of them was responsible for as many deaths as were caused by Krakatau's tsunamis. The more than 150 villages in Java and Sumatra in which people were killed were not the only places destroyed by these tsunamis. Numerous small boats were sunk near shore and those in them drowned as telegraph cables were severed, and all kinds of docking and other shore installations were swept out to sea. A number of larger ships that were some distance from Sunda Strait when the eruption occurred were not affected in any way as they were still in deep water.

As soon as the scale of the disaster became known, corrective steps were taken to minimize additional damage. Warships were stationed on both north and south entrances to the Sunda Strait to stop all approaching ships. This was normally a very busy shipping area so, until the nature and extent of the changes that occurred below sea level were known, the Strait had become an unsafe waterway. On land, the damage affected both human and animal life. Agriculture, the main livelihood of almost all of the people, was suddenly and completely stopped because of the deep layer of ash everywhere. Fodder for animals was unavailable so emergency food supplies had to be found for them. Fruit and palm trees constituted a major source of wealth for the native people and they depended for food on other crops that had been destroyed. The loss of coffee and tea plantations created additional concerns among the colonial officers. These plantations were the sources of profits for the European nations concerned and the main reason for their presence in that area.

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34

Charleston, South Carolina, earthquake

August 31, 1886

The epicenter located sixteen miles north of Charleston

Charleston, South Carolina, experienced the most powerful earthquake ever to strike the east coast of the United States. Because of the epicenter's closeness to the city, damage was extensive in and around Charleston and the quake was felt in places all the way from Canada to the Gulf of Mexico

Charleston was the scene of a 7.3 strength earthquake on August 31, 1886, the greatest quake to hit the east coast of the United States in historical times. More than a hundred buildings and many thousands of chimneys in the city were destroyed. About sixty people were killed. The reason for the enormous amount of damage to chimneys and the lesser destruction of buildings generally stems from an edict dating back more than forty years following a disastrous city fire. During that fire, older wooden buildings had been burned to the ground so it was mandated that, for all future construction, brick was required. Unfortunately, an inferior type of mortar was used in the construction of many of the newer buildings and, accordingly, these were the buildings that toppled in the August 31 event. This earthquake was felt all the way from Canada to the Gulf of Mexico.

Any earthquake in this part of the nation in and surrounding Charleston, South Carolina, causes damage over an area larger than that influenced by comparable quakes in the West both because of lower bedrock density and because of its location within the continental plate rather than at the area of interaction between two plates. This Charleston event was similar to three events in the eastern and central parts of the United States: the offshore earthquake in Massachusetts in 1755 and the Madrid earthquakes of 1811 and 1812. Overall, the pressures at work were similar for all three of these. The ocean crust moved westward from the Mid-Atlantic Ridge, pushing North America slowly toward Asia and, in doing so, created tensions in the continental lithosphere that caused these major earthquakes as well as numerous minor ones. Pressure from the Juan de FICA Plate as it moves crust in the opposite direction heightened these tensions, slowing the process slightly but not stopping it.

There were numerous aftershocks after the 1886 earthquake and earthquakes will occur again in or near Charleston. Of the over 400 earthquakes reported to have occurred in this area since 1774, most were aftershocks from the 1886 event. Furthermore, recent research revealed evidence of large quakes near Charleston approximately 600 and 1,300 years ago, suggesting that the frequency of these monster quakes may be of the order of every 500 years. After the 1886 quake, people reinforced their buildings with wall anchors that tied walls and roofs to the floor in order to prevent them being blown out in another earthquake. The effectiveness of these measures has yet to be tested and may not be tested in the lifetimes of

Figure 19 Derailed locomotive on Ten Mile Hill after the August 31, 1886, earthquake in Charleston, South Carolina.

Figure 20 The worst earthquake wreck in Charleston, South Carolina.

the next several generations. For the present, there needs to be a change of attitude toward the danger of earthquakes in the eastern part of the continent. The western portion of the continent tends to receive the majority of the attention when it comes to earthquakes because of the frequency and size of the events that occur in that area. Since the 1960s and the deployment of the Global Seismograph Network (GSN) which records small quakes as well as larger ones we now know that a small earthquake strikes somewhere within the regions of Appalachia and the Coastal Plains every day.

In the aftermath of the 1886 earthquake, railroad tracks buckled in a number of locations and telegraph wires were cut, leaving Charleston with no communication links to the rest of the world for a couple of days. Even then, there was no serious lack of food but the means for preparing the food that was available were inadequate since few houses escaped damage and many were totally destroyed. Much of Charleston was built on what was known as "made" land; that is, land formed by filling in existing creeks or extending shorelines with deposits of sand and rock. Older houses stood up better than newer ones because they had employed handmade bricks with a rough surface that were able to maintain a strong bond with mortar. One family that lived in an older house slept through the earthquake without knowing it had occurred. Well-built wooden homes with parts carefully pinned together withstood the shaking as well. These homes had an elastic quality enabling them to stretch under pressure and then return to their original shape.

There were two epicenters for this earthquake, one sixteen miles north of the city and the other thirteen miles to the west. The close proximity of these epicenters to Charleston accounted for so much widespread damage. Summerville, a town of about 2,000 people near the north epicenter, experienced sounds like major explosions on October 27 and 28. When the earthquake struck people in the town were tossed from side to side and frequently thrown to the ground. Houses appeared to be receiving heavy blows from below; chimneys fell down, sometimes carrying fireplaces with them as they collapsed into a heap of rubble. All indications pointed to strong vertical motion. Aftershocks gave a powerful boom sound. Ground fissures were everywhere and from some of them water was extruding, sometimes in the form of jets, at other times mixed with sand. The severity of the earthquake was felt over a much bigger area than the environs of Charleston, albeit in terms of lesser amounts of damage. For an area within eight hundred miles of the city severe shaking was experienced.

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35

Yellow River, China, flood

1887 AD
The flood occurred in Henan Province

High rain fall caused the Yellow River to overtop its banks leading to a widespread flood and the deaths of 900,000

Throughout China's history, on both of its major rivers, flooding has always been a common experience. This has been especially true on the Yellow River, locally known as the Huanghe, because of the large volume of loess silt that it carries. This kind of light silt can easily be dislodged from the side of the river and carried along by the stream. At the lower reaches of the river, where the land is relatively flat the speed of the river decreases, much of the silt is deposited. The dykes on both sides of the river were originally built to prevent river overflows that would destroy the farmlands, the only source of livelihood for the peasants who own and work the farms. From time to time, however, sudden heavy rainfall can make the river overtop these dykes and flood the neighboring farms. That is what happened in 1887 when the worst flood in Chinese history occurred. The Yellow River overtopped its dikes in Henan Province in the lower reaches of the river. Five thousand square miles were inundated. Eleven large towns and hundreds of villages were destroyed. Nine hundred thousand people died, and two million were left homeless. "River of Sorrow" is another name that has been given to the Hwanghe and it is easy to understand why.

The process by which a catastrophic flood occurs is tied to both the amount of silt and the height of the dykes. Throughout most of its history, the Huanghe was not dredged so there was always a slow buildup in the level of the river compared with the surrounding land. Earthen dykes supported by stones were built on the sides of the river and periodically raised to higher levels as the river rose so that river water was always below overtop level. Thus, in the thousands of years over which farming was carried on beside the river, the overall picture was of a river flowing along at a high level above the adjacent land. When the river overtopped its banks the damage caused was enormous because of the advantage of height. The kinetic energy in the water leaving the river enabled it to wash away large segments of the dykes. The overflow of water then continued until it reached the lowest point in the broken dykes. It took some time for the water to drop to this level and then the hard manual work of rebuilding the dykes had to be undertaken.

As a precaution against flooding, people had to watch the weather and the level of water in the river. As soon as the water level became too high, an army of people was supposed to rush to the scene and raise the level of the dykes. It was not always possible to identify the right moment to do this or to get people in place in time to do this corrective work. In the year 1887, heavy rains poured right through the latter part of summer and into September. On the twenty-eighth of that month, a major collapse of dykes took place unexpectedly and water began to spill all over the land on both sides. The province of Henan where this happened has an average elevation above sea level of six hundred feet or less, very different from the mountainous regions from which the Yellow River had come. Henan is close to the sea and close to the mouth of the Yellow River. It is often referred to as the North China Plain. Immediately after the break in the dykes the alarm was sounded and a large number of people rushed quickly to the river in the hope of repairing the breaches. Before they could reach the river, the breaks had expanded to more than 2,000 feet in length. There was little that could be done. Many of the people tried to run or walk upstream in order to reach a level above that of the flooded area, but they were caught in the fast-moving huge volume of water and drowned.

The breaches in the dykes took place near the city of Zhengzhou and, within an hour, a lake as big as Lake Ontario had formed on the adjacent plain. People from the city attempted to reach as many victims as they could by rowing around in small boats. Some of the peasants were able to reach terraces that were slightly higher than the water level and there they waited for someone to reach them. Others desperately tried to stay alive by clinging to straw barrows. The overall temperature is quite low by the end of September and on the day of the tragedy there was a strong wind that made everyone feel colder than it was. It was slow work for the small boats as they tried to go from terrace to terrace and take people to safety. Often there would be as many as a hundred families on one terrace. Some homes were still erect though under water and survivors stood on these as long as they could before either hunger or cold took over and they lost their lives. Here and there an old tall tree was standing and people of all ages were seen clinging to branches in the hope that help would arrive. One family, knowing that it had no chance of surviving, placed a baby on top of a chest along with some food and a piece of paper with its name, and this chest stayed afloat long enough for the child to be rescued.

There was very little organization or resources for the rescue work. Foreign missionary societies shared their meager food supplies with survivors but their food supplies did little for the starving thousands. One report described the situation as thousands of people all around, stunned and hungry, crying out for food. Efforts by individuals and government agencies continued unabated all through the winter months. It took a lot of time because there was so little organization in China at that time for dealing with emergencies. When the water finally stopped residents saw a plain on which there lay a heap of loess mud about eight feet deep. As it dried out, the whole region looked like the Sahara Desert rather than the green fertile plain that was there a few days before. People unfamiliar with life around the Yellow River often wonder why peasants insist on living and working in such dangerous areas. The same people also wonder why peasants live and work very close to volcanoes. The answer in both instances is the same: it is near volcanoes that the best soils for farming are found.

The cleanup of the farm fields and the rebuilding of the dykes had to be undertaken immediately despite the approaching cold weather of winter. Farm work in this part of China is a year round activity. Furthermore, the danger of a new flood would increase once the warmer weather of the following year came around. Every person was familiar with the routine for dyke repair. Thousands of tons of earth had to be moved in wheelbarrows and, in the process of both removing the mud from their farms and rebuilding the dykes, almost all of it had to be passed from place to place by hand buckets. The stones needed for the work had to be carried in ox carts from places as far away as a hundred miles.

Thousands of feet of damaged dyke were subject to constant crumbling and when wet the silt facing was slippery. From the top of the dyke the river may be forty feet below, so it is easy to imagine the amount of work that had to be done to build up the dyke to prevent any further breaches. It was a common experience for workers to see their fellow laborers lose their footing and fall to their death in the river. It was not until the early part of 1889 that the dykes were finally closed. By that time the spread of disease had added its troubles to all that had been experienced from the flood and the famine.

In ancient times, dykes would often be deliberately broken in order to flood the fields of an attacking enemy but no one was prepared for the use of that same technique in the twentieth century. In the 1930s, years before World War II began, China was invaded by Japanese soldiers in flagrant violation of international agreements and by 1938 had captured and destroyed large areas of the country. In June of that year, a large part of the Japanese army was about to march westward across the North China Plain, a few miles south of the Yellow River, in order to capture a major railway juncture. The Chinese government of that time decided that its only hope of survival was to use the age-old method of breaking the dykes. This they did and it certainly stopped the Japanese advance, but there were terrible unexpected consequences from its action. The Yellow River flooded an area of about nine thousand square miles and drowned half a million Chinese peasants. Millions of others were left homeless. The plain remained flooded until the end of World War II and the surrender of Japan, seven years later. In 1947, with help from the United Nations, China returned the Yellow River to its former channel and two million acres of farmland was once again in productive use.

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36

Johnstown, Pennsylvania, flood

May 31, 1889

A dam above and north of Johnstown

The town of Johnstown, Pennsylvania, was devastated by the nation's worst flood. Poor maintenance had allowed a dam built high above Johnstown to give way and flood the town

On May 31, 1889, the town of Johnstown, Pennsylvania, population 30,000, was devastated by the worst flood in the nation's history. Over 2,200 died and many others were homeless. A small lake, about four hundred feet higher than the elevation of Johnstown, once used to supply the old Pennsylvania canals, had been purchased by a private group, The Hunting and Fishing Club, and they had enlarged it, raising its dam to a height of one hundred feet. This club failed to give attention to the old sluiceways at the bottom of the dam so that, as heavy rain raised the water level in the lake, the only escape route for water was over the top and the dam had never been designed to restrain the weight of water at that level. On May 31, 1889, heavy rains raised the lake level to the top of the dam. Leaks began to appear in several places and within a short time the whole dam collapsed. The waters of the entire three-square-mile lake thundered down the valley to Johnstown.

Johnstown was a steel-company town in 1899, a growing and industrious community known for the quality of its steel. Founded in 1794, Johnstown prospered with the building of the Pennsylvania Mainline Canal in 1834 and still more with the arrival of the Pennsylvania Railroad and the chartering of the Cambria Iron Company in the 1850s. There was one drawback to living in the city—Johnstown had been built on a flood plain at the fork of the Conemaugh and Stony Creek rivers. Because the growing city had narrowed the river to gain building space, heavy rainfall quickly raised the river's water level, frequently flooding parts of the town. Fourteen miles up the Conemaugh River, Lake Conemaugh, at an elevation of four hundred feet above Johnstown, with a poorly maintained dam, was a constant source of concern to the people farther down the valley. Every spring, as heavier rain arrived, there was talk that it might not hold back the water, especially if its level rose very high.

At 4:00 P.M. on the wet afternoon of May 31, 1889, the inhabitants heard a low rumble that grew to a roar like thunder. Some knew immediately what had happened. After a night of heavy rain, the South Fork Dam had finally broken, sending sixteen million tons of water crashing down the narrow valley. Boiling with huge chunks of debris, the wall of floodwater grew at times to sixty feet high, tearing downhill at 40 mph, leveling everything in its path. Thousands of people desperately tried to escape the wave. Those caught by it were swept up in a torrent of oily, muddy water, surrounded by tons of grinding debris, which crushed some while providing rafts for others. Many became helplessly entangled in miles of barbed wire. There were no telephones or anything similar beyond the telegraph stations at different locations to warn the people of Johnstown of the approaching deluge.

A young civil engineer who was the first to see the impending break in the South Fork Dam rode his horse as fast as he could down the valley shouting, "The dam is breaking, run for your lives." At South Fork Station he stopped to send a telegraph message to Johnstown, ten miles down the valley. Some paid attention to his cry, most ignored him. He lost his life

WRECK OF THE IRON BRIDGE AT WILLIAMSPORT, PA.

Figure 21 Wreck of the Iron Bridge at Williamsport, Pennsylvania, after the Johnstown flood.

as he crossed a railway bridge below Johnstown and was caught in a wall of water and debris as the bridge collapsed. It was all over in ten minutes, but for some the worst was still yet to come. As darkness fell, thousands were huddled in attics, others were floating on the debris, and many more had been swept downstream to the old Stone Bridge at the junction of the rivers. Piled up against the arches, much of the debris caught fire, entrapping forever eighty people who had survived the initial flood wave.

Floods are familiar events in most parts of the world and they most frequently occur when humans compete for the use of flood plains. The natural function of a flood plain is to carry away excess water when there is a flood. Our failure to recognize this fundamental fact has led to extensive development on flood plains, without adequate attention being paid to the behavior of water, and hence an increase in floods. Because these places are ideal locations for agriculture, there are good reasons for living and farming there. In this book and in the second volume, there are examples of human use of flood plains and also the disastrous consequences of inadequate planning in time of flood. One of these examples is China's terrible experience of a flood on the Yellow River in 1887. In that event, heavy rains raised the water level in the river so high that the levees were overtopped and then partly destroyed so the flood plain became a deep lake. Close to a million people lost their lives. While this example involved huge numbers of people and a large amount of land, the cause of the tragedy was exactly the same as the Johnstown one. There had not been sufficient strength in the methods used to hold back the water neither in the levees in China nor in the dam above Johnstown.

The outstanding example of flood plain problems is the Mississippi River basin. It is the largest in the world and it occupies almost half of the total surface area of coterminous United Sates. Floods have been a constant feature of this river from the beginning of historical records. For most of this time period, Mississippi's floods were considered to be local responsibilities. When the flood of 1927 occurred, killing 246 people, flooding 137,000 buildings, and leaving 700,000 people homeless, it became clear to all that national action was essential if the ravages of flood damage were to be effectively minimized. At the mouth of the Mississippi, human activity of various kinds is destroying the wetlands that would normally develop if the river were free to deposit its silt naturally. Sixty square miles of wetlands are lost annually in this area, a higher percentage that occurs on any other U.S. coastal area. Yet we know now, in the aftermath of Hurricane Katrina, that these wetlands provide the first line of defense against deadly hurricanes, by both limiting the storms' access to the warm ocean water that drives them and by creating a physical barrier to the floodwaters that they generate.

Johnstown is not the only example of flooding in the U.S. caused by a dam failure. There are numerous other examples, large and small, of similar failures. Two of them are described in one of these two volumes, Buffalo Creek and Teton, each quite different from the other. The dam failure

Figure 22 The Johnstown flood and "A slightly damaged house."

in Buffalo Creek was very similar to that in Johnstown—it was the failure of a dam in a community that, like Johnstown, was dominated by a single company, a coal-mining company in Buffalo Creek. As so often happens when a single owner has complete control of the economic life of a community, there is a temptation to minimize safety precautions and maximize profits. In the case of Johnstown various officials provided ample warning that the dam posed a great risk to the whole community and external, objective advice was needed to assess that risk. In spite of these recommendations the Cambria Iron Company decided to assess the risk, concluding that the dam was safe. No one seemed to be able to insist on a second opinion. The Teton Dam was quite a different story. It was a public corporation set up to access the water supplies of a region to provide both flood control and, at the same time, supply water for irrigation. The disaster that occurred was caused by technical errors on the part of the geological engineers who designed the dam.

Once the dam collapsed and the wall of water and debris started moving down the valley toward Johnstown there was little that anyone could do to save lives. The only communications possible were shouts of warning. Within twenty minutes of the dam's collapse it was all over. Men, women, and children had been carried along to their deaths in a tornado of water and debris, frantically shrieking for help. The speed of the flow of water and materials made it impossible to rescue anyone and the aftermath was painful in every way. Recriminations soon appeared. Why was the water level in the dam allowed to rise so high? Even as late as May 30, action could have been taken to release large quantities of water from the dam. The most urgent task was the burial of bodies, large numbers of them unknown by name or association. A mass funeral and mass burial was arranged but there were no pallbearers. Ox teams and carts, each cart carrying six burial boxes, brought the bodies to a mass grave. There were memories of the final day recounted many times, stories of heroes and of villains as is always the case in such situations.

In the offices of the Cambria Iron Company, south of Johnstown, an assistant cashier noticed that the water had reached as far as the second floor where he was and where the money for the workers was kept in a safe. The dam had not yet collapsed but the numerous leaks had already turned the river into a torrent that was steadily rising higher and higher. The cashier took the money from the safe—it was in packages of bills, altogether amounting to 12,000 dollars—and climbed to the next floor and within a short time went on to the roof, the only place that was still above water. Moments later the entire office building disintegrated and he jumped on to a house that was floating past. This temporary spot carried him downstream and, fortunately, the house got stuck for a time against a bank. He managed to clamber his way on to land and then found his way into the woods where he hid for the night in order to safeguard the money. There were other memories too from the days immediately following the tragedy. Memories that people would like to forget but cannot. Some young men came from Pittsburgh, fifty miles away, to observe the scene, found some barrels of whisky and in a state of intoxication began to rifle the dead bodies. Rings, clothing, jewelery, and anything else that might have value were stolen.

The telegraph line was the only form of communication with other places at this time, so the telegraph operator was always a vital part of efforts at saving people. Some telegraph lines had been swept away by the flood and later partly reconnected by volunteers who strung wires across trees wherever they could. As had happened elsewhere in similar situations, the importance of the telegraph connection was so important that operators often stood there until it was too late to escape. That was the story of the lady who had been telegraph operator for the Western Union Telegraph Office. She sent messages to every place that might be affected but waited too long to save her own life. In the days and weeks that followed, aid money and help of all kinds poured in from governments, businesses, and people in all walks of life. President Benjamin Harrison, who had been sworn in as president in the same year as the flood, convened a meeting of eminent citizens to plan relief. He also sent a gift of money as a personal contribution to the community.

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37

Louisville, Kentucky, tornado

March 27, 1890
The downtown area of Louisville, Kentucky

A tornado of strength 4 struck Louisville, Kentucky, killing seventy-six. The tornado's path was wider than Louisville had ever experienced. Most of the city was devastated

A tornado of strength 4 swept through the downtown section of Louisville, Kentucky, on the evening of March 27, 1890. Its path was wider than the city had ever previously experienced and because of the violence of the damage inflicted there was some doubt about categorizing it as a strength 4 storm. In all likelihood it was the main part of series of storms that arrived almost simultaneously. It gained the name of the Louisville Cyclone. All through the day air pressure kept falling but news that the tornado was imminent did not reach the city in enough time for people to take shelter. The impact on Louisville lasted only five minutes but in that time most of the city was devastated. Seventy-six people lost their lives.

Dozens of residences, businesses, large stone warehouses, the railroad station, and several churches were among the places destroyed in these five minutes. One of the most tragic sites of the storm's violence was the Falls City Hall, on West Market Street, where a local chapter of the Knights and Ladies of Honor were meeting when the storm hit. Located in the same building on the lower floor were fifty-five children and their mothers who were taking dancing lessons. The building collapsed, burying about two hundred people, forty-four of whom died. This was one of America's greatest loses to a tornado in one building. The first sign of danger was the rocking of the building. Shortly after, a window was blown from its casings and plaster began to drop from the ceiling. The floors gave way and all fell to the basement level with parts of walls and debris on top of them.

The Union depot railroad station on Seventh Street completely col-

Figure 23 Stereoscopic image of the destruction of the 1890 Louisville, Kentucky tornado.

lapsed. Some heard the large building crack. The wind struck from the south and lifted the roof from the structure, throwing it several feet away. It was estimated that some fifty people were in the station when the cyclone struck. Many were trapped and seriously injured, but fortunately no one died. A special concern was the destruction of the Waterworks stand tower, which could have resulted in cutting off the water supply to the whole city. The standpipe through which all water was forced into the reservoir was demolished; there was only enough water available to last six days. There was fear of a water famine. Special notices appeared in the newspapers for water consumers to limit their use of water to cooking and drinking.

The newspapers were full of notices for relief efforts and aid for the cyclone victims. It became a national, as well as, an international interest. Telegrams came from all over the world offering to help with whatever aid was needed. At the same time, familiar problems common to disasters worldwide surfaced; namely the activities of thieves seeking to take advantage of the disorder. The mayor and chief of police ordered the Louisville Legion to patrol the affected streets, to control the crowds and to warn looters that they would be shot on site, not arrested. The path that the tornado had taken from the south, at times on the Indiana side of the Ohio River where it caused three deaths and $150,000 worth of damage, at other times and finally on the southwest part of Louisville, was almost identical to the route taken by another tornado that hit the city in 1852.

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38

Japan earthquake

October 28, 1891
The epicenter was in Nobi, the provincial capital of that region

The Nobi Region north of Nagoya, Japan, was hit with an earthquake of magnitude 8. The earthquake was felt all over the island of Honshu as many buildings came down and 7,000 lost their lives

On October 28, 1891, The Nobi region of Japan, a rich agricultural area north of Nagoya, experienced an earthquake of magnitude 8. It rocked the main island of Honshu all the way from Tokyo to Osaka. Iron bridges and brick walls of buildings came tumbling down, about 7,000 people lost their lives, tens of thousands were injured, and 100,000 became homeless. Most of the destruction was in the smaller towns and agricultural hamlets. Gifu, the provincial capital of Nobi, and Ogaki, both large towns, were completely destroyed. They were very close to the epicenter. Extensive fires broke out in the city of Nagoya because pipelines and communications had been broken.

Earthquakes are familiar to the people of Japan. School drills in preparation for the next one are a regular feature of life as are also the positive, creative responses of people in all walks of life to an earthquake. Nevertheless, there are times when one arrives at critical moments in the nation's history. Old-standing attitudes appear at such times and the earthquake is explained in terms of political events or the choices made by leaders. In 1891, Japan, like the rest of the world, knew little about how earthquakes happen. It was prior to the 1991 event that Japan had come through two revolutionary changes: the Meiji Restoration, the restoring of imperial rule and moving the capital from Kyoto to Tokyo and, secondly, the establishment of new strong ties with the Western World. There was a determination to make use of the expertise of countries like the United States and Britain in order to create a modern economy and society. Students were sent to Europe and the United States to study modern science and technology, while foreign experts were hired to help in the design of factories and educational institutions. Many Japanese suggested that the quake was punishment for bad choices like these.

These thoughts about the cause of the 1891 event became evident as the details of damages were publicized. For example, news of what happened in Osaka, Nagoya, and Kobe was known before anyone was aware of the damage to rural areas. In these big cities many buildings were constructed of brick. Two large textile mills, built of brick, had collapsed in Nagoya and Osaka and the supports of a western-style steel railway bridge had given way. One newspaper focused on these details, adding that although Osaka had been severely shaken almost all of its Japanese-style houses survived. The editor concluded that it was because of their wood construction that the Japanese houses had survived. Conversely, other buildings had collapsed because they were made of brick. The newspaper went on to affirm that all the foreign-built factories were more or less destroyed. When the reports from the rural areas came in it was clear that tens of thousands of Japanese wooden homes had collapsed and burned. However, by that time, a picture had emerged of a failed, foreign, type of building, a view that persisted as Japan sought to come to terms with its new relationships with foreigners.

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39

Imperial Valley, California, earthquake

February 23, 1892

Uncertainty persisted over the exact location of the epicenter as this area had few residents in 1892

An area close to the California–Mexico border experienced an earthquake of magnitude 7.8. Damage was caused in San Diego County and as far south as San Quentin in Baya, California

On February 23, 1892 an earthquake of magnitude 7.8 struck an area close to the California–Mexico border. The destructive power of this earthquake demolished all adobe buildings in San Diego County and did comparable damage 250 miles east of San Diego, in Arizona. South of the California border, along the Pacific Coast, major damage was reported as far south as San Quentin, Baja California, 180 miles south of the border. Aftershocks were felt all along the coast northwards to Santa Barbara and there was one report of aftershocks in Visalia, five hundred miles north of the Imperial Valley. In Ensenada, fifty miles south of the border, in Baja California, local residents declared that they had never in living memory experienced an earthquake of this strength. There were numerous aftershocks with one weather station having recorded 155 of shocks within a twenty-four hour period. Large parts of the total area affected was unoccupied by people who might have provided detailed information about the earthquake, as a result we do not have a clear indication of the epicenter's location.

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40

Georgia/South Carolina hurricane

August 1893
The hurricane made landfall at Savannah, Georgia

A hurricane of strength 3 struck South Carolina and Georgia in 1893 killing 1,500, making it the deadliest U.S. storm prior to 1900

A category 3 hurricane, known as the "Sea Islands Hurricane," made landfall in South Carolina in August of 1893 killing 1,500 people in Georgia and South Carolina, making it the deadliest U.S. storm prior to 1900. This hurricane was born as a tropical storm in the Cape Verde Islands and became a hurricane a week later. After a second week of travel, the hurricane reached South Carolina late in August. It gained its name because of the extensive damage it caused in the Sea Islands. Many of the people on these islands decided to leave before the storm actually hit, so the death toll there was minimal. The storm gradually turned toward the north, running parallel with the coast for about one hundred miles. Landfall occurred north of Savannah, Georgia, and from there it moved up the U.S. coast until it dissipated in the colder waters of the North Atlantic.

A heavy storm surge, at times as high as sixteen feet, accompanied the hurricane during its passage along the coast and at landfall. Destruction was widespread, homes everywhere having been destroyed. About 30,000 residents were homeless as a result. The tragedy was worsened by a delay in the arrival of the American Red Cross. The Red Cross had been fully occupied with the destruction caused by an earlier hurricane and was unable to reach Savannah until early in October. Even after its arrival, further delays occurred as some staff were called away to assist with damage from yet another storm. On the Atlantic Coast, in terms of number of hurricanes, the decade of the 1990s was one of the busiest ever. Not until the 1950s was there a comparable rate of hurricanes.

Hurricanes in the Southeast United States have always come in cycles rather than in trends toward more frequent or stronger storms. The period of the 1850s to the mid 1860s was quiet, the late 1860s through the 1890s were busy, and the first decade of the 1900s was quiet. There were five hurricane seasons with at least ten hurricanes per year in the active period of the late 1860s–1890s and none in the quiet periods. Earlier work had linked these cycles of busy and quiet hurricane periods in the twentieth century to natural changes in Atlantic Ocean temperatures. Advocates of the dangers of global warming continue to support this point of view; they feel that the devastation of New Orleans in 2005 supports their position. It is not a view that is held by all experts at the U.S. Hurricane Center and some from that center point out that the tragedy of New Orleans was due to faulty levees not temperature.

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41

Louisiana hurricane

October 2, 1893
Beginning with areas southeast of New Orleans
this storm moved to the northeast over Alabama

A hurricane of strength 4 struck the area southeast of present-day New Orleans. This hurricane left behind a trail of enormous destruction, including the death of at least 2,000

On the morning of October 2, 1893, Hurricane Chenier Caminanda, with winds peaking at a speed of 135 mph, struck the area southeast of present-day New Orleans. The hurricane then curved eastward across southeast Louisiana and turned northward over Alabama. Leaving behind a trail of destruction and caused the death of 2,000. This became the second deadliest hurricane in U.S. history prior to Hurricane Katrina in 2005. Indeed, the 1893 hurricane began in the Caribbean five days before hitting land and followed a route that became familiar at the time of Katrina, first moving to the northwest and striking the Yucatan Peninsula before moving into the warmer waters of the Gulf where it gathered enough strength to become a category 4 hurricane as it reached New Orleans.

It is difficult to be precise about the causes of death during the 1893 hurricane. Throughout almost the entire nineteenth century, New Orleans suffered from yellow fever with occasional outbursts of epidemics that killed large numbers of people. The question arises whether Chenier Caminanda's destruction caused additional deaths besides those that would already have occurred from yellow fever. Overall, more than 41,000 people died in the city from yellow fever between 1817 and 1905. The number of fatalities ranged from zero, in the few years in which the plague caused no casualties, to more than a thousand in nine of the eighty-eight years during which the fever was active. The cause of the yellow fever outbreaks was quite readily identified as inadequate disposal of human waste. A city that is about at the same elevation as the sea needs a special system to dispose of the contents of home privies and, for most of the century, no plan proved to be effective. Only during the Civil War, in order to protect the soldiers, and then only for a period of three years, was waste disposal efficiently handled.

Following a serious epidemic in 1853, a city ordinance was enacted by which every home had to empty its privy when its contents reached a level of one foot below the land surface. The homeowner was required to deposit the contents into the river or the sea and, if he failed, public authorities were required to ensure that it was done. For various reasons the plan never worked. An observation by the local medical officer describes the failure in simple but tragic language. He stated that the people have a huge privy in common and the inhabitants of New Orleans live upon a dung heap. A yellow fever epidemic struck the city in 1878, much worse than that which struck in 1853. The disease started in New Orleans in July and took nearly four months to run its course through the Mississippi Valley. When it was over, the nation reported more than 100,000 cases of fever and a toll of 20,000 deaths. Particularly hard hit was New Orleans where 5,000 lost their lives.

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42

St. Louis, Missouri, tornado

May 27, 1896
In and near St. Louis

A series of tornadoes struck St. Louis and east St. Louis. Two of the tornadoes, both F4 in strength, impacted St. Louis and East St. Louis

At 6:30 P.M., May 27, 1896, two F4 tornadoes touched down near and on St. Louis, Missouri, almost simultaneously. One passed over the city and moved in a southeasterly direction, leveling entire farms in such communities as Richview and Irvington sixty miles east of St. Louis. The other, a much more powerful tornado, was the third deadliest tornado in U.S. history, responsible for the deaths of 255 people on both sides of the river before it finally petered out in East St. Louis, Illinois. People died in homes, factories, saloons, hospitals, mills, railroad yards, and churches, as the half-mile-wide swath of this killer tornado cut its way across the center of St. Louis. At least 137 people died and 300 were seriously injured. People living on shanty boats may have perished in the Mississippi River, but were not counted because their bodies were washed downstream. In east St. Louis, the swath of the tornado narrowed and, as so often happens in such circumstances, the funnel's speed and power increased. Devastation was complete and 118 people died. Two million dollars worth of damage had been done in east St. Louis.

The tornadoes did not carry away the majority of roofs and trees in most areas. Instead, tress and roofs were thrown to the ground while homes were swept away in other areas. Lafayette Park became a wasteland of stripped trees and stumps. One record of barometric pressure was retained.

Figure 24 Anchor Hall, Jefferson and Park Avenues. In: "Photographic Views of the Great Cyclone at St. Louis, May 27, 1896."

It stood at 26.74 inches, a rare level of low pressure and a clear definition of the power of the tornado. A bridge across the Mississippi that had been built as tornado proof in the aftermath of earlier tornadoes was covered with iron plate, with a thickness of five-sixteenth of an inch. The tornado pierced the bridge with a two by ten inch white pine plank. The plank did not weaken the strength of the bridge but it illustrated the ability of a powerful tornado to generate missiles. On every side lay the bodies of dead horses, overturned heavy freight cars that had been lifted from their tracks in their entirety and hurled yards away, frequently plunging down embankments and landing upside down.

By the water's edge are the battered steamboats, thrown high and dry upon the shore. Many steamboats went to the bottom of the river. One agency estimated the property loss at $50,000,000. This loss is as complete and thorough as though its equivalent in money had been thrown into the ocean, for there was so little tornado insurance carried in the city that its total barely covered a small fraction of the losses. A fund of $15,000 for the immediate relief of the homeless was quickly raised on the floor of the Merchant's Exchange and this sum could have been increased to $100,000 if necessary. Congressman Joy introduced a resolution in Congress, arranging for the use of army tents for those who were homeless.

Figure 25 Broadway and Soulard Streets. In: "Photographic Views of the Great Cyclone at St. Louis, May 27, 1896."

President Cleveland promised to sign the resolution. Conditions in east St. Louis were worse than in St. Louis because of the greater power of the tornado as it reached that place.

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43

Sanriku, Japan, earthquake and tsunami

June 15, 1896
The earthquake occurred offshore from the northeast coast of Honshu Island, in the prefecture of Iwate. The epicenter was ninety miles from shore

This disaster included a powerful earthquake of magnitude 8.5, followed by a massive tsunami. It struck the northeast coast of Japan. There was little awareness of the earthquake because of its distance from shore and because of its character, but the tsunami that ensued was massive and did overwhelming damage on shore and killed 26,000 people

On June 15, 1896, an earthquake of magnitude 8.5 struck the Sanriku coast on the northeast of Honshu, Japan, in the Iwate Prefecture. Its epicenter was ninety miles offshore, near an area of very deep water known as the Japan Trench. The impact on shore was much weaker than would normally be expected from such a powerful earthquake so there was little expectation of a tsunami, even though this part of the Japanese coast experiences earthquakes frequently. Thirty-five minutes after the earthquake, the most devastating tsunami in Japan's history reached the shore at the same time as high tide. The first wave receded back out to sea and returned in a second wave five minutes later. At times the tsunami's wave reached a height of 125 feet. Everything in its path was totally devastated. Twenty-six thousand people were killed and nine thousand homes destroyed. Its epicenter on a reverse fault near the Japan Trench was the reason for the mild impact felt on shore. The earthquake lasted for five minutes and was accompanied by a slow shaking.

Many villagers were at the beach celebrating two events when the earthquake occurred: the return of soldiers from a successful war with China, the first Sino-Japanese War of 1894, and the annual Boys' Festival. Villagers observed minor shocks in the earlier part of the day, many hours before the earthquake. There were also reports of unusual phenomenon on that same day—low water levels in wells and large numbers of tunas every day. The violence of the tsunami was yet another unusual feature of the day. Usually victims in tsunami disasters die by drowning but, in the Sanriku tsunami, there was extensive damage to the bodies of victims; fractured skulls, bodies heavily scarred, and legs and arms broken. The impact of this tsunami carried across the Pacific. In Hawaii, wharves were demolished and several houses swept away. In California a 9.5 foot-high wave arrived. Unfortunately, in spite of the long history of tsunamis on this coast, very little beyond immediate humanitarian assistance was done by public authorities.

On June 16, the day following the tsunami disaster, a telegram reporting the disaster reached the Interior Ministry. After reporting to the Meiji emperor, the minister of the Interior Ministry contacted all ministries to deliver relief and rescue for the tsunami victims. The emperor delegated one person to visit the disaster site and cheer up the survivors with encouraging words. The governmental agencies dispatched inspectors and the army sent medical specialists. The military authorities also sent soldiers to secure public order, military engineers to recover bodies from the rubble, and the navy to search the water for bodies of the victims. The Japanese Red Cross Society and the Nurse Association sent doctors and nurses to treat the injured. However, it took a further thirty years before action was taken on detailed preventive measures.

In 1937, another very strong tsunami hit the coast of Sanriku. This time the local authorities were better prepared for it. They had installed tidal embankments, trees, and escape roads. They also prepared a booklet on precautions for preventing a disaster. This booklet included a warning about weak earthquake shocks, the kind of event that was so much misunderstood in 1896. At the same time it pointed out that a loud noise like thunder might indicate an approaching tsunami. Other things listed in the booklet included avoiding the recession of the tsunami's first wave and being prepared to evacuate the coast quickly and move to higher ground.

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44

Assam, India, earthquake

June 12, 1897
The area we now know as Bangladesh
experienced the main force of the quake

A violent earthquake of magnitude 8.7 struck northeast India in 1897. Destruction was massive all over northeast India and 6,000 people lost their lives

The Assam earthquake of June 12, 1897 was a violent 8.7 in magnitude and reduced to rubble all buildings within an area equal in size to several New England states. Reports from north, south, and west of India all told of the earthquake having been felt in these places. Dacca, south of Assam, and now the capital of Bangladesh, experienced the largest number of deaths. In all, 6,000 people lost their lives and fifty miles of railway track were completely destroyed. In Darjeeling in the far northwest of Assam, the tea industry was destroyed, including both buildings and crops. The eastern Bengal railway line was closed down due to several bridges having collapsed. The weather added additional hardship. Temperatures were 120 degrees in the shade and rain was heavy as the monsoon was just beginning. Cherrapunji, the world's wettest place, is in Assam. It has an average of 450 inches of rain every year and in some years it is much more.

A lady living in a tea garden in Assam wrote to her friends in Britain a day after the disaster. The letter arrived several weeks later and gives a good picture of the devastation caused by the quake and also of the limited resources available at that time for coping with disasters. This lady was sitting in bed when the earthquake struck. She had been ill and was quite unable to get out of her house. The thunderous noise of the quake from below coupled with a general shaking of everything made her crawl toward the door where her native servant met her to take her free of falling objects. In her letter she told of the impossibility of standing. Her servant somehow managed to get her away from the building before it, along with everything else around, collapsed. The earthquake was described as the worst she had ever experienced or even heard about. It was raining hard as the monsoon rains had just arrived and those buildings that were still standing were swaying backwards and forwards like a ship in a bad storm. The ground too was moving in waves like those of the sea. All communications with other places had been severed; that is, there was no telegraphic link, the only direct method of communication available in 1897, so this person had no knowledge of conditions in other places. Her concluding observations included masses of debris everywhere, deep holes in roads, and an ongoing series of earth tremors, aftershocks, which lasted for the rest of the day.

Assam is a plateau, often referred to as the Shillong Plateau, Shillong being the capital city for the region. It is set in the midst of a mountainous area where elevations range from sea level to that of Mount Everest, but the Shillong Plateau is less than five hundred feet above sea level. It is well watered by the monsoon rains and its soils are rich, the gift of the Brahmaputra River, India's biggest in the eastern part of the country. The plateau rises in the Himalayas and flows through Assam at a point where it is still a thousand miles from the sea. Assam, or the Shillong Plateau, lies between several countries—China on its north, Nepal on its west, Myanmar on its east, and Bangladesh on its south. It is no surprise that Britain, as the colonial ruler of the time, was particularly interested in this part of India. Its low elevation, warm climate, and good soils made it an ideal agricultural region, able to produce large quantities of rice, the staple food of the native people and the product whose surplus could be sold to secure a profit for Britain. Tea plantations were developed there to meet the British demand for this drink and Darjeeling, in the northwest of Assam, became for a time the tea capital of the world.

The British colonial authorities were totally unprepared for a major disaster. This was evident over a hundred years earlier at the time of the Bengal famine. Furthermore, colonial powers were mainly and sometimes only concerned with how to make a profit for the home country not the welfare of their colonial subjects. It seems that by 1897 they had learned a few lessons about the importance of native rights because their behavior was in sharp contrast to their former actions. There were no public medical services, no disaster preparations, and no established social services such as food banks and emergency shelters for coping with emergencies. Anything that might help the native people who had lost their homes and were sleeping outside in the midst of the rainy season had to come from the generosity of the colonial governor. He decided to open all the government buildings that remained standing and allow the homeless to take shelter in them. At the same time he decided to donate the money planned for the Queen's celebrations to help those in need of food. A celebration in honor of the Queen's diamond jubilee had been planned for some time. This particular jubilee year, 1897, was the sixtieth anniversary of Queen Victoria's accession to the throne so it was an important occasion to recognize. Queen Victoria must have heard of these decisions because she sent a message of sympathy regarding the earthquake and congratulations on the action taken to help the natives.

It took many years of research and consultation to establish the cause of the 1897 earthquake. Nothing on this scale had ever been experienced anywhere in India. It was more than a century later that researchers from the universities of Colorado and Oxford finally arrived at certainty over the nature of the forces at work. They concluded that for the past five million years the Indian Tectonic Plate was restricted in its advance within Assam as it pushed against the Himalayas. As a result, there was a build up of pressure against the Shillong Plateau and it was the release of this pressure that caused the earthquake. Two adjacent faults, both of them about seventy miles long and located ten miles underground, slipped and triggered the earthquake. The slope of these faults was downward toward the south away from the Himalayas and they moved by as much as forty-five feet, one of the largest slips ever calculated for any earthquake anywhere. The extreme violence of the quake forced the overlying Shillong Plateau to shoot upwards by as much as fifty feet in a matter of a few seconds. Boulders, tombstones, and anything else on the surface, even people, were thrown into the air. Fortunately, an earthquake as powerful as this one only occurs once in 3,000 years.

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45

Eureka, California, earthquake

April 16, 1899
Coastal area around Eureka, California.

This earthquake had a magnitude of 7 and, while extensive damage was done, there was no loss of life because few people lived here in 1899

On April 16, 1899, a magnitude 7 earthquake struck a coastal area north and south of Eureka, California. It was one of the severest ever experienced in this part of the country. In spite of the unusually long duration of the main shock–fifteen seconds–only a lumber mill in Eureka suffered damage. The reason for the low mortality was simply that few people, other than the native population, were living here at the time. Shocks were experienced along a two hundred mile coastal stretch from Crescent City, near the Oregon border, to Albion in the south.

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46

New Richmond, Wisconsin, tornado

June 12, 1899
New Richmond, Wisconsin

An F5 tornado struck New Richmond, Wisconsin. As the tornado traveled toward New Richmond it destroyed many farms, killing in all 117 and injuring 200 others

On June 12, 1899, the New Richmond tornado of F5 level strength originated as a waterspout on Lake St. Croix, about twenty-five miles northeast of New Richmond, Wisconsin. As it became a tornado and moved southwest toward New Richmond it leveled farms on its way and killed three people in them. The tornado entered New Richmond about 4:30 P.M., shortly after a crowd of 1,000 had dispersed. The crowd had come in from surrounding areas to watch a circus that was there for the day. New Richmond had virtually all of its buildings either totally destroyed or seriously damaged as the tornado passed through the center of the community. A total of 117 people lost their lives and more than 200 were injured. The damage was estimated at $300,000. The death toll might well have been much higher had visibility been poor, as it was, the funnel cloud could be seen at a considerable distance and many were able to get to safe shelters.

The massive amount of flying debris resulted in multiple deaths in twenty-six families. Each of six families lost four of their members. The main reason for these unexpected multiple deaths was the presence of the Gollmar Brothers Circus and the large numbers of whole families that had come into New Richmond for the occasion. Schools had closed down at the end of the previous week so children were free to join the rest of their

Figure 26 A cropped view of a panoramic photograph taken after the New Richmond, Wisconsin, cyclone of June 12, 1899.

family. A 3,000 pound safe was picked up and carried for a distance equal to the length of one block. Trees and timber were thrown high into the air. The community's electrical plant and water facilities were destroyed, so fires were out of control. Many bodies found in the aftermath were burnt beyond recognition. It was impossible to tell if they had died from the tornado or from being trapped and burned alive. The damage wrought by the tornado was so complete that the town had to be rebuilt.

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47

Yakutat, Alaska, earthquake

September 10, 1899
Yakut region of Alaska

A series of earthquakes, all of them of magnitude 7 or more, struck the Yakut region of Alaska. The main quake had a magnitude of 8 and struck on September 10, 1899. The whole coastal area of Alaska north and south of Yakutat Bay was shaken for a distance of six hundred miles

During the month of September 1899 the region of Yakutat Bay was shaken by a series of very severe earthquakes, all of them of magnitude 7 or more. Fortunately, the number of people living in this region was very small and no one was killed. All of these events profoundly changed the topography of the area, raising the elevation of the land in places by as much as forty-seven feet, the greatest amount of displacement by an earthquake ever known in historic times. The most powerful earthquake of the series was the magnitude 8 quake that struck on the tenth of September. This earthquake was experienced as a strong shaking from Fairbanks all the way to Sitka, a distance of more than six hundred miles. The geologists who visited the area five years later found dead barnacles and other shellfish everywhere. They saw several uplifted beaches and areas of subsidence as deep as six feet. The tenth of September earthquake lasted ninety minutes and was followed by many aftershocks.

The whole southern coast of Alaska, including the Aleutian chain of islands that stretch westward as far as the International Date Line, is a 1,500-mile-long chain of volcanic activity constituting the volcanic capital of America. There are more active volcanoes or earthquakes here than in all the other United States combined, an average of one event occurs every year. The Aleutian Islands, many of them standing high above sea level, together with the mountains of the main part of Alaska, are all outcomes of millions of years of volcanic eruptions and earthquakes. The Pacific Tectonic Plate is constantly pressing against and sliding beneath the North American Plate. The contact area between these two massive plates is curved and this condition gave rise to subsidiary movements around faults, or cracks in the seabed, that force the main plates to slide past each other rather than collide. Often the sliding past type of action can be more destructive than a head-on collision. Two of these subsidiary faults, the Queen Charlotte and the Transition, especially the Transition, are the ones most involved in the earthquake of the tenth of September 1899. Their actions in causing earthquakes are not yet fully understood but it is clear from what happened that they are very important.

Yakutat Bay is a deep indentation in an otherwise unbroken concave stretch of coastline between Cross Sound and Controller Bay. Eastward of this coastline are the St. Elias and Fairweather ranges—St. Elias with heights of 18,000 and 19,500 feet respectively in Mount St. Elias and Mount Logan. These mountains do not rise directly from the sea, but are faced by a low foreland, or coastal plain, made up of glacial debris. The northwest side of Yakutat Bay is still occupied by the ice plateau of the Malaspina Glacier. On its west side, the bay is bordered by a foreland of glacial gravels which are still being deposited by streams issuing from the Malaspina and other glaciers. The changes that the earthquake effected in the glaciers included a rapid retreat of Muir Glacier, 150 miles to the southeast, and a general advance of several other glaciers near Yakutat Bay. Muir Glacier, which hundreds of travelers had visited annually up to 1899, became inaccessible to tourist vessels in that year and remained so until 1907. By 1903 the glacier had retreated by as much as three miles and, by 1907, almost eight miles. Before examining further the details of the earthquake of September 10, 1899, a short account of Alaska's earthquake history will help to set the stage.

Early reports of earthquakes in Alaska were fragmentary. The first event in this incomplete record occurred in July 1788 when a tsunami inundated the islands of Sanak and Unga and a part of the Alaska Peninsula. Overall, the record of earthquakes identifies two areas as having experienced most of the state's seismic activity—one area is the Aleutian Island Chain and the other is the coastal and inland region north and south of Yakutat Bay. From 1899 to 1969, eight earthquakes of magnitude 8 or more on the Richter Scale occurred in Alaska. Four of these caused extensive property damage and topographic changes; the other four were centered in areas with no nearby towns, and, except for being recorded by seismographs, went relatively unnoticed. The Alaskan earthquake that is outstanding in the memory of most is the Anchorage quake of 1964. It had a magnitude of more than 9 and it will be described in detail later in this book. In October of 1900 a magnitude 7.9 earthquake was felt from Yakutat Bay to Kodiak, and probably even farther westward. On Kodiak

Island chimneys were downed, and a man was thrown from his bed. The shock was probably centered in southeastern Alaska. Property damage was very moderate for such a great shock because of the low population densities in the affected areas

Andreanof Island sustained an earthquake of magnitude 8.8 in 1957 which caused very severe damage on Adak and Unimak Islands. This earthquake initiated a tsunami and its forty-foot wall of water smashed the coastline of Unimak Island. On Adak Island two bridges were destroyed and considerable damage was done to roads and docks. The tsunami caused millions of dollars of damage in Japan and Hawaii, both parts of the world that have suffered damage from Alaskan tsunamis from time to time. During the period 1899 to 1969, eight great earthquakes of magnitudes 7–7.9 occurred in Alaska. Thirteen earthquakes occurred in or near populated regions and caused minor to severe damage. On July 22, 1937, a magnitude 7.3 earthquake occurred in central Alaska, about twenty-five miles southeast of Fairbanks. It was felt over most of Alaska's interior, over an area of 300,000 square miles. About ten years later, on October 15, 1947, a magnitude 7.3 shock occurred in the same region. It was preceded by a swarm of shocks, some very minute, others violent. On April 7, 1958, a magnitude 7.3 earthquake hit central Alaska. Within a 40–50 miles radius of Huslia, cracks in lake and river ice, and many ground cracks and mudflows, were observed. The strongest shock since those of September 1899 at Yakutat hit southeastern Alaska on July 9, 1958. It was rated magnitude 7.9 on the Richter Scale.

The U.S. team of geologists who visited Yakutat Bay in 1905 came upon clear evidence of recent uplift in barnacles attached to ledges high above the reach of the present tide. They conducted detailed observations along the affected shoreline until practically every foot of its 150 miles had been examined, and evidences documented of uplift, depression, faulting, avalanches, earthquake waves, and changes in the locations of glaciers. Local native fishermen and prospectors provided detailed accounts of what had happened when the earthquake struck. For example, eight men were in the fiord portion of the Yakutat Bay inlet on the tenth of September. They had camped on the east side of the moraine-covered margin of Hubbard Glacier. They were prospectors, washing the gravels they had collected in hope of finding gold. Alaska and Yukon Territory in Canada had been the center of gold rushes a few years earlier and the findings from that time were still inspiring new seekers of gold. These men lost everything they possessed when the earthquake struck and they almost lost their lives too. For the team of geologists they provided good descriptions, as much as they could remember in the context of a terrifying experience.

As nearly as can be made out from the prospectors' descriptions, their camps were on the moraines and alluvial fans. Three men were on one side of a glacial stream and the others were on the opposite side. As is common in major earthquakes or volcanic eruptions, there are minor tremors that precede the main event. The men decided to rig up a simple device that would indicate the strengths of these tremors. In 1899 very little was known about the forces that cause earthquakes and there were no instruments suitable for measuring their strengths. All the men could do was improvise. They hung up two hunting knives in such a way that their points were touching. Any earth tremor would cause a jingle between the knives and the strength of the sound would give them some idea of the power of the tremor. These men were well acquainted with earthquakes from their experiences in Alaska and they hoped to be able to detect danger moments among the tremors and so get away to a safe place before the main quake struck. They counted fifty-two tremors in all before the big quake struck but it was difficult to identify increasing strengths in them. Their plan was a clever one; unfortunately, it failed to give them the kind of advance warning they needed.

One man was about six miles from the spot where the shore was lifted up forty-seven feet and two miles away from another spot where the shore had been uplifted seven feet. It was impossible for anyone to stand unaided as everything around was moving. Even the ground cover of alder bushes kept shaking and bending over as if they were under the influence of a strong wind. All of the enormous uplifts of shore areas began to take place early, around nine, and this was followed by a succession of further shocks that ended with the biggest shock of the day around two in the afternoon. At that time the men were sitting in their tent. As they tried to get out one of them was physically thrown over the camp stove and across the length of the tent. The other men took hold of the tent pole and held on to it for the duration of the quake. The ground below was moving like waves in the sea for the minutes it took for the earthquake to subside. Immediately, a pause occurred in the total amount of movement all around, the men then ran outside, leaving everything. They never recovered any of their possessions. As they watched they saw the Hubbard Glacier, one that measured five miles in diameter, slide out half a mile into Yakutat Bay. At the same time a lake of two acres in size and thirty feet in depth that had stood above the men broke away from its site and crashed down on the place where their camp had stood. The men were already away from the area by this time.

They had started running away from their camp as soon as there was a slight pause in the violent ground shaking. They felt that the safest place was the lowest elevation and so they had made for the shore. The collapse of the lake brought water, rocks, and debris down the mountainside but, within a short time, a tidal wave, triggered by the uplift of land, brought a wall of water twenty feet high on to the high ground, sweeping the debris from the lake back up on to the moraines. The men heard the sound of this ocean wave but by that time they had found a place of safety and they stayed there. Notching the fiord walls at various levels was a series of sea cliffs, which the waves had cut in the headlands and which, with their associated rock benches, were hoisted above sea level during the faulting.

The benches are broadest and the cliffs highest where the weaker rocks outcrop on exposed points and they are narrowest and the cliffs lowest where the more resistant strata occur. These elevated benches are not remnants of glacial marginal channels, as is proved by the barnacles and other sea forms still attached to their ledges. All in all, they form one of the most striking, obvious, and spectacular of the physiographic evidences of uplift. The amount of land created from the sea during these changes of level far exceeded the amount submerged by the sea in places where there were depressions.

In summary, these earthquakes were most severe on two dates, September 3 and 10, especially on the tenth, when there were more than fifty small shocks and two violent ones, the second of which was extremely violent and probably caused the greater part of the changes observed in and around Yakutat Bay. There were many additional shocks. The view of the geologists who visited the area within five years of the events concluded that they had no record of any other region on earth that experienced such shaking as had occurred here. The great earthquake in the afternoon of the tenth of September was concentrated in Yakutat Bay. The shock of it, though locally sharp and of world-shaking caliber, seems to have been more restricted and was observed at fewer localities in Alaska than the earlier earthquake on the same day. The volume affected by the earth movement must be great in order to shake such a wide area. During all these seismic disturbances there was no recorded loss of life and little damage to property, simply because of the sparseness of population in the shaken area and the fact that few buildings were there. Most of the buildings were low, one-story rustic cabins built loosely of heavy logs or boards. Past experience has shown that homes of this kind are well able to withstand earthquakes as they are difficult to tear apart by shaking.

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48

Galveston, Texas, hurricane

September 8, 1900
The island on which Galveston stood

The worst natural disaster before Hurricane Katrina struck Galveston in 1900. This hurricane flooded the island where Galveston was located, destroyed buildings, and caused the loss of 8,000 lives

Galveston, Texas, was the site of the worst natural disaster ever to strike the United States up to that time. On the eighth of September 1900 a hurricane with wind speeds of more than 140 mph created a twenty-foot storm surge that covered the entire island on which Galveston stood. At least 8,000 people died, more than lost their lives in any one of the Chicago Fire, the Johnstown Flood, or the San Francisco Earthquake of 1906. Thousands of buildings were destroyed. U.S. Weather Bureau forecasters believed the storm would travel northeast and affect the mid-Atlantic coast. This was based on an assumption that when storms begin to curve in a particular direction they continue on that course. Weather forecasting in 1900 was largely amateurish. Few of today's technological tools were available. Cuban forecasters disagreed with their U.S. counterparts. They were convinced that the hurricane would continue to move to the west. Unfortunately there was little cooperation between the U.S. and Cuban forecasters and the U.S. view prevailed.

Early on the Saturday morning of the eighth, the level of the ocean continued to rise despite only partly cloudy skies. Largely because of this weather condition as well as the weakness of the warnings that came in, few residents paid much attention to the threatening storm. Forecasters at the U.S. Weather Service had seen their earlier prediction fail. The storm had not reached Florida and the East Coast, and reports were coming in from stations along the Gulf Coast showing clearly that a storm was moving westward in the Gulf. The warnings that came in from the Weather Service never used the word hurricane. There was a reason for not using this term. The Director of the U.S. Weather Service in Galveston had long been convinced that Galveston would never be seriously damaged by a tropical storm. Thus, by Saturday afternoon few people had left the city across Galveston's bridges to the mainland. By the time people became fully aware of the impending disaster it was too late to attempt an escape. Throughout the afternoon and into the early evening, as the sea level rose and wind speed increased, people sought shelter in homes and large buildings.

Galveston in 1900 was a major port, about fifty miles southeast of Houston, on the northeast end of the thirty-two-mile-long Galveston Island. Highways and ferries linked the city to other places. With a population of 42,000 and an annual growth rate of 3 percent it was the most important city of Texas, just as New Orleans was for Louisiana, and it competed with Houston to gain recognition as the state's premier port. One newspaper called it the New York of the Gulf. However, it was a city on an island where the average elevation of the land was five feet above sea level, only slightly higher than New Orleans. Furthermore, the coastal area offshore to the south of Galveston is shallow for a great distance and the water is therefore warmer than in deep water. As the hurricane neared landfall it was greatly strengthened by this warm water. Of even greater importance to the citizens of Galveston on this Saturday in the year 1900 was the fact that a storm had hit the island about sixty years earlier, totally submerging it to such a degree that ships were able to sail across it.

The twenty-foot storm surge of water that swept over the island in the evening of the eighth of September, fifteen feet above the elevation of the land, leveled everything in its path with wind, waves, and the debris it collected. Houses on the waterfront were the first to go and, as they disintegrated, their timbers became flying missiles that were lethal for anyone in their path and weapons of destruction against any structures farther inland that were still standing. Very few buildings survived this onslaught. No one thought that the hurricane would be so violent because no one had given the city any indication of its strength. All telegraph communication between the island and the mainland had been cut off by mid-afternoon. A ship at sea close to Galveston was battered by the storm and almost unable to stay afloat. It recorded a very low level of air pressure, only slightly higher than 28.47 inches, the one registered at Galveston during the storm. This ship had no means of transmitting this valuable information to shore, always an accurate indication of a storm's strength, because the techniques of wireless that had been invented in the late 1990s were not yet installed in ships.

Isaac Cline was the U.S. Weather Bureau's director in Galveston, the person who had said, nine years earlier, that it was absurd to imagine that his city would ever be seriously damaged by a storm. As the city was being destroyed he gathered his family and forty-five others around him within his house. Shortly afterward the house collapsed. Cline, his brother, and three others were among the eighteen of the fifty who survived by clinging to pieces of debris. Most of those who died had drowned or been crushed as the waves pounded the debris that had been their homes hours earlier. Many survived the storm itself, but died after being trapped for several days under the wreckage of the city. Rescuers were unable to reach them. On the mainland on the other side of Galveston Bay no news of the disaster reached the rest of the country for two days until one of the few ships that survived the storm sailed into Galveston Bay. Messages were sent to the State Governor Joseph Sayers and the U.S. President William McKinley.

The bodies were so numerous that arrangements for individual burials

Figure 27 Lucas Terrace under which fifty-one people were buried during the Galveston, Texas, hurricane of 1900.

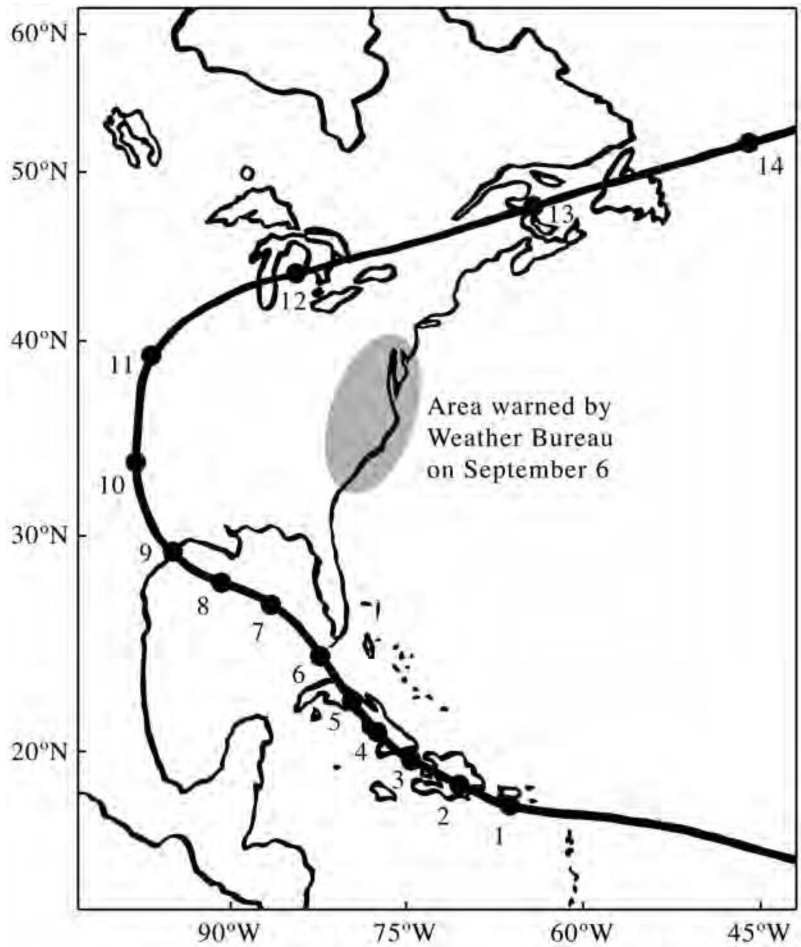

Figure 28 The path taken by the Galveston hurricane of 1900.

were impossible. Funeral pyres were set up wherever the dead were found. These pyres burned for weeks. Survivors set up temporary shelters in surplus U.S. Army tents along the shore. Others constructed lumber homes from the debris. Within four days, basic water service was restored and Western Union began providing minimal telegraph service. Within three weeks, cotton was again being shipped out of the port. Reconstruction work began almost immediately. A massive seventeen-foot seawall was built along the entire Gulf side of the city, extending along the coast for eight miles. The most extraordinary effort of reconstruction was the raising of the level of the city. Dredged sand was used to accomplish this feat, bringing the whole city to a height of seventeen feet above sea level. Many buildings, including St. Patrick's Church, were restored to their places in the city, now at the new elevation. In the year 2001, the American Society of Civil Engineers honored the reconstruction work by naming it a National Historical Civil Engineering Landmark. In 1915, a hurricane of the same strength as the hurricane of 1900 struck Galveston. It brought a twelve-foot storm surge and the new seawall was able to repel it. Two hundred and seventy-five people lost their lives in this storm.

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49

Cook Inlet, Alaska, earthquake

December 31, 1901
Cokk Inlet reaches inland 180 miles from the Gulf of Alaska to Anchorage

Earthquakes are frequent in Alaska but less frequent in magnitudes over 7. This 1901, magnitude 7.1, earthquake was related to a volcano nearby that erupted frequently. The earthquake caused widespread destruction and triggered a tsunami but, because there were so few people living in the area in 1901, there was no record of casualties

On the morning of December 31, 1901, a 7.1 magnitude earthquake shook Cook Inlet in Alaska. The quake was accompanied or followed soon after by several tsunamis, all of them created by the Augustine stratovolcano on the Island of Augustine in Cook Inlet. It, like other stratovolcanoes, has a symmetrical, cone-shaped appearance and over the past two centuries it has erupted more frequently than any other of the many volcanoes in this southern part of Alaska where most of the state's people live. It was active in 1812, 1883, 1902, 1935, 1963, 1971, 1976, and 1986. As recently as 2006, the volcano was very active again, sending plumes of smoke and ash 30,000 feet into the air. It is hard to separate the earthquakes of Cook Inlet from the volcanic eruptions on Augustine Island. Both are so frequent that it is likely that they are interrelated. Between 1899 and 1903, the period within which the 1901 occurred, there were five earthquakes in and around Cook Inlet, each one of magnitude greater than 7, a rare thing even for Alaska.

The tsunamis that Augustine produced in 1883, a well documented event, rose as high as sixty feet in inlets like the one at Port Graham, fifty miles from Augustine on the east side of Cook Inlet. Elsewhere on the inlet, at Homer and Anchor Point seventy-five miles northeast of Augustine, deposits from earlier tsunamis were later identified at elevations of twenty-four feet above sea level. A description of the 1883 event indicated that the summit was destroyed, leaving a jagged crater at the top of the mountain. The tsunamis that accompanied the eruption completely destroyed the boats that were moored at English Bay and Port Graham and they also deluged the homes that were close to the ocean. Smoke and ash flows covered the whole area. These features were repeated again and again in the eruptions of subsequent years. Cook Inlet had become famous a hundred years earlier as the site where Captain Cook attempted to claim this part of the world for Britain. In 1778 Captain Cook sent a boat ashore on what is now Turnagain Arm with one of his lieutenants who was instructed to bury an earthen bottle with a parchment inside it on which he wrote a formal ownership claim for England of all the land drained by the waters of Cook Inlet. The bottle has never been found and this may explain why Alaska became the property of Russia until it was purchased by the United States in 1866.

During this age of exploration, the latter part of the eighteenth century, it was common for captains to make a formal act of possession when they found lands that no other country had already claimed. When Cook left England in 1776 he knew the Spanish were planning another voyage to the Northwest Coast, so he made his first claim north of where he thought the Spanish might have reached. He succeeded in getting closer to places such as Cook Inlet and Prince William Sound than any other explorer of that time. The Russians had only reached the western coastal areas of Alaska. Cook met with Russian explorers and they shared charts. Quite apart from discovering new lands there was another purpose behind Britain's desire to explore the northernmost part of the Pacific Ocean. Different European nations wanted to find an ocean passage to Asia via northern Canada. Both before Cook's time and after it different explorers had tried to find such a sea passage but none of them were any more successful than Cook. We know today that theirs was an impossible task, even in summertime, with the kinds of ships they had in the eighteenth century. Now, in the light of global warming and the increasing volume of ice that is seen to be disappearing from the Arctic Ocean, it might be a very different story if people on wooden sailing ships were to try again.

Apart from the competition among Europeans to be the first to find new lands to claim, there was very little about southern Alaska in 1901 that interested either the U.S. or Europe. The contrast between 1901 and today is as great as one could find anywhere in the world. Air travel and oil have transformed life for everyone in Alaska. A brief summary of Augustine's eruption in 1976, an event that was carefully monitored simply because, by that time, major commercial and industrial enterprises were active in southern Alaska and they needed to know the extent to which they might be harmed by Augustine's eruptions. Advance warnings of impending action came in the form of swarms of earthquakes deep down within the mountain. This was followed by six major explosive eruptions. Ash was repeatedly blasted skyward to heights of 40,000 feet, then fell back to cover an area of more than 100,000 square miles. In between the explosive episodes, ash and gas avalanches swept down gullies in the mountain's sides, often at speeds of 100 mph, to end up in Cook Inlet. The internal temperatures in these flows reached 1,000 degrees Fahrenheit. The destructive effects of the ash were felt in many places. It stripped the wax from skis, irritated eyes, especially those with contact lens, and endangered turbines, forcing industries to stop and clean their machines.

In the late 1980s before Alaska's Volcano Observatory was installed, Anchorage was being used as a refueling stop for flights between the U.S. or Europe and Asian cities. The great circle route, the shortest path between two points, happens to pass through Anchorage so more and more airlines used this city as a convenient stopover. On December 15, 1989, a Boeing 747 en route from Amsterdam, carrying 231 passengers and a crew of thirteen, began its descent into Anchorage. Another 747 had followed the same descent path only twenty minutes earlier and had landed safely. The plane from Amsterdam however ran into a cloud of ash 150 miles downwind while still at an altitude of 22,000 feet. The volcano had erupted about ninety minutes earlier. As the pilot attempted to climb out of the ash, some particles that were melted by the heat of the engines began to solidify, forming a glassy coating on the turbine blades, thus restricting air intake. All four engines shut down. For the next eight minutes the plane glided steeply, losing 12,000 feet of altitude before the pilot was able to restart the engines. He managed to get the plane back to Anchorage and land it safely. All four engines and the electrical circuits had to be replaced and all the fine ash removed. Total cost of these repairs was $80 million. Shortly after this incident new efforts were launched by the installation and constant monitoring of the Alaska Volcano Observatory to make sure, as far as was humanly possible, that an event of this kind would not happen again. There are monitoring stations now all along the volcanic arc, with special additional sites close to the main airport.

When volcanoes erupt explosively, high-speed flows of pyroclastic ash and landslides can devastate areas ten or more miles away, and huge mudflows of volcanic ash and debris can inundate valleys more than fifty miles downstream. Around island volcanoes, like Augustine in Cook Inlet, pyroclastic flows and landslides can generate tsunamis that threaten nearby coastal communities. Explosive eruptions can also produce large earthquakes. In 1912, at Katmai, fourteen quakes of magnitude 6 to 7 rocked the region, and countless smaller shocks occurred. However, the greatest hazard posed by eruptions of most Alaskan volcanoes is ash. Minor amounts can create health problems, close roads and airports, disrupt utilities, and contaminate water supplies for hundreds of miles downwind. Since it is now possible, through observation of the frequency and strength of earthquakes immediately prior to an eruption, to predict to within a few hours when the eruption will occur, people will not again be taken by surprise. To cope with the difficulty of seeing the Augustine Volcano during an eruption, seismometers were installed. These instruments can sense earthquakes caused by magma and other fluids moving beneath and within the volcano. The challenge of safe air travel is one, and perhaps the easier of the two revolutionary developments that have changed the face of Alaska in the second half of the twentieth century. The other challenge is oil. The cold northern shores of Alaska do not look like a place that once was a warm tropical environment, full of rich vegetation, but that is exactly what it once was, hundreds of millions of years ago. Oil and gas are being extracted from this area and moved by pipeline to the south coast of Alaska for onward transportation by ship.

The permafrost terrain through which the oil has to be taken is a constant challenge to the engineering skills of those involved. Equally challenging is the problem of remediation when accidents occur. The Arctic environment is fragile and the low temperatures of water ensure that pollutants remain in place for long periods of time. The oil and gas reserves for the whole petroleum province, with a concentration in and around Prudhoe Bay amounting to seventy billion barrels of oil and forty trillion cubic feet of gas, is one of the largest in the United States and represents about one-fourth of the nation's production of oil. There is a continuous flow of oil tankers, day and night, transporting oil to southern places and they have to approach land through narrow channels. As they move in and out they have to contend with unexpected masses of ice released from eruptions on volcanoes like Augustine and scattered over the neighboring ocean. In 1989, the oil tanker *Exxon Valdez* ran aground on Bligh Island in Prince William Sound, spilling ten million gallons of oil. More than 5,000 kilometers of Alaska's coastline was contaminated and all kinds of marine life were decimated. While mistakes were made in the course of navigating the ship though the Sound, the initial source of the problem was the rerouting of the ship to avoid a sudden mass of ice that had covered the normal route.

In 1912, Alaska was very sparsely populated, and there were few airplanes. Now, nearly three-quarters of a million people live in the state, and aircraft carrying more than 15,000 passengers and millions of dollars in cargo pass near Alaska's more than forty historically active volcanoes each day. The heavy ash fall produced by another eruption like the one that happened at Katmai in 1912 would bring the state's economy to a standstill and kill or injure hundreds. Clinics would be overwhelmed by people with eye, throat, and lung damage. Building ventilation systems would have to be closed to outside air. Ash entering computers, bankcard machines, and other electronic equipment would cause them to break down. Automobile, snowmobile, and boat engines would also be damaged. Airports, including Anchorage, which handles the largest amount of air cargo of any airport in the United States and is a refueling stop for many trans-Pacific flights, would be closed until runways could be cleared of ash. To avoid the ash cloud, aircraft would have to be diverted around most of Alaska, Canada, and the Northern United States, seriously disrupting national and international commerce.

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Mount Pelee volcanic eruption

May 8, 1902
Island of Martinique in the Lesser Antilles

The eruption burst out of the side of the volcano rather than from the top. As a result the cloud of pyroclastic material swept rapidly across the ground, overwhelming the city of Saint-Pierre

On May 8, 1902, Mount Pelee, a volcano on the Island of Martinique in the Lesser Antilles, Caribbean, erupted and destroyed Saint-Pierre, a city of 30,000 people that was located about four miles from the volcano. Every person in the city, with a few exceptions, was killed. A pyroclastic flow of superheated gases and fragments of volcanic material had swept rapidly along the surface of the ground instead of moving upward into the atmosphere as often happens with volcanic eruptions. In this case it seems that a mass of magma had solidified near the top of the volcano, preventing the escape of material vertically when internal pressures reached the point of eruption, thus forcing a horizontal outburst of hot lava and gases. The people of Saint-Pierre as well as those on ships in the harbor were overwhelmed by a mass of red-hot volcanic material racing toward the city at 100 mph.

Martinique, in 1902, was a colony of France with a total population of less than 50,000. Its first European occupant was Christopher Columbus in 1502 but European permanent settlement did not occur for another 133 years. In 1535, one French company took possession of the island and set up plantation for the production of cotton, tobacco, and sugar. Slavery was introduced early in the eighteenth century in order to provide sufficient labor for these plantations. Slavery was finally abolished in 1848 and today it is a self-governing overseas department of France with a population of half a million. Martinique forms part of a chain of islands in the eastern

Figure 29 Mount Pelee erupting, 1902.

Caribbean south of the Tropic of Cancer. Mount Pelee is still there, inactive, towering 4,000 feet high over Saint-Pierre, now just a village. In 1902 it was the principal city on the island, often referred to as the Paris of the West Indies, a popular tourist destination. There were plenty of warnings in 1902 of the approaching eruption. For more than a week before May 8 there had been a continuous sequence of minor explosions at the summit and numerous tremors and showers of ash that reached Saint-Pierre making breathing difficult. In addition, large numbers of red ants, centipedes, and snakes moved away from the mountain and invaded the city. Fifty people died as a result of snakebites during this time. A group of colonial officials visited the mountain four days before the eruption and declared that there was no need for an evacuation.

When the volcano actually erupted and the pyroclastic flow reached the city, thousands of barrels of rum stored in the city's warehouses exploded, sending rivers of the flaming liquid through the streets and into the sea. The flow continued to advance over the harbor to destroy twenty ships anchored offshore. The hurricane force of the blast capsized the steamship *Grappler*, and its scorching heat set ablaze the American sailing ship *Roraima*, killing most of her passengers and crew. The *Roraima* had the misfortune of arriving only a few hours before the eruption. Those on board could only watch in horror as the cloud descended on them after annihilating the city of Saint-Pierre. Two sailors managed to get overboard into the protection of water. The surface water was too hot but by staying at a deeper level as long as they could and only coming to the surface briefly for air they were able to survive until temperatures dropped to a level that would not destroy their lungs. They saw the city covered with a dark, dense cloud, from beneath which emerged a constant roar, like the noise of cannons, as homes and storage units caught fire. When the black cloud lifted for a few minutes they saw that there was another layer of cloud beneath, a yellow one, presumably sulfur gases. Later, as the temperature became bearable, they swam to shore. They found a scene of total desolation with no sign of life of any kind and no ships anywhere.

The only ship that managed to escape from the harbor on May 8 was the *Roddam*, a steam-powered vessel from England. One or two sailors were able to slip the anchor chain and allow the ship to crawl away. The captain was seriously injured and in great pain but was able to navigate his ship to port in Saint Lucia, an island fifty miles south of Martinique.

Figure 30 Reflections of ruin in the streets of Rum, St. Pierre, Martinique, French West Indies.

Those from there who came aboard the *Roddam* described its condition. A fine bluish mass of dust covered everything. It looked like cement and was five feet deep in places. It was evident that the dust had fallen all over the ship in a red-hot state, setting fire to everything that was flammable. It fell on people, burning off limbs and large pieces of flesh. Much of the latter was uncovered after debris was removed from the deck. Eighteen dead bodies lay on the deck. All the rigging, tarpaulins, and awnings had been either charred or burned. Stanchions and spars had gone overboard, skylights were smashed, and the cabins below them were filled with volcanic dust. Some of the more substantial stone buildings in Saint-Pierre, though seriously damaged by the eruption, were still erect next day, but an aftershock from Mount Pelee hit the area less than two weeks after the first one and reduced to rubble whatever remained standing. Saint-Pierre became a dead city. Fort-de-France is now the main urban center for the island.

One lucky person happened to be a prisoner when the eruption occurred. He had been sentenced to solitary confinement for a week in the prison's dungeon. On May 8, he was alone in his dungeon with only a small grated opening cut into the wall above the door. In the morning of May 8 his cell became dark and he was overcome by intense gusts of hot air mixed with ash that had entered through the grated opening. He held his breath as much as he could in spite of the intense pain of having to inhale red-hot air. Gradually the heat subsided. He was severely burned but fortunately the amount of hot air that came into his prison was far less than the amounts experienced by everyone else in Saint-Pierre. He remained in his prison for four days, managing to survive in a half-conscious state, suffering great pain and having difficulty breathing, until people found him. After he recovered, he received a pardon and eventually joined the Barnum & Bailey Circus, where he toured the world billed as the "Lone Survivor of Saint-Pierre." The saddest aspect of the whole terrible catastrophe that had struck Saint-Pierre was the appearance of looters. They came looking for money, jewels, and other valuables in the ruins. The French colonial authorities were ruthless with situations of this type. Their marines put an immediate stop to it, often shooting looters on sight when necessary.

Mount Pelee's geological setting explains the frequency of its eruptions. The Caribbean Tectonic Plate of which Martinique forms a part is being pushed upward as the North American Plate slides beneath it. This plate includes an area of the Atlantic beyond the land areas of the continent. At a rate of about an inch a year North American Plate slides westward beneath the Caribbean Plate. The magma that moves upward into Mount Pelee originated in an area between the North American Tectonia Plate and the crust near the surface of Mount Pelee. Mount Pelee first erupted about 200,000 years ago and, over the years, geologists have found eruptions emanating from it at intervals of 50–150 years. Over historic times this mountain was active in the following years: 1792, 1851, 1902, and right up to the present time. The remains of three craters are visible at the higher elevations of Pelee. The largest and oldest of these was the focus of eruptions from earliest times right up to 40,000 years ago but over the years since that time the topography of the mountain has changed considerably until by 1902 only the two smaller craters were visible. By 1898 the first signs of new activity became clear. Tragically, politics—concentrating on an upcoming election—and lack of knowledge of volcanic eruptions, contributed to the indifference that was shown by the people of Martinique to the warning signs that came before May 8.

One day before the eruption of Mount Pelee, an almost identical type of event occurred on the island of Saint Vincent, a hundred miles south of Martinique in the same chain of islands that form the Lesser Antilles. The volcanic mountain that erupted on Saint Vincent was La Soufriere. The day before the eruption there was an earthquake in the same location and many concluded that this earthquake was the trigger than initiated the eruption. Fortunately, unlike Martinique, the people of Saint Vincent had taken precautions as they saw menacing signs coming from the mountain so the death toll was much less than it would otherwise have been. As La Soufriere erupted, a red-hot ash cloud, mixed with steam and gas, swept down on the citizens in the towns below. People perished quickly from ash asphyxiation or from burns. Some escaped by going into cellars and others were able to get into the ocean before the deadly blast of volcanic material reached them. Two thousand people lost their lives. One newspaper report from that time described Saint Vincent as being covered with ashes to an average depth of eighteen inches, so that all crops were ruined and many homes had collapsed under the weight of falling ash. Five thousand destitute citizens were in need of assistance from their government.

Saint Vincent had to cope with the problem of burying those who died, a task that never arose in Martinique since the devastation was total and very little was left of the bodies of the dead. This part of the world has a very hot climate, so bodies decompose quickly. Gangs of men were organized to pick up the dead and arrange to have them buried in mass graves. It was not always possible to do this as many had taken shelter in huts and they died there. It was difficult to get each body out of these huts and there was little time available for the task before decomposition raised the danger of disease. Decisions had to be made quickly because this was a Catholic society, used to burying people in the ground, and the situation demanded incineration. Quite apart from the urgency of burying the dead there were large numbers of injured people who needed attention. The Ambulance Corps attempted to help these victims. They were in great pain, wanting a drink of water but unable to consume it because of the damage done to their faces. Almost all of them died within a short time.

Many eminent researchers visited Mount Pelee and Soufriere after the eruptions because they were interested in the exceptionally high death toll and the unusual feature of Mount Pelee's eruption emerging as a horizontal blast of volcanic substances. A new aspect of the study of volcanology began to take shape. Among the scientists there was one, Thomas Jaggar, an assistant professor of geology at MIT, who was overcome by the high death rate and the extensive level of destruction. He decided, then and there, to devote his career to studying eruptions in order to save lives and began to search for a place that would be suitable for such a research center. The quest took him to the state of Hawaii and to the Kilauea Volcano. He managed to raise funds for the establishment of a research center at the site of that volcano. He searched the world for a volcano suitable for continuous study and chose Kilauea. The entrepreneurial Jaggar raised the funds, took a leave of absence from MIT, and established the new Hawaiian Volcanic Observatory (HVO) in 1912. HVO would be dedicated to the development of monitoring tools, strategies, and knowledge. All focused on his motto for HVO, "no more shall the cities be destroyed."

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51

Goliad, Texas, tornado

May 18, 1902
Goliad, Texas, south of San Antonio

This tornado claimed 114 lives, injured 230 others, and caused damage equal to $50,000 in 1902 dollars

The Goliad Tornado struck the town of Goliad, Texas, on May 18, 1902, touching down on the south side of the San Antonio River at 3:35 P.M. It claimed 114 lives, injured 230 people, and caused damage equal in value to $50,000 in 1902 dollars. It is considered to be one of the two most destructive tornadoes in the history of Texas, the other being the Waco strike of 1953. Of the 114 deaths, fifty were members of an African-American Methodist church who died when their church was destroyed. This tornado sounded like a heavily loaded freight train. The northwest section of the town saw an area one mile long and half a mile wide, totally wiped out and one hundred homes lost. The dead were buried in one long trench, for there was no time to dig separate graves or conduct individual funerals. Following the disaster, the Goliad County Courthouse served as a temporary hospital and morgue.

The town of Goliad is built around its courthouse a building designed by Texas architect Alfred Giles and erected in 1894. Limestone was used in the construction, hauled from Austin by oxcart. The courtyard was enlarged and restored in 1964. Along with the nineteenth and early twentieth century structures surrounding it the courthouse was entered on the National Register of Historic Places in 1976. Goliad today is primarily based on oil, agriculture, and cattle, but tourism is also a vital component. The moderate climate provides habitat for a variety of wildlife and rich grasslands for ranching. Landscape is an important historical resource, from the plants and animals that thrive there to modern day roadways that follow centuries-old trade routes. Giant oak trees dominate the land cover, traditionally used for grazing herds of cattle and horses. The San Antonio River flows through the town. On the north lawn of the courthouse there is a tree called "The Hanging Tree." At various times between 1846 and 1870, this tree served as the site of court sessions. Death sentences pronounced by the court were carried out immediately with a rope and a strong limb. During the 1857 Cart War, in which Texan freighters perpetrated a series of vicious attacks against Mexican cart drivers along the Indianola-Goliad-San Antonio Road, this site witnessed a number of unauthorized executions before the conflict was brought to an end by Texas rangers.

By the early eighteenth century, when Spanish missionaries and soldiers arrived in the mid-coastal area of Texas, they found the native peoples as long time residents of the area. The Mission Espiritu Santo was founded in 1722 to serve these native people. The site was abandoned in 1724 and the mission moved twice to places within the Indian community. Later it moved back to the original site near Goliad. Mission Espiritu Santo became the first large cattle ranch in Texas, with jurisdiction over all land between the Guadalupe and San Antonio Rivers as far north as Capote Hills near Gonzales. On this land, the mission's 40,000 or more cattle grazed. The mission continued as a mission for more than a hundred years, longer than any other Spanish colonial mission in Texas. In 1848, the Goliad City Council rebuilt its principal structures for use as public school facilities. Later it became Aranama College, the first institution in Texas established for education of Spanish-speaking Texans. The college for men lasted until the outbreak of the Civil War when the student body marched off to join the Confederate Army.

Designated a National Historic Landmark in 1967 and considered the world's finest example of a Spanish frontier fort, Presidio La Bahia had first been founded on the banks of Garcitas Creek, near Lavaca Bay. Previously owned by the Catholic Church and currently operated by the Catholic Church, the Presidio dates from its present site next to Goliad in 1749. It is the oldest fort in the western United States, and the only Texas Revolution site with its original 1836 appearance. As a permanent settlement by Spain in the early days it had been given the name La Bahia meaning "The Bay." The Spaniards used the fort as protection. Nine flags of different nations have flown over the Presidio in the course of its long history. It is the place where the first Declaration of Texas Independence was signed on December 20, 1835. The saddest page of Texas history, the Goliad Massacre, the largest single loss of life in the cause of Texas Independence, occurred here. Nine miles east of Goliad on Highway 59 is the site of the Battle of Coleto Creek. In March 1836, during the Texas Revolution, Texas troops under Colonel James Fannin surrendered here to superior Mexican forces after a day and a half of fighting. Colonel Fannin was one of the wounded individuals from the battle of Coleto Creek. He was helped out of the chapel where the prisoners and wounded had been held for a week. On Palm Sunday, March 2, 1836, the men were led out in three directions from La Bahia and massacred; the wounded were shot in the compound of the fort. The bodies were stripped and left unburied. When the shooting ended, 302 men were dead and about twenty-eight escaped. Fannin and thirty-nine other men who were wounded at the battle of Coleto Creek the week before the massacre were killed inside the Presidio, bringing the total killed to 342. A monument marks the grave of Colonel Fannin and 342 men who had surrendered to Mexican forces during the Texan Revolution and massacred at the orders of General Santa Anna.

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52

Santa Maria, Guatemala, volcanic eruption

October 24, 1902
Santa Maria, near the city of Quezaltenango
in northwestern Guatemala

Santa Maria's first eruption in five hundred years exploded into action with a VEI of 6, the same size as that of Krakatau. The eruption devastated 120,000 square miles of surrounding territory and killed 5,000 people

The first eruption of Santa Maria in recorded history occurred on October 24, 1902. Before 1902 it had been dormant for at least five hundred years. The eruption, with a VEI of 6, equivalent in magnitude to both Krakatau in Indonesia in 1883 and Katmai in Alaska in 1912, was the second biggest of the twentieth century. The eruption formed a large crater on the mountain's southwest flank and blasted volcanic ash twenty miles into the atmosphere. The ash that subsequently fell devastated most of the 120,000 square miles of surrounding territory. Volcanic ash was detected as far away as San Francisco—a distance of 2,500 miles. The crater on the southwest flank was half a mile in width and a thousand feet deep. It stretched from just below the summit down to the 7,000-foot level. Because of the lack of previous activity at Santa Maria, local people failed to recognize the warning signs that arrived in the days before October 24. At least 5,000 people were killed by the eruption. Many more died from a subsequent outbreak of malaria.

The city of Quezaltenango sits below the 11,000-foot-high Santa Maria. It is the second most populous city of Guatemala and has a present population of 300,000. It is located in the Sierra Madre range of volcanoes that extend along the western part of Guatemala, separated from the Pacific Ocean by a broad plain. These volcanoes are formed by the subduction of the Cocos Plate under the Caribbean Plate. Eruptions at Santa Maria are estimated to have begun about 30,000 years ago and continued intermittingly for many thousands of years right up to the quiescent period that preceded the event of 1902. This enormous blast of ash and pyroclastic material was followed by twenty years of dormancy. Then, in 1922, a new volcanic vent formed within the existing crater, forming a new volcano. It was named Santiaguito and it has been erupting ever since and now forms a cone a thousand feet tall, reaching a height of 7,000 feet. Thus, today it is possible to climb to the top of Santa Maria and look down on the ongoing eruptions at Santiaguito, 4,000 feet below.

Dome growth at Santiaguito has alternated between growth caused by the emission of lava flows, and inflation caused by the injection of magma into the middle of the dome. Activity has been concentrated at several different vents, and Santiaguito now has the appearance of several overlapping domes.

Although most of Santiaguito's eruptive activity has been gentle, occasional larger explosions have occurred. In 1929, part of the dome collapsed, generating pyroclastic flows and killing several hundred people. Occasional rockfalls have generated smaller pyroclastic flows, and vertical eruptions of ash to heights of 2,000 feet above the dome are common. The areas to the south of Santa Maria are substantially affected by volcanic activity at Santiaguito. The most common damage comes from mudflows in the rainy season due to heavy rainfall on loose volcanic deposits. The town of El Palmar was twice destroyed by these mudflows and infrastructure such as roads and bridges have been repeatedly hit. One hazard, potentially devastating, is the possibility of the collapse of Santa Maria. The 1902 crater has left the southern flank of the mountain above Santiaguito very steep. A large earthquake or an eruption from Santiaguito could trigger a huge landslide.

In light of the threat it poses to nearby populations, Santa Maria has been designated a Decade Volcano, identifying it as a target for detailed study. Since volcanic eruptions can have additional local effects such as the disruption of air traffic by ash clouds, the unique perspective provided by views from a space shuttle or from the International Space Station (ISS) enable scientists to see not only the horizontal influence of the eruption within the atmosphere, but also the vertical effects. The ISS can plan passes over any give target two or more times daily, so that astronauts can photograph happenings many times and can coordinate with ground observers as well. Volcanic eruptions, another Dynamic Events target of Crew Earth Observations, produce aerosols that are distributed globally and influence atmospheric temperatures, cloud formation, and rainfall.

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53

Turtle Mountain, Alberta, Canada, landslide

April 29, 1903

Turtle Mountain is near Coleman, Alberta, Canada

Excessive amounts of coal were removed from the mountain without adequate protection from overlying layers of rock. As a result seventy people in the small town of Frank were killed

Early in the morning of April 29, 1903, a gigantic slab of limestone rock broke away from Turtle Mountain at the 3,000-foot level. It weighed about seventy-five million tons, was half a mile wide, and as it crashed down the side of the mountain it broke apart into huge boulders. With the momentum acquired in descent this mass of rocks cut across the valley of the Old Man River at the foot of the mountain, continued up the slopes on the other side of the valley, and destroyed most of the town of Frank. Seventy of the town's residents were killed. Debris from the landslide can still be seen today.

Turtle Mountain was built up in the ancient past with sedimentary rock, mainly limestone. Geological structures of this kind are a common setting for coal deposits. Layers of coal seams are found alternating with layers of rock. In this location mining the coal was especially easy as the seams slanted downward toward the face where the mine entrance was. Gravity did most of the work, and very little blasting was needed. One thousand tons of coal was being extracted daily within the first year of operation but, despite some telltale signs, little thought was given to the effects of the work on the stability of the mountain. On any given shift seventeen miners extracted coal somewhere along a ten-foot-wide seam that, after a year, stretched back for 5,000 feet into the mountain. Early in 1903 miners

Figure 31 Results of the rock slide of 1903 at Frank, Alberta, Canada. In less than two minutes, forty million cubic yards of rock from Turtle Mountain slid along a plane of structural weakness to cover the town of Frank.

noticed, as they came to work, that some of the supporting pillars were badly splintered, pillars that had been in good shape at the end of the previous day's shift. With today's understanding of geology it is easy to explain what was happening, but that was not obvious in 1903.

The sedimentary formations of rock that constituted Turtle Mountain form a series of horizontal strata. Some of these may be coal, some limestone. Any weakening in one of these layers can trigger a slide, allowing upper layers of rock to cascade downwards along the general slope. In Turtle Mountain this slope was quite steep so any movement would be accelerated by gravity. When the landslide occurred, the mine entrance was blocked, leaving seventeen men trapped inside. Three other men who had just left the work area to take loads of coal to the entrance escaped the trap that caught the seventeen men but they were overtaken by the cascading material of the landslide and were never seen again, buried forever under tons of rock. As the reality of the event became obvious to the seventeen men inside, they ran to the mine entrance, only to find that it was now a heap of shattered timbers and fallen rock. They were now cut off from the outside world at a point three hundred feet inside the mountain. Before their lamps faded they examined their options. First they made their way to a lower level, hoping that the exit there was still open, only to find that the river had flooded that entrance and was rapidly backing up into the mine.

They realized that closures of entrances together with widespread flooding might have already cut off their supplies of fresh air. They had to act fast before their small amounts of fresh air would soon be used up. Hoping that they were sufficiently close to the surface they decided to try to cut a tunnel upwards and outwards. To remove the mass of material at the entrance was impossible. Over a period of twelve hours they worked steadily in shifts and finally came out on the face of the mountain to stare at the destruction below. The scene before their eyes was terrifying. Where their homes had been there was now a mass of white limestone rock. All but a part of the town's center was gone. The falling rock had swept across a mile of intervening ground before landing on the town of Frank. A mile-long section of double-track railway line, the main highway, and the coal-mining plant had been destroyed. Old Man River began to back up and form a lake behind the mass of rock. A freight train entering Frank at the moment of the slide was lucky enough to escape. It arrived as the landslide began to move down the mountain and it was able to speed past the town before everything crashed around it.

The rock mass that constituted the landslide was shattered by impacts against the side of the mountain as it came down. Long before it reached the valley below it had been transformed into several large boulders plus a myriad of fragments of all sizes so, in one sense, it was no longer a landslide. It began as one but ended up as something else. The different pieces of rock traveled for one or two miles from the base of the mountain over uneven ground by a series of skips and jumps until it reached the 400-foot level on the other side of the Valley of the Old Man River. There was no way of escape for the residents of Frank before the rocks reached it. The total amount of time involved was less than a minute. The history of the landslide can be read today in the indentations made on rocky surfaces by bouncing boulders as they made their way across the valley. As the mountain was examined after the event it became clear that the dislodged slab of rock had broken away along lines that were ancient fissures formed by successive faulting throughout the long history of the buildup of the mountain to its size in 1903.

One man who kept a boarding house in Frank woke up when he heard the sound of the slide and rushed to the entrance of his house. He was just in time to see the masses of rock fragments sweep past him at a distance of a few feet. Another workman who lived in one of the cottages that was destroyed woke up and, before he could do anything, was aware that his cottage was rocking backwards and forwards. The only thing he remembered after that was that he was forty feet from the house with his bed lying twenty feet farther away. His leg was broken and he had been wounded in several places by small rocks. The story was similar with many of the others who survived. In one home when a couple and their children were asleep there was no time to escape before their home was shattered and they somehow survived, albeit with numerous injuries.

The first action of both the Mining Company and the government of

Canada inspectors was the assessment of the cause of the disaster. Some accusations had already been made such as that the mining company had not provided adequate support of the higher strata, thus reducing pressure on them and so endangering their stability. The Mining Company insisted that the mine was in first class condition before the landslide and that the few instances of movements in the coal walls were normal for any mine. A senior miner pointed out that new movements of walls were observed from time to time in the six months before the landslide, each one occurring between one and three in the morning, presumably when temperatures were at their lowest. This miner described the experience of these movements as being like a ship's violent shaking when struck with a large wave and he added that they alarmed many of the workers. Some left the mine because of the shaking. Weather records were examined and it was established that the day before the landslide was warm and wet and the night that followed recorded temperatures far below anything experienced throughout the previous six months.

The weather factor, it was agreed, was one causal factor. Water expands and contracts wherever there are places that allow water in. These are all normal processes of nature that will be at work everywhere whether or not there is human intervention. Mining inevitably creates new spaces into which water can enter. In addition, even with the maximum number of supporting pillars, the removal of a thousand tons of coal daily changes the density or weight of one part of the mountain and, as was the case in the early weeks of April 1903, if there is a sudden increase in the amount of coal being removed every day, this change in the distribution of weight on he mountain accelerates the strain on its stability. The fact that the mountain was composed of a series of horizontal layers of rock and coal makes it particularly sensitive to any movement that would interfere with its stability. Since the coal seams sloped parallel to the mountain's layers there was a constant challenge facing the Mining Company to ensure that the supporting pillars were always doing their work.

The government inspectors concluded that the landslide could not be explained by a single cause. A combination of factors, acting together, led to the disaster. Nevertheless, it is difficult to get away from the conviction that the coal mining operations were the main cause, especially when it was noted, after the event, that the location of the edges of the break where the mass of rock came away from the mountain coincided exactly with the upper limit of operations of the coal workings. The coal was being removed from within huge spaces measuring more than three hundred feet in height. Loosened coal offers very little resistance to the enormous pressure from above, that is to say the pressure from the rest of the mountain, so inevitably there must have been some movement from time to time along the roof of the coal seams. The Mining Company was well aware of the reports brought back by the miners regarding the splintering of the wood pillars that supported the overhanging rock and this should have persuaded the company to install more and stronger timbers.

When coal mining resumed at Frank years later, safety features that should have been there in 1903 were firmly in place. After 1903, some people began to move away from the mountain, fearing another slide. The town did expand over the years, but there was nowhere for it to grow eastward, so the town of New Frank took root just northwest of the original town. In 1911, a Royal Commission study found the North Peak of Turtle Mountain to be structurally unstable. In reaction to this study, the government ordered everyone out of that section of Frank. People moved to other areas and many settled in New Frank, the present location of Frank. Today, the remains of the old town of Frank and the rocks that came down the mountain in 1903 form a tourist attraction. Limestone rocks in depths ranging from 5 to 100 feet litter the entire area. There is an information booth beside the highway and a number of displays that re-enact the events of more than a century earlier.

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Chicago, Illinois, fire

December 30, 1903
Iroquois Theater, Chicago

The theater that was claimed to be fireproof went up in flames shortly after its first opening. Of the 1,900 people in attendance six hundred lost their lives

Chicago's deadliest fire of the twentieth century occurred shortly after the opening of the new, fireproof, Iroquois Theater. On December 30, 1903, when the Iroquois Theater was packed for a holiday matinee of the popular musical "Mr. Blue Beard, Jr.," a fire suddenly broke out. The management was quite unprepared for the panic that ensued. Out of the 1,900 people in attendance, mostly women and children, six hundred lost their lives. The United States had a long history of fires, and this was not the only twentieth century urban fire, but it was a particularly tragic event. The new fire precautions had been well established and were well known. Several theaters had already implemented them. Sadly, at the Iroquois, there was indifference to two extremely important safety procedures: ways of getting people out of the building quickly and stationing firemen close to the stage with fire extinguishers and hoses ready for use. Neither of these procedures was in place on December 30.

There were firemen on duty in the theater at the time of the fire but the only firefighting equipment they had was a quantity of powder to sprinkle on a fire. The powder proved to be quite useless. When a velvet curtain ignited at the stage, an asbestos backup curtain, standard equipment in all theaters of that time, failed to drop down and contain the fire. Someone had raised the curtain higher than its usual position in order to provide a better view of the stage for those on the balcony. It got stuck in the higher position. Additionally, there were no ushers at the exits to guide people out and avoid panic. Iron gates had been installed over exit doors and some of these were locked. Those that were unlocked were difficult to open because of a lever that was unfamiliar to most patrons. The result was a combination of panic and pileup at the exits. A large number of casualties, perhaps the majority of the six hundred, were people and children who had been trampled to death at the doors or were killed when they jumped down from the balcony. The speed with which everything happened added to the rush and confusion. Canvas backdrops on stage, painted with highly inflammable oil paints and mounted in the air, had caught fire instantly and created a firestorm. It was all over in fifteen minutes.

The Cook County Coroner's Inquest documented the tragic sequence of events and came down hard on the theater's management. It listed 571 deaths and hundreds of people injured. Thirty of these latter died in the weeks that followed. The fact that the casualties were mostly women and children, and that it happened so near to Christmas, made it all the more poignant and blameworthy. It was Chicago's worst tragedy since the fire of 1871. Out of the tragedy came new, stronger regulations for theaters. New laws about fire safety were passed. Among them was the requirement that all exits had to be clearly marked and their doors so arranged that they could be pushed open from the inside. The largely undamaged Iro-

Figure 32 The stage of the Iroquois Theater, looking down from the balcony.

quois building reopened less than a year after the fire and ran on for a further twenty years. Both before this fire and after it there were other urban fires across America. Wood was still the dominant building material in use for homes, for piers, and even for walkways in some of the newer communities. The New Jersey shore of the Hudson River was a busy shipping center at the start of the twentieth century. There were many wooden piers at which ships tied up while awaiting the loading of their cargoes.

On Saturday afternoon, in June 1900, stacks of baled cotton and about a hundred barrels of whiskey were stacked on one New Jersey pier when a fire broke out in one of the cotton bales. Cargoes of flammable materials lay around waiting to be put on board. Fire immediately erupted. Dozens of kegs of whiskey were ignited and these exploded and added fuel to the fire. The cause of the fire was not known; it could have been smoldering for some days before bursting into flame. In spite of efforts to limit the spread of the fire things got out of hand within an hour. Several ships and numerous smaller vessels caught fire as most of the crews from ships were ashore and large numbers of visitors were visiting the ships. There were also many canal boats and barges loaded with oil, coal, cotton, and gasoline, all highly inflammable materials which were being transferred to the ships. These added fuel to the already raging fires, helping to spread the flames to neighboring piers. All the ingredients for a devastating fire were at hand. The piers were old, already saturated with oil from previous ship-

Figure 33 Investigators standing inside the Iroquois Theater after the fire.

ments. Cargoes of flammable materials lay around waiting to be put on board.

Tied up at a pier, on the New Jersey side of New York harbor, were four ships of 5,000–10,000 tons in size. A 14,000-ton liner, the *Kaiser Wilhelm der Grosse*, held the Blue Riband, the much-coveted Atlantic-crossing record. This ship was the pride of the German marine fleet. It was built in 1897, carried a crew of five hundred men, and had an average speed of 20 mph. It was the first ship built with four stacks and the first to be fitted with remote-controlled watertight doors. It was also the first ship to carry a radio. In 1900 it carried a radio that had a range of twenty-five miles. The *Kaiser Wilhelm* plied the Atlantic sea lanes for years after the Hoboken fire then, at the outbreak of World War I, it was converted into an armed merchant vessel but was sunk within a month of the war's outbreak. A red and yellow plume shot skyward as flames spread from place to place and longshoremen soon realized that the wooden piers under them were catching fire They shouted a warning to others and ran for their lives. Forty men who did not move fast enough were incinerated. Trapped on the ships, some on deck and others below the level of the deck, were hundreds of visitors. Many of the casualties were people who were unable to get away in time.

The nearest horse-drawn fire-fighting carriage arrived within six minutes and the men on it fought the fire all evening and through the night until they finally got it out by the morning. The *Kaiser Wilhelm* had hundreds of sightseers on deck and many of them panicked when flames engulfed her bow. Tugs rushed to the rescue from both sides of the harbor and pushed the big ship into mid-stream. The stern also caught fire but the crew was well organized and fought every outbreak persistently, even using their uniforms to smother the smaller fires. No lives were lost. It was a very different story on the other ships. All of them were completely on fire and the tugs attempting to pull them away from the pier caught fire too and had to give up. The damage to the three ships was extensive and they had to stay in port for some time for repairs. Since the piers in this area of Hoboken were under the care of the North German Lloyd Steamship Company, owners of the *Kaiser Wilhelm* and the other three ships, the company had to make arrangements for the burial of those who died. For most of them it was almost impossible to establish any identity. The tools that are at our disposal today were not available at that time. A mass burial was arranged at the Flower Hills Cemetery nearby and the shipping company, to its credit, looked after the maintenance and repair of this burial site for the whole of the twentieth century.

Lack of attention to fire regulations and inexperience in dealing with new hazards were also evident in ships at sea. One of the favorite trips of the 1930s was a pleasure cruise from New York to Havana. Cuba was a very different place at that time than it is today. Costs were low compared with their equivalents in the United States and large numbers of New Yorkers made the short two-way trip to the capital, Havana. The *Morrow*

Castle was one of the ships that plied regularly between these two places and, in September of 1934, it was returning to New York when a small fire broke out in the writing room in the middle of the night. Instead of notifying the captain, three sailors decided to put out the fire on their own. When they found that the fire was spreading and they were unable to control it they sent an urgent message to the captain who should have been on the bridge because the ship was quite close to New York at this the time. What they did not know was that the captain had had a heart attack and died a few hours earlier. His chief officer, in accordance with standing regulations, had immediately taken command but he was quite inexperienced and did not know what to do about the fire. A second message went to the bridge but again there was no response. Within an hour the fire was out of control and the new captain sent out an SOS message. Chaos followed. A few managed to get away in lifeboats. Out of the total of 550 on board, one hundred thirty-five either drowned or were incinerated.

All of these fires occurred in places of entertainment and commerce. It was a very different story in a fire that broke out in New York in 1911, in a place where new immigrants to America had just secured their first jobs, where pay was at a minimum level, and where working conditions were poor. These new immigrants fitted the traditional description, "tired and poor," and probably spent their last nickel to get to America. The garment industry in Lower Manhattan gave many of them their first job in the new world, a job that required little prior experience and hence paid little. They had to work long hours each day to make enough money. The history of New York's clothing industry is full of examples of poor working conditions and inadequate safety precautions. It was common practice for management to lock the emergency doors during working hours, as was done in one tragic instance. This was to prevent workers stealing things and leaving the building via fire exits instead of the main doors. Shirtwaist, or ladies' blouse, was a popular item in the early 1900s, worth a significant amount of money, the sort of thing that workers might be tempted to steal.

The Triangle Shirtwaist Factory was one of the thousands of clothing factories in lower Manhattan. They employed the immigrants, mostly Jewish and Italian, who streamed into New York and factory managers were able to take advantage of these new arrivals. Even after fifteen hours of work a day many of them had to take clothing home to be finished there in order to make enough money. No health or insurance benefits were provided, no extra money for working overtime, and frequently children were employed. "Sweatshops" and "fire and death traps," were the terms often used to describe these places of work. It was in these factories that some of the strongest trade unions took shape to fight for better working conditions. They had to work hard for the right to present workers' grievances to managers. In many cases the managers refused to recognize their existence and even threatened workers who supported them. In 1909, facing persistent refusal from management to listen to their complaints, 20,000 shirtwaist workers, mainly women, went on strike. There were no laws guaranteeing them this right so business leaders persuaded the police to arrest them for lawless behavior. There were also acts of brutality by the police to intimidate them. In spite of the conflict the strike secured some concessions and there was a general pay raise and the workweek was fixed at a maximum of fifty-two hours.

The Asch Building at the south of Manhattan Island, New York, was a modern structure and had a reputation for being fireproof. It had ten floors and the top three floors belonged to the Triangle Shirtwaist factory. Five hundred women worked in these three floors. Shortly before five o'clock in the afternoon of a day in March of 1911, as workers were about to leave, a fire broke out on the eighth floor. Like the two other floors above it, this floor was filled with sewing machines crammed so close together that little aisle space was left for moving about. Scraps of cloth and paper patterns lay around and they soon increased the spread of flames and smoke. The fire had started quickly and flared out just as rapidly. A number of workers from the eighth floor rushed to the stairway in time to see the whole floor erupt in a mass of flames. Many of them managed to escape with their clothes on fire. It was a different story on the ninth floor. The elevator quit and never reached that floor. The emergency door leading to the fire escape had been locked previously and by the time someone broke it down the fire escape had collapsed under the heat of the fire. A few who reached the fire escape were killed as it collapsed. Others, desperate and with nowhere to turn, chose to jump to their death rather than be incinerated.

Firemen had difficulty bringing a ladder into position because of the bodies strewed over the pavement, not all of them yet dead. Furthermore, their ladder, when it was erected, could only reach as far as the eighth floor. Life nets were brought in to try and catch those falling down but the women fell with such force that they went right through the nets. In less than two hours 147 bodies lay dead on the sidewalk below. The events of March 1911 were exceptional because of the large number of workers killed but other aspects were typical of the times. The fire and its effects were all over in two hours and firemen were left with the task of removing the bodies of those who had died on one of the upper floors. By the standards of the time the Triangle Shirtwaist Company was not held responsible for the fire and loss of life even though it was quite obvious that it had failed to ensure safety for its workers. Action was taken immediately by city authorities to institute factory inspections, fireproofing, and installation of sprinkler systems. The union representing the garment workers was not satisfied with these moves. They felt they could no longer trust anyone but themselves for their safety and took action within a few days of the tragedy.

Parents and friends of the victims of the fire met with the Ladies' Waist and Dress Makers' Union a few days after the tragedy to give them support. They were completely in favor of the union's demand that the company owners be brought to trial. They were also concerned, as was the union, about the disposal of the $100,000 that had been collected for the families of the victims. These two issues galvanized the union. They were convinced that appeals to authorities for corrective action were simply not working and they resolved to be more militant in the future. This is what their president said at the time: "Just because a safety committee was appointed and newspapers devoted pages to the problems in the factories, we cannot assume that the 30,000 shops in the city will suddenly become perfect. As long as the enforcement of labor laws is in the hands of political people, factories will remain unsafe and unhealthy. We must depend entirely upon ourselves for improvements." In later years other trade unions referred back to them as pioneers of the trade union movement.

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55

St. Petersburg, Russia, revolution

January 22, 1905
St. Petersburg at the Winter Palace

A thousand of the workers were killed and thousands more were injured when the Czar's soldiers opened fire on the protesters. The Czar of Russia had absolute power at this time and his cruel actions contributed to the bigger revolution that followed twelve years later

Russia's emperor in 1905 was Czar Nicholas II. As czar, Nicholas had absolute power. In other words the country's form of government was an autocratic monarchy. Any protest that the czar disliked was met with force and as the country became industrialized the confrontations between impoverished workers and the state became more and more violent. Many were killed in the course of these protests and the number of strikes increased year by year. On January 22 1905, one hundred thousand workers, led by a priest, marched peacefully to the czar's Winter Palace in the Russian capital of St. Petersburg. They were demanding better working conditions. Instead of a friendly reception the workers met a volley of bullets. A thousand were killed and thousands more wounded. It was a turning point in Russian history.

The peaceful protests of January 22 at the Winter Palace in the nation's capital of St. Petersburg were intended to resolve growing tensions without confrontation. The opposite was the outcome as extreme violence erupted. In the months that followed, Czar Nicholas II knew that he could no longer stop protests with bullets. That era of Russian dictatorship belonged to the past and he recognized the necessity of making some concessions. The wide publicity that had been given to the march made it different from others. If the czar's representative had acted differently when the protesters arrived at the Palace, the more bloody events of 1911, the Communist Revolution, might never have taken place. As it happened, they were only delayed for six years. The amount of concessions that the czar granted in the course of the year that followed were inadequate and they only ensured some delay before the bigger confrontation of 1911 became inevitable.

On the Saturday evening prior to the protest, Father George Gapon, who organized the event, sent a letter to the emperor assuring him that everyone would behave peacefully. Gapon was well-known as a follower of Tolstoy's creed of non-violence so there was every reason to treat his assurances as credible. Gapon knew that the czar had arranged for extensive military protection all around the Winter Palace so in his letter he urged him not to use force against innocent civilians. He said this because he was afraid the czar's ministers might have given him false information about the protest. He then made a special personal appeal to the emperor, asking him to receive his address of devotion which he was going to bring along with a statement of the people's needs. His final words declared that he and all the workers with him would guarantee what he called "The inviolability of your person."

The origin of the march was unrelated to the various political groups that formed in the preceding years. Rather it was a reaction to the way management had victimized a group of workers for participating in a strike. Gabon felt that every worker had the right to strike and so he was convinced that a personal appeal to the czar would support his position. Gabon was a priest and for a time had been a prison chaplain but his main interest was the ongoing fight for workers' rights. He knew that the planned protest march to the Winter Palace was illegal. The police knew this as well but they did nothing to warn him. Even when Gabon sent the details of the march to the city authorities ahead of time nothing happened. The czar would not be in the palace on the day of the march so all decisions would be left to the Grand Duke Vladimir, the military commander of St. Petersburg.

The marchers set out in five columns all moving toward the great square in front of the Winter Palace. The authorities knew their route because they had been given the details a day before. No one among the thousands felt concerned about the outcome. They felt that their peaceful purpose would be enough to prevent violence. As they marched through the city the police made way for them, holding up traffic where necessary to let them pass. Banners were held aloft, while holy icons and portraits of the czar were also prominent. Onlookers gave them respectful attention as they passed by. It was only as they came near their goal, the great square, that they encountered firm opposition and were told to stop. They continued to move forward but within a few minutes they were physically confronted and pushed back by a cavalry troop. Clearly the soldiers had been given orders to stop the march.

Gabon requested a hearing for the petition they carried but the response by the soldiers remained the same. No one and no petition would be allowed past the entrance to the palace. Meanwhile the crowd of 200,000 waited. Gapon, dressed in his golden vestments and holding aloft a crucifix, requested that the petition be forwarded to the emperor. The officer in charge refused. For a few moments, the mass of marchers stopped, then, after a few moments of discussion among themselves, they decided to oppose the order to stop and moved forward. A volley of shots rang out from the soldiers on guard, fortunately all blanks, but it was followed a moment later with live bullets. Within a minute there was a third volley of live bullets. Men, women, and children fell in heaps and those who could escape scattered in all directions. Father Gapon, who was not hit, stood still, aghast. A thousand, maybe five thousand as was reported elsewhere, had been killed and thousands more wounded.

Reports in U.S. newspapers on the following day contained accounts of the extraordinary strength of the protesters. Even after a violent attack on them by cavalry with horsemen wielding swords, they persisted in moving forward toward the palace, calling for the emperor and shouting abuse at the troops, yet avoiding any appearance of acting violently. Their form of passive resistance made little difference to the soldiers' actions. Within half an hour of the previous violent assault on helpless citizens a second attack occurred on those who remained. They were told to disperse but before they could get away volleys of shots rang out. Most were shot in their backs as they attempted to escape. Bodies were scattered over the sidewalk. A witness to the tragedy identified women, children, as well as men, among the dead. Splashes and streams of blood stained the snow. Only a very few survived because the volleys were fired from twenty feet away. Ambulances had little to do. Policemen found a large number of sleighs to carry off the dead. Cries of anguish and despair were mingled with shouts of "murderers, murderers!"

Early in the morning of January 23 it could have been obvious to anyone that the military commander at the palace anticipated a major revolt, despite his recognition of Gabon's opposition to any form of violence. What the commander was opposed to, obviously, was any form of protest, however harmless. Every street and every bridge crossing the River Neva had been ringed with triple rows of defenses, as if an invading army was at the city gates. Because different things were happening in different places it was difficult to get an overall picture. Some days later it was discovered that large numbers of protesters in suburban areas had been shot before their procession began to move. On January 24, the military commander declared martial law and went on to station troop detachments at all strategic points around St. Petersburg. The *New York Times*, because of the time delay, was able to carry the previous day's news on its January 23 issue. The front page was headlines with phrases like "Day of Terror in Russia," and "Czar's subjects arm for revolt."

Bloody Sunday, as the January 22 event was known, led to further unrest as people became radicalized by the treatment they received. In the weeks that followed disturbances broke out throughout the country. In factory after factory close to half a million workers went on strike. Uprisings also took place in territories that bordered Russia and were part of its empire such as Russian Poland, the Baltic countries, and Finland. Sailors on one battleship mutinied. Maxim Gorky, the Russian novelist, took the side of the strikers. On Monday morning he spoke of the previous day as inaugurating revolution in Russia. He said that the emperor's prestige had been irrevocably shattered by the behavior of the military units. Gorky was arrested in Riga, Latvia, two days later and held in prison for a month, after which he was released on bail.

Gorky pointed out that Father Gapon persuaded the workers to believe that a direct approach to the one he called "Little Father" would be successful. Now he and all with him have been deceived. Gorky went on to say that peaceful means of change will not work and therefore force must be employed. He insisted in speeches to large crowds that the country now has no emperor because too much blood lies between him and the people. Because of the great respect accorded him, Gorky's words carried a lot of weight, especially when he urged his listeners to begin the people's struggle for freedom. Some began an appeal for arms. Others proposed a letter condemning the soldiers at the Winter Palace while commending those in Moscow who had refused to fire on protesters.

The czar knew for the first time that he could no longer solve peaceful protests with bullets; he had to make some concessions. He faced what Vladimir Lenin would later call a revolutionary situation. His style of addressing the situation sounds strange to us but it underlines the reality of the absolute power he held. Even the smallest concession on his part would represent a major change for all of Russia. Eight months after Bloody Sunday he issued a proclamation to the country. In it he describes himself as "We, Nicholas the II, Emperor and Autocrat of All the Russias, Czar of Poland, Grand Duke of Finland," which is a strange way for a single individual to talk. He then went on to say how the people's sorrow was also his and, therefore, that we, using that same word again, must do everything possible to bring an end to unrest. Maybe he was including his wife and children along with himself when he made the plural reference to the czar.

There were three parts to the proclamation. First, everyone was assured civic freedom based on the integrity of the individual. This included freedoms of speech, conscience, assembly, and association. Second, all those who were at that time deprived of their franchise would be given access to the country's parliament, the Duma, and have an opportunity to vote in it. Third, the Duma would have full power to pass or reject whatever laws were proposed. Implied in these new freedoms was the right of work-

Figure 34 Reproduction of a Russian propaganda painting of czarist soldiers in front of the palace firing on protesting workers, St. Petersburg, Russia, January 1905.

ers to form trade unions and peasants to create their own individual small farms. Up to that time all lands were held in common with no individual owning land. All of these changes, while modest as we might see them, changed Russia forever. Russia could never go back to being a dictatorship. The people's revolution had succeeded in getting a constitution that gave them new and permanent rights.

At the same time, power remained in the hands of those who held the large tracts of land because this was still a rural society and whoever had most land got most votes in the Duma. Society became divided in a new way. No longer was it the people against the czar. Now two social classes appeared, the have-nots and the haves. In later years as the communist revolution of 1917 broke out and transformed Russia back into another dictatorship for seventy years, the revolution of 1905 was seen as its dress rehearsal. The many workers' movements that emerged in the interim twelve years created opportunities for Lenin who was able to unite the most powerful among them. He then used these groups to set up the new communist dictatorship by force.

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Mongolia earthquake

July 9, 1905
An area of Mongolia, close to the Chinese border

A vast area of two million square miles was damaged by this earthquake and the shaking was felt over a distance of 1,500 miles

On July 9, 1905, an earthquake of magnitude 8.4 occurred in the Gobi–Altai region of southwestern Mongolia, close to the Chinese border. At that time very little was known or documented about geological changes in that part of the world. This catastrophic event in 1905 was an exception. It was one of the very few for which detailed data was available. An aftershock of almost the same magnitude occurred in the same location two weeks later. A land area in parts of Mongolia, China, and Russia, covering as much as two million square miles, was affected by these events and people experienced the shaking from east to west over a distance of 1,500 miles. A large number of rocks rolled down from the 12,000 feet high surrounding mountains, trees were uprooted, and two lakes, each of eight acres in size, disappeared.

Deep fissures, one stretching for seventy-five miles and another for two hundred miles, formed in the wake of the July earthquakes and from within these fissures water was forced out on to the surface. Subsequent research, mainly in modern times after World War II, identified a series of earthquakes subsequent to the 1905 quake. One occurred in 1931, one in 1957, and one in 1967, each one of magnitude 8 or greater, a rare record in the history of earthquakes anywhere in the world. Additionally, each one of these events gave rise to fault movements as big as twenty feet and rupture lengths of several hundred miles. How could so many catastrophic earthquakes occur within a single century and within two hundred miles of one another? Geologists have concluded that, in this poorly understood region, events like these appeared in cycles over geological time with recurrence rates of several thousands of years. All of the information we now have about the 1905 event came from one Russian seismologist who traveled to the area of the earthquake at his own expense, in 1905, and by primitive means of transportation. His notes and maps lay in the archives of the Russian Geographic Society until they were discovered in 1957.

With the data from 1905 available to them in 1957, and encouraged by the new interest in eastern Siberia by political leaders, geologists began to study the Gobi–Altai region in greater detail than had ever been previously attempted. U.S. geologists in particular saw similarities between the layout of fault lines in this part of Mongolia and the fault lines associated with the Venture and the San Andreas faults. In particular they saw that what had happened in the Gobi–Altai earthquake, namely the simultaneous rupturing of two major faults, were to happen in California, it would be worse than anything that had yet hit that state. The new interest in the Gobi–Altai Region enabled the geological societies of Russia, China, and Mongolia to work together in the investigation of the 1957 earthquake when it struck. A year later the Academy of Sciences of the USSR, the name of the country at that time, appointed a group of geologists to investigate the Gobi–Altai area, to map it in detail and to carry out seismological investigations over a large area.

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57

San Francisco, California, earthquake

April 18, 1906
In and around the city of San Francisco

This was the first devastating Californian earthquake to destroy a major city. Three thousand lost their lives because of it

Early in the morning of April 18, 1906, while most people were still in their beds, a 7.8 strength earthquake hit San Francisco. The shock lasted for less than a minute but that seemed like a year to those who were rudely awakened and had to rush out into the streets with whatever clothing they could lay hands on. Aftershocks soon followed and the destruction they could see in every direction convinced most people to stay away from their crumbling homes. The worst horror came later in the morning with fires all over the city, sixty in all. A firestorm erupted to add to the terror. The fires raged for three days with a total destructive power twenty times that of the earthquake, one of the most devastating in the history of California. There were three thousand deaths.

It took this event, the first major assault on a big city by an earthquake, to set in motion a serious quest for the cause of the earthquake. About five hundred city blocks had been devastated. Masonry buildings collapsed but wood frame homes and skyscrapers withstood the shock. One exception was the landfill areas in Marina District near the water. Wood frame homes there simply disintegrated. There is a special reason for the damage in this area. This district, south of Market Street, was a filled area; that is, it had been constructed by pouring unconsolidated materials, sand and rocks, on stream beds and other places that were too close to the water line to allow for construction. Buildings were then erected on this artificial foundation, and when the shaking from an earthquake occurred, liquefaction took place. Water seeped from below and changed land that formerly seemed quite solid into a watery mess, quite incapable of supporting buildings. Because this was the industrial part of the city people felt they could risk the possibility of a disaster from an earthquake. The cost of building on filled land was much lower than anywhere else in the city and industrialists felt that this lower cost would offset the price of reconstruction after a quake.

Unfortunately, as so often happens in human-induced disasters like this one, the lessons learned are not remembered when there is a different kind of event involving filled land. Over the years, people forgot the dangers of filled land and the area that had been an industrial site was rebuilt again, this time as a fashionable residential subdivision. When the Loma Prieta earthquake struck in 1989, this area was totally demolished and many lives were lost. San Francisco was not the only city to forget the past. Tokyo did the same thing, or rather allowed the same thing to happen. Many years before the 1923 earthquake, one area of the city had been built up on filled land and the authorities in the city knew that this was the case. They also knew about the San Francisco earthquake because Japan experiences more earthquakes than almost any other place on earth and there are always ongoing studies of earthquakes in other parts of the world. Nevertheless, nothing was done about the filled land and new homes were built on it after 1906. When the 1923 event hit Tokyo the buildings on filled land collapsed immediately and many people died. One part of the San Francisco filled land that did not collapse was the Palace Hotel, although it did catch fire.

Most of the buildings in the city were built of wood and, as such, they would normally withstand earthquakes because of the ability of wood to expand and contract under shaking. Most of them were lost because of fire and even those that survived had trouble because their chimneys toppled, ripping plaster off ceilings and walls and breaking floors as they fell. Some places at considerable distances from the city suffered severe damage, far more than other locations at equivalent distances from San Francisco, simply because they happened to be on one of the many faults that stretch out from or run parallel to the main fault. Santa Rosa was one of those places. It is nineteen miles away from the source of the earthquake and it experienced extreme damage. Fifty people were killed there. It was a similar story in several places west of the San Joaquin Valley even though they were thirty miles south of the earthquake's epicenter. Because of their proximity to water courses these areas experienced liquefaction, rift fissures, avalanches, and earth slumps.

Electrical power lines, water mains, and all the other normal services were cut off. When the first fire broke out nothing could be done about it because there was no water. Then a firestorm erupted. These fires raged for three days and the whole city was incinerated. All attempts to create firebreaks failed. There were probably three or more thousand killed, 1 percent of the total population. When the fires finally subsided people searched for their homes or what might be left of them. It was a difficult task. All the familiar landmarks had vanished. The quake was felt over an area close to 200,000 square miles, all the way from Oregon to south of Los Angeles and eastward to Nevada. Cities closer in proximity suffered varying amounts of damage. Stanford University was one of the worst affected. Several buildings were completely destroyed there. One person's observation on the morning of the earthquake sums up the experience of most: the street was undulating as if it were the ocean with waves sweeping toward me. I was terrified.

Earth waves rolled across the state with clear depressions between the swells. When they finally broke open there were parallel fissures with lengths of six hundred feet or more. Another type of fissure took the form of a rectangular-shaped block that dropped, leaving a trench with vertical sides. Landslides occurred wherever the banks of rivers were steep and where there were steep bluffs. Frequently forests were carried down or were overthrown by the slides. Several sections of land were raised as much as twenty feet above the highest flood level for the area concerned. Other places dropped by as much as fifteen feet although the majority of these were of the order of seven feet. The forests of different areas, that altogether added up to 150,000 acres, were completely destroyed. About forty miles to the south of San Francisco, near the limit of the earth-

Figure 35 San Francisco, California, earthquake, April 18, 1906. Downtown San Francisco showing residents watching fire after the 1906 earthquake.

Figure 36 San Francisco, California, earthquake, April 18, 1906. Stanford University. Looking towards Chemistry Building after the Statue of L. Agassiz fell from a height of thirty feet and pierced the concrete sidewalk.

quake's destructive power, the Spanish mission of San Juan Bautista, built a hundred years earlier, was severely damaged.

San Francisco was a flourishing city in 1906. It had sprung into fame as the premier city of the West Coast during the gold rushes of fifty-five years earlier and at the time of the earthquake it had a population of 400,000. San Francisco's prosperity was due to new mining developments in western Nevada, to truck farming from surrounding agricultural areas and, most of all, as a seaport for Asian trade. Fires destroyed large parts of the city six times in the course of its short history and their frequency persuaded builders to switch from wood to brick and stone. They also inspired the leaders of the city to create a brand new fire department. It earned the name of being the best in the world. Sadly, the one consideration that ought to have been uppermost in the minds of the city officials was missing—the provision of emergency supplies of water in the event of the city's mains being severed by an earthquake. As had happened with filled land, so here too, San Francisco's lack of emergency water supplies was a mistake that was repeated in subsequent urban earthquakes, as in Tokyo in 1923. A plan to pump emergency water supplies from San Francisco Bay had been laid out but never implemented.

Figure 37 San Francisco, California, earthquake, April 18, 1906. View showing damage the San Francisco City Hall resulting from the San Francisco earthquake and fire of 1906.

The fear of earthquakes was never evident in San Francisco in spite of the fact that the city had experienced the tremors of three quakes, those of 1836, 1838, and 1868. Memories seemed to be short. In the immediate aftermath of the quake and fires, with all the awareness of their neglect of adequate preparation for emergencies, and with a quarter of a million of the city's population, more than a half of the total, homeless, everyone took responsibility for the task of reconstruction. Money contributions, practical help, and the provision of military units from the federal government all helped to speed up the recovery. Every individual could, and did, participate in the clean up and in the practical work of either building homes or carrying supplies to building sites. Within three years San Francisco was back to a near normal level of operation and was growing at a fast rate.

San Francisco has the highest density of underground faults of any urban area in the United States. Furthermore, the break in the San Andreas Fault that caused the disaster was six miles below ground and the amount of lateral displacement was as much as twenty feet in places. Costs in 1906 dollars were close to $500 million. That would be about $7 billion

Figure 38 San Francisco, California, earthquake, April 18, 1906. View south from 4th and Market streets, showing results of fire. April 20, 1906. San Francsico County, California. April 1906.

today, a figure close to the cost of the 1989 Loma Prieta earthquake. Earthquakes had struck California before. In 1812, an area south of Los Angeles was hit and more than thirty people were killed by it. In 1857, another quake caused considerable damage over an area northeast of Los Angeles. Some decades later a geologist from the University of California who had observed a fault line south of San Francisco, decided to trace its extension north and south. He and his students found, to their surprise, that this was no ordinary fault. It was the San Andreas Fault and it ran almost the full length of the state, close to the coast for the most part but veering inland in the south.

This discovery was made in the 1890s, long before there was any understanding of plate tectonics, so little was done with the new information. Now, with hindsight and present knowledge of tectonic plates, the story of the San Andreas Fault is the key to understanding most of California's earthquakes. First attempts to understand its behavior began within a year of the 1906 disaster, first by a geologist who had lived through the quake. He recognized that the cause of the earthquake was slippage on part of the San Andreas Fault, later identified as a segment that stretched for 250 miles from Monterey Bay northwards. Pipelines and roads that crossed the fault line had been broken and displaced by an average of twelve feet with the western side always moving northwards with respect to the eastern side. It was evidently a strike-slip fault but until the era of plate tectonics everyone regarded it as an anomaly, a one of a kind event unique to California. With the increasing public concern today about the potential for destructive earthquakes in California since the great Alaska earthquake of 1964, and the general acceptance of the concept of plate tectonics and seafloor spreading in the late 1960's, the San Andreas Fault has received new attention. It is closely related to such recent earthquakes as the Loma Prieta of 1989 as well as the much earlier quake in Fort Tejon in 1857.

At the northwest end of the fault system, the Mendocino triple junction represents an intriguing structural knot where the North American, Pacific, and Gorda plates join. A fourth block at depth, made up of material below the North American Plate but east of the San Andreas Fault and south of the Gorda Plate, is juxtaposed with these three named plates. The San Andreas Fault is the one that dominates in the interaction between the huge Pacific and the North American plates and some of its effects are felt far inland across the western part of the country. It is a rare situation to find these two plates, the Pacific and the North American, meeting on land as they do here. As a strike-slip one it moves as much as two inches a year and it has been doing this for more than fifty million years with a total displacement of hundreds of miles. Massive earthquakes are associated with it. Both the Pacific and North American plates are moving relative to the deeper parts of the earth, so the San Andreas Fault boundary is also moving, changing its shape in the process as the adjacent plates deform. In southern California, the sector of the fault from north of Los Angeles to east of San Bernardino has been rotating slowly counterclockwise. We tend to think of the margins between these plates as narrow lines because this is the way they are depicted on maps and we also tend to imagine the rest of the Cordillera as being static. The reality is quite different. The plates are moving on a sphere, not on a flat surface. In some places the plate margin may be hundreds of miles wide and the whole of California may be in motion at different rates in different places.

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58

Socorro 1, New Mexico, earthquake

July 16, 1906
Socorro, 150 miles north of the Mexican border

Considerable damage was done to homes but little loss of life, as far as is known, because of the low population density in 1906

On July 16 of 1906 Socorro, a town in New Mexico in the Valley of the Rio Grande, 150 miles north of the Mexican border, experienced an earthquake with a magnitude of at least 7. Numerous tremors preceded the event of July 16. They began on July 2 and there were equally numerous aftershocks that followed. Albuquerque, a hundred miles north of Socorro and even San Antonio in Texas, more than five hundred miles away, were shaken by this earthquake. Within the town of Socorro the walls of adobe houses were cracked and brick chimneys thrown down. Many people left their homes and lived in tents for a time to avoid the risk of their homes collapsing on them. The Socorro Hotel, a brick building in the eastern part of the town, had to be abandoned because of the severe damage it sustained.

The ground movements experienced during this earthquake were unusual. Boulders rolled on to railway tracks, breaking the tracks in some places and destroying ties elsewhere. Fissures formed in the ground near the center of the town and the land surface moved in waves as if it had been a lake. The entire business block in the center of town was very heavily damaged. Newspapers, in one or two cases, provided sensational accounts of what happened. One reported that the temperature of nearby hot springs had increased and another that the entire town of Socorro was in ruins with all its inhabitants fleeing. These were subsequently recognized as being false. In addition, as had happened prior to the earthquake, aftershocks in the form of recurring smaller tremors continued throughout the following months right up to the major event of November 15 of the same year.

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59

Socorro 2, New Mexico, earthquake

November 15, 1906
Socorro, 150 miles north of the Mexican border

Considerable damage was done to homes but little loss of life, as far as is known. Damage was much more extensive than in the July 16 earthquake because some development had occurred in the intervening months

An earthquake with a magnitude of at least 7 hit the town of Socorro on November 15, 1906. It was more powerful than the one that had occurred on July 16 of the same year. In the months between July and November there had been a succession of lesser tremors. Any place within 180 miles of Socorro felt the impact of this earthquake. It greatly increased the damage done by the July 16 quake and, in total, represented the most severe shock of the year 1906. Chimneys on the County Courthouse that had been rebuilt after previous damage were thrown down, plaster shaken from walls, upper floors of some two-storey buildings collapsed, and bricks were dislodged from a few houses. Many people in Texas and Arizona remembered the earthquake.

Isoseismals, lines joining places with equal earthquake intensity, are difficult to draw for this earthquake or for its predecessor in July of the same year, because of the limited amount of data available. Nevertheless, it was well known that strong shaking was experienced by people all over New Mexico and in parts of Arizona and Texas. Smaller shocks were observed to be single vibrations backwards and forwards while stronger ones vibrated in different directions. This pattern is usual in strong earthquakes like that experienced in November. There were also different sounds accompanying the vibrations. The search for the epicenter of this earthquake leads to an examination of the geological history, especially the existence of fault lines. The formation of new fault lines or volcanic eruptions or both of these are the two known causes of earthquakes. The lack of volcanic eruptions and the general character of the shocks suggest that no new fault lines appeared. It seemed likely that the cause of the earthquake was a slip action on an existing fault and its location was on the west side of Socorro.

The evidence for the location of the epicenter is found in the different things that happened. The overthrown chimneys and gables fell to the east. Both the directions taken by falling objects, and the directions in which earth movements occurred were measured in 1906 by hanging pendulums and marking the extent and direction of movement on the floor beneath. These pendulums had to be watched as they moved in response to the earthquake and the length of support as well as the end weight had to be consistent in order to make comparisons over time. The fact that both the July and the November earthquakes were preceded and followed by smaller tremors is consistent with the geological history of this region. Earthquakes have frequently occurred here in clusters over the past few thousand years. One series of earthquakes hit the area between 1898 and 1900. The November 1906 shock was the strongest recorded since 1869.

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60

Ecuador offshore earthquake

December 31, 1906
Offshore off Colombia, Ecuador, and Peru

An earthquake of this extraordinary size is capable of great damage. It created a huge tsunami that killed a thousand people along the coasts of the three countries and destroyed a large number of homes

Three very large earthquakes shook North and South America in 1906, the first on April 18 in San Francisco, California, the second on August 17 in Valparaiso, Chile, and the third on December 31 in the Colombia-Ecuador region. In all three cases, the earthquakes caused massive destruction of cities and a large number of casualties. Since early in the twentieth century seismic source investigations have revealed considerable information about earthquakes, though scientists are still unable to predict when they will occur, and these three dramatic events have give us fresh understandings of the enormous amount of activity occurring between tectonic plates all along the eastern coasts of the Pacific Ocean. In the case of the San Francisco earthquake it was a slip-slide movement of the plates on either side of the San Andreas Fault rather than subduction, and in South America it was the subduction of the Nazca Plate beneath the South American Plate.

With all the earthquakes that we hear about in Indonesia and Alaska, most of them of the subduction type, just like the ones of 1906, we get the impression that these two areas of the world have the biggest earthquakes of this type. This is not the case. A 1960 earthquake off the coast of Chile accounted for almost half of all the seismic action released worldwide in that year. The 1906 quake in Ecuador, beneath the margin of the South

American Plate, carried a rupture than was three hundred miles in length and was of magnitude 8.8, a rare event in geological history, only matched by such extraordinary events as the Alaska earthquake in 1964 and the Indonesia quake in 2004. Furthermore, the speed of subduction by the Nazca Plate is much greater every year when compared with Indonesia or Alaska. Subduction earthquakes occur when tectonic plates, as they gradually and continually move beneath other plates, encounter some resistance that slows them down. As tension builds up over time under mounting pressure from below there comes a moment when resistance snaps and one of the plates, usually the upper one, moves and causes an earthquake.

When one plate, usually the lighter continental crust, rides up over the top of the other it's called a subduction zone, because one plate margin is being subducted under the other. The lighter continental South American Plate is riding up over the heavier oceanic Nazca Plate. Deep down where the leading edge of the Nazca Plate is diving down under the South American Plate it makes contact with the molten magma of the earth's mantle. This melts the Nazca Plate margin sending magma chambers rising to the surface where they sometimes break through in volcanic eruptions. The chain of volcanic mountains known as the Andes is a result of the rumpling of the South American Plate where the Nazca Plate crashes into it. In view of the huge impact on land by these subduction earthquakes, why are there not more reports of damage to people? One reason is that the earthquakes are frequently offshore and another is that they equally frequently occur in places of low population density. The western part of Indonesia and the coastal areas of Peru and Chile are exceptions to these patterns and hence it is common to have large loss of life with South American events.

Whenever an earthquake as strong as the 1906 earthquake in Ecuador occurs, tsunamis can follow. In this particular case, about a thousand people on the coasts of Peru and Colombia were killed by the tsunami and many homes were destroyed. Other places also experienced tsunamis from this source. It was felt all along the coasts of Central America and in California. In the harbor at San Diego, boats at anchor were shaken and swung around by the force of the tsunami wave that reached this part of the United States. Similar effects were felt in San Francisco where tidal charts showed a rise in water level above normal. The Valparaiso earthquake of August 1906 triggered a tsunami that had similar effects in these Californian cities. Across the Pacific the Ecuador tsunami reached the Big Island of Hawaii about twelve hours after the earthquake and did a lot of damage around the port of Hilo. It must have traveled across the Pacific at more than 400 mph. Tsunamis can travel much faster than that depending on the obstructions they encounter. Japan too was hit by this same tsunami.

The story was the same when another earthquake, this time one in the interior of the continent, shook the interior of Chile. It was an intra-plate quake, on the border between northern Chile and Argentina, in the southern part of the province of Atacama. It struck on November 11, 1922, and it had a magnitude of 8. A tidal wave swept over Coquimbo, a coastal city about 250 miles to the south of the epicenter taking the lives of several hundred people and caused enormous property damage, subsequently estimated as ranging from $5 to $25 million. As happened with so many other earthquakes in South America the tsunami from this eathquake also hit Hawaii, reaching Hilo on the Big Island, the nearest point to Chile, in 14.5 hours with a wave height of seven feet. Many boats were washed away, and some damage was done. The tsunami reached the next part of Hawaii, Honolulu, half an hour later. On the west coasts of California the same tsunami wave was recorded at both San Diego and San Francisco with wave heights of less than a foot.

The Valparaiso quake of August 17 was more deadly than the one in Ecuador. The city of Valparaiso was destroyed and twenty thousand people lost their lives. The following description is taken from reports of people who lived through the tragedy. The earthquake seemed to go on for about fifteen minutes and the whole experience felt like standing on a wagon racing across uneven ground. Everything was thrown down, chairs, tables and desks inside, and buildings everywhere outside. The cries and the behavior of animals shocked us. Their squealing and lowing, coupled with the cries of people everywhere made the whole scene all the more terrifying. Rail lines and bridges were all out of action and the telegraph communications cut. A locomotive on a siding was thrown to one side and ended upside down beside the track. Huge openings in the ground appeared here and there, one of them big enough to swallow a large trunk. In addition, shallow fissures appeared in the ground, some over six feet wide and two hundred yards long. Large rocks rolled down from neighboring mountainsides and blocked roads.

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61

Monongah, Pennsylvania, explosion

December 6, 1907
Monongah, Pennsylvania

Monongah was an exceptional example of the great risks that have always faced miners. While some reduction in risks has occurred as technological improvements are brought into use, the risks still remain at an unacceptably high level

Pennsylvania and West Virginia were major producers of coal in the early years of the twentieth century. In Monongah, West Virginia, on December 6, 1907, the full horror of mining's dangers was brought home to everyone when 363 miners went down below to work and only one returned. Work began early on that morning soon after five o'clock. Coal dust, a potentially lethal material unless it is thoroughly dampened, lay all over the floor of the pits and was used by the men to pack the holes they had drilled and loaded with black powder explosives to loosen the coal. It was always a risky business as they used carbide lamps with open flames as their only source of light. Five hours after work began a huge explosion shattered the two connected pits. The explosion rocked the buildings above ground and was heard eight miles away. The devastation below was total and it was amazing that even one man escaped. He happened to be at the site of an open-air vent that reached the surface. For all the others death was instantaneous.

Dozens of bodies were so badly dismembered by the explosion that they could not be identified. The night before the explosion, instructions had been given to have the coal dust watered down but the person responsible

Figure 39 The day after the massive explosion at Monongah Mines in Marion County, West Virginia, that killed 361 coal miners in 1907.

for that work was moved to another mine shortly before he was due to do this work. The whole tragedy was the worst coal disaster in the nation's history and it marked the beginning of, for that time, new safety regulations. Connecting of underground mines in order to make them a single operation was made illegal immediately in West Virginia. Three years later the United States Bureau of Mines was established and it stopped nationally both the use of black powder as an explosive and the tamping of drill holes with coal dust. Accidents continued to occur across the United States for one of three reasons—explosions, fires, or roofs collapsing—and, in the years from 1900 to 1910, human error led to many tragedies. Knowledge of the dangers and ability to cope with them were both poor.

Throughout Europe, North America, and Australia, coal was the early twentieth century's primary source of energy for industry and transportation. It was mined intensively and often with inadequate attention to safety. The accelerating demands of industry led to shortcuts that increased output but endangered the lives of miners. Coal still remains a major source of energy, particularly for generating electricity, and there are enormous quantities available across the United States. At present rates of consumption supplies could last a thousand years. The room and pillar method of mining, in which in which masses of coal seams were left standing to support the overlying rock while the coal around them was taken out, was in widespread use. In this environment miners had to encounter and get used to new areas of work all the time. Death rates were very high. Even today they are higher than in most other industries.

In 1946, immediately after World War II, these rates in U.S. mines were still high, over seven hundred annually. Thirty years later, the death rate every year had dropped to one-third of the 1946 figure. Sometimes a whole underground region was endangered when a mine was not carefully closed down. In one place in Pennsylvania a mine was abandoned after a fire but some smoldering embers were ignored. Twenty years later the underground fire was still slowly burning.

Prior to the devastation at Monongah, similar disasters were occurring in different locations across the United States. Coal resources were widely available and the demand for coal continued to grow. Local initiatives could be launched to meet the needs of the market. In the period before 1910 there was little federal regulation of operations, and there was also limited state supervision. Mines were planned and worked by their owners and supervised by owner-appointed inspectors. On May 1, 1900, at the Pleasant Valley Company's Schofield Mine in Utah, two hundred lives were lost when a series of explosions occurred in two shafts. The cause of the tragedy was either ignorance or indifference. Thirty containers of black powder had been stored in one of the pits. None of the miners at work on an adjacent pit, using explosives, were told of the bomb next door. The story was often similar in other countries. Australia, like Britain and the United States, was heavily dependent on coal in the first part of the twentieth century. On July 31, 1902, a gas explosion occurred at a mine on the coast, fifty miles south of Sydney, killing ninety-six and injuring 152 others.

At this particular Australian mine, operations date back to 1883 where an eight-foot seam of coal was being worked. It was located some distance below ground and access was gained via a horizontal shaft below the coal seam. By the very nature of the site it was clear from the beginning that an explosion and fire would trap every miner and make escape or rescue almost impossible. An explosion would release quantities of coal, adding fuel to the fire and blocking off exits. For this reason responsibility lay heavily on the mine manager to ensure that no one went underground if there was the slightest indication of gas, especially since, at the time of the explosion in1902, open-flame lamps were still in use. As the explosion occurred roofs collapsed and coal cars were thrown about like toys. Blasts of hot gas swept through the work areas. Subsequent inquiries revealed that the mine manager was aware of small pockets of gas in the mine, despite his assurance to the miners, on the day of the explosion, that there was none. The explosion and subsequent tragedy was caused by contact between a miner's lamp and one of the gas pockets.

For the most part, in the early years of the twentieth century, most mine disasters were the result of either not dampening coal dust or not checking carefully for the presence of gas. With open flame lamps as the normal type of lighting it is easy to see now that these two things should have been given top priority. On July 10, 1902, at the Johnstown Mine in Pennsylvania, 112 men lost their lives in an explosion because no one checked for the presence of gas even though the mine was known to have gas. At the Hanna Mine, Wyoming, on June 30, 1903, the same neglect occurred and 169 miners were killed in the explosion and fire that ensued. Conditions were even worse then elsewhere in this case. Work was stopped for a time because of the accident but later resumed on a different level without attending to the problem that had led to the work stoppage. There was a second explosion and fifty-nine miners died. Local outrage forced the permanent closure of the mine.

In Alabama the men who worked the mines were often black chain-gang inmates who were serving time in hard labor. There was little recourse open to these men if something went wrong and this may explain why managers often took greater risks there than they should. Short fuses were sometimes used to save costs but that meant that workers had less time to get away from a blast site. On March 23, 1905, too much dynamite was used in one blast, triggering a general explosion that killed 112 men. Two years later, at another mine, an explosion took the lives of thirty-seven convicts because the management had not dampened the heavy layers of coal dust on the pit floor. Four years later, on April 8, 1911, at Alabama's Banner Mine, the same neglect of failing to check for gas and not dampening the coal dust caused an explosion that killed 128 men. The story of inadequate safety can be traced to other states where attention to the presence of gas and dry coal dust was neglected. In Colorado on April 27, 1917, managers of a mine with a history of tragedies allowed 120 men to go below without first checking for gas. All 120 were killed in the explosion that followed. It was the same outcome and again due to the same neglect of the mine's lethal elements that caused the death of 170 miners in Utah on March 8, 1924. The similar tragedy of 1900 in Utah seemed to have been forgotten.

Other factors than gas and coal dust can sometimes lead to catastrophic mining events. The Cherry Mine in Illinois had an excellent record for safety. On November 13, 1909, however, because there was a temporary problem with the electrical power circuit, electric lamps could not be used so open-flame gas lamps were introduced for the day. Mules were being used at this time to haul the mine carts and fodder for them, bales of hay, were stacked at the mine's entrance. A miner's lamp touched one of the bales but no one took any notice of it for some time. The hay smoked a little but there was no fire. Quite suddenly a flame shot up into the air and workers scrambled to get the hay away from the mine entrance, unaware that the big ventilation fans had already boosted the fire. It was too late to stop it and the heat forced everyone to step back.

Flames soon spread to the mine's wooden support pillars and almost simultaneously triggered gas explosions within the mine. The mules panicked and ran back into the shaft to get away from the smoke and heat. So did the miners who knew the lethal power of gas and smoke in the small spaces where they worked. The small handful of men who were outside the mine when the fire broke out decided to go down in the cage and rescue those trapped below. They were overcome by gas fumes and were all dead when the cage was pulled back up. In an equally futile and ill-informed move, the mine superintendent sealed off the entrance thinking that this would smother the fire. Underground damage was widespread and nothing could be done until the morning of November 14 when it was safe for rescuers to go down below. Rescuers found 170 men still alive. They had been able to get into small crevices away from the smoke. Another 259 men had died. It was the worst mine disaster in the history of Illinois.

In all of the above instances the tragedies were due to one of two things, carelessness or lack of experience on the part of miners, or failure by mine managers to take adequate safety precautions. The idea of a safe mine is now a top priority throughout the industry. The growing environment movement is expressing concerns about pollution and health risks. Companies are determined to show that, whatever environmental damage they may cause, at least they are deeply concerned for the safety of the miners. There is greater understanding of the geology of mine structures, better and safer equipment for all aspects of mining, and emergency resource kits. All these make it easier to safeguard the lives of those who work below ground.

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62

Amite, Louisiana, tornado

April 24, 1908
Amite, Louisiana, north of New Orleans

A series of tornadoes was triggered by thunderstorms. Amite was the strongest of these and it was responsible for the deaths of 143 people out of a total death toll of three hundred

In the first half of 1908 a series of severe thunderstorms triggered eighteen tornadoes across the central part of the Gulf states, killing more than three hundred people. The strongest of these was Amite, so named because it was in Amite that it did the greatest amount of damage. This F4 strength tornado arrived on April 24, 1908, and swept bare a path two miles wide as it raced along through Louisiana into Mississippi. Most of the town of Purvis, Mississippi, a town of 2,000, was leveled by it, leaving only seven of its 150 houses standing and causing half a million dollars worth of damage. By day's end Amite was responsible for the deaths of 143 and the injuring of 770 others, making it one of the country's deadliest.

Amite began as a two-mile-wide tornado and, as it passed on into Mississippi, its path narrowed to a width of half a mile and then to two hundred yards. As always happens when a tornado's path is narrowed, its destructive power increases, and so Mississippi experienced a more devastating storm than was seen in Louisiana. A railroad crew at work hid from the approaching storm inside boxcars but their refuge was far from being safe. The boxcars were thrown a distance of 150 feet and torn apart in the process. Seven people lost their lives in them. Thousands of tall pine trees were uprooted, broken and scattered.

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63

Louisiana hurricane

September 20, 1909
Grand Isle, south of and close to the city of New Orleans

Six million dollars of damage was caused in New Orleans and 350 people were killed

The Louisiana hurricane of September 20, 1909, is often referred to as The Grand Isle Hurricane because it was in Grand Isle that it first touched down and where it completely devastated everything around it. It came ashore on September 20, 1909, as a category 4 hurricane and moved across New Orleans causing huge amounts of additional damage, later estimated at six million dollars. It also was responsible for the deaths of 350 people largely as a result of the fifteen-foot storm surge brought by the hurricane. Extensive flooding occurred in its wake in the northern undeveloped swamp area north of New Orleans. Extensive flooding of this kind in New Orleans is exactly what happened in Katrina but, because low lying areas within the city limits at that time had little residential build up, the consequences of the flooding were much less severe than those of Katrina. The storm dissipated over Southern Missouri by September 22, leaving a memory of being one of the deadliest ever to hit the United States.

Hurricanes are part of a family of weather systems known as tropical cyclones. The word hurricane comes from a West Indian word that means big wind and it normally begins its life as a storm system over warm, tropical waters in the Atlantic. When a storm becomes more organized, it is classified as a tropical depression and given a number by the National Hurricane Center. If the winds increase to 40 mph, it is re- classified and given a name. Later, when the winds reach 75 mph it is upgraded to a hurricane. The winds of a hurricane are structured around a central eye, which is an area free of clouds and relatively calm. Around this eye, clouds wrap in a counter-clockwise direction. This wall of clouds, wind, and rain, is the most destructive part of the storm. In fact, it is the wall that creates the eye, since the rapid spinning clouds in the wall reduce the pressure in the eye and suck out any clouds that may be there. Hurricanes are usually compact storms, with maximum wind velocities extending out from 7 to 80 mph from the eye. Of course, one can still experience gale-force winds as far way as three hundred miles from the eye.

An overview of a season sometimes helps to understand a particular event within a season. The 1909 Atlantic hurricane season for example began officially on June 1, 1909, and lasted until November 30, 1909. These are the dates that conventionally define the period of each year when most tropical cyclones form in the Atlantic basin. The 1909 season was an average but destructive season; eleven storms formed, of which six became hurricanes. Four of those hurricanes became major hurricanes with winds of greater than 111 mph. The season started early, with two tropical storms and a hurricane. The first storm hit Nicaragua in mid-June and the second hit Texas as a category 2 hurricane near Brownsville. The third hit southeast Florida in late June. Activity continued through July, when a fourth, a tropical depression, formed over the southern Lesser Antilles in Mid-July. The storm attained tropical storm strength south of Jamaica, and reached hurricane strength near the western tip of Cuba. It ultimately hit near Freeport, Texas, on July 21 as a category 3 hurricane; with a ten-foot storm surge, this was the first test of Galveston's seawall, built after the destructive 1900 hurricane. Damage came to $2 million and forty-one people died.

The fifth tropical storm of the season formed on August 6 and hit Mexico twice, first on the Yucatán Peninsula and then near the border between Veracruz and Tamaulipas. The sixth storm formed east of the Lesser Antilles on August 20. The storm went westward, hitting the Dominican Republic and Southeast Cuba. The storm strengthend to a category 3 hurricane and hit the Northeast corner of the Yucatán Peninsula; a transmission on the hurricane from a vessel near the Peninsula became the first "ship report" to be used in a forecast. After weakening, it regained strength and hit Tamaulipas as a major hurricane on August 27. The death toll from this storm was staggering. Floods and landslides killed an estimated 1,500 people. The seventh storm formed over the Bahamas on August 28, hit near Miami as a tropical storm, and went out to sea. The eighth storm formed south of Hispaniola on September 13. It reached hurricane strength south of Cuba, and eventually hit southern Louisiana as a category 3 or 4 hurricane, making landfall at Grand Isle with a fifteen-foot storm surge. Warnings came to New Orleans before 1909 and even more after that date, reminding the city of its vulnerability to hurricanes long before the days of Katrina in 2005. A major hurricane hit the city in September of 1722, leveling many of the buildings in the young city. The year 1794 was perhaps as dreadful a year as the city of New Orleans ever experienced, as it was hit by two hurricanes in addition to a major fire.

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Oregon earthquake

August 5, 1910
Offshore from Oregon's coast

The strongest earthquake in Oregon's history hit the State from an offshore epicenter. Damage from this particular earthquake was minimal

Two of the largest earthquakes in Oregon occurred in 1910 and 1993. The 1910 earthquake was the largest historical shock within the state's boundaries at a magnitude of 6.8, but it occurred too far offshore to cause damage, whereas the damaging 1993 earthquake was the largest historical earthquake beneath the land area of Oregon, with a magnitude of 5.9. There have been no big earthquakes in Oregon's brief history, and there is no question that damaging earthquakes have been far less frequent in Oregon than in California or Washington. However, geologic research tells scientists that Oregon will some day experience big earthquakes, and both the Scotts Mills earthquake of March 25, 1993, and the Klamath Falls earthquake of September 20, 1993, confirm such research. Because the Oregon is poorly prepared, the damage could be great.

Geologic research has shown that Oregon and Washington have probably been shaken by numerous subduction zone earthquakes during the last several thousand years. Subduction zone earthquakes occur when two great crystal plates slide past each other beneath the coast of Oregon and Washington. These earthquakes occur, on average, every 300–600 years, and the most recent was about three hundred years ago. The subduction zone earthquakes were probably centered just off the coast of Oregon and Washington and may have been as large as magnitude 8 to magnitude 9. Such earthquakes would cause significant shaking and damage in much of western Oregon. Scientists cannot predict whether the next such event might occur in two years or two hundred years.

Local earthquakes are most common in the Portland metropolitan area, northern Willamette Valley, and Klamath Falls area and may threaten the coast from Coos Bay south to Brookings. There is little knowledge at the present time as to the risk of local earthquakes in most other parts of western Oregon. All of Oregon west of the Cascades, as has been pointed out above, is at risk from the subduction earthquakes that will come some day as the Juan de Fuca Plate continues to move beneath the North American Plate. The amount of earthquake damage at any place will depend on its distance from the epicenter, local soil conditions, and types of construction. To date, no fault in western Oregon has been proven to be likely to move in an earthquake. Although many faults have been identified, it cannot be said yet whether being near a fault is any more hazardous than being far from one.

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65

Titanic iceburg tragedy

April 15, 1912
The North Atlantic, four hundred miles south of St. John's, Newfoundland, and eight hundred miles east of New York

The unsinkable Titanic *was suddenly sunk as it collided with an iceberg. Through a variety of failures the* Titanic *was sunk by an iceberg and, due to an equally tragic series of failures in terms of sufficient lifeboats, 1,490 lost their lives*

Their regulations had been written in 1894 and they stipulated that every ship over 10,000 tons must carry sixteen lifeboats. The ship's designers knew that the *Titanic* could stay afloat if four of its sixteen watertight compartments were flooded, but it could not survive if five were flooded. No one ever suspected that as many as four would be flooded at one time and this fact may have given rise to the idea that the ship was unsinkable. On April 10, 1912, the *Titanic* left Southampton on its maiden voyage to New York. Next day the ship received radio messages telling of large icebergs that were much farther south than usual. Captain Smith accordingly altered course toward the south, maintained speed at twenty-two knots and gave instructions to lookouts to be especially vigilant.

Titanic, on its first transatlantic voyage from Southampton to New York, was eight hundred miles east of Halifax, Canada, on April 15, 1912, when it hit an iceberg. Within a minute or two, a 300-foot gash was cut in the ship's steel side and about an hour later the *Titanic* was listing seriously. The captain ordered everyone to take to the lifeboats and two hours later the ship sank. Of the 2,227 passengers aboard 1,490 lost their lives.

In the years before World War I there was heavy sea traffic between Europe and North America. Immigration from Europe to the United States was at a peak and the growing industrialization of the United States was a magnet for European businessmen. Ships competed for both economy and luxury travel. Speed of travel was also in demand and some ship owners concentrated on that. In 1907, the British White Star Line decided to build ships that would focus on luxury, size, comfort, and safety, rather than speed. On May 31, 1911, four years later, the first of these ships, the *Titanic*, was launched. From its moment of launch it was known as a "safe" ship compared with all other vessels of that time.

The *Titanic* weighed more than 46,000 tons, stood eleven stories high and four city blocks long, was divided into sixteen watertight compartments for safety, and carried twenty lifeboats. This was four more lifeboats than the Board of Trade regulations required. The *Titanic*'s reputation of being unsinkable created an atmosphere of complacency, almost arrogant indifference, from the captain all the way down to the least deck hand. So widespread was this outlook that when the call to abandon ship was made a large number of passengers refused to believe what they were told. There was a casual approach to safety in the minds of the ship's officers as evidenced by the things that were not done. No formal boat drill was arranged for passengers, a normal procedure to ensure orderly behavior in an emergency. There were lifeboats for only one-third of the passengers, legally correct but hardly responsible, and there was little concern over the danger of icebergs.

Radio was a fairly new thing in 1912 and large numbers of passengers used it to send messages to friends in Europe and the United States, describing life aboard the *Titanic*. The ship's radio operator was so heavily engaged in sending these private communications that he paid little atten-

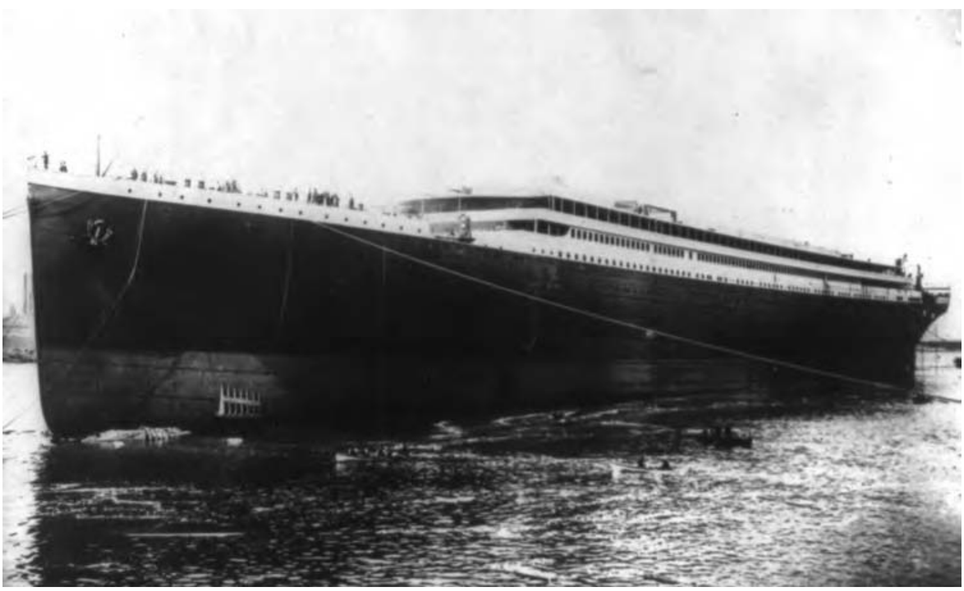

Figure 40 The *Titanic*.

tion to the warning signals about icebergs from other ships. Some urgent messages about icebergs that arrived at noon did not reach the navigation officer until 7:00 P.M. Even a drop in the outside air temperature around the ship, a clear indication of proximity to an iceberg, from forty-three degrees to freezing in the course of one day was ignored by those in command. Sunday, April 14, 1912, was cold but visibility was good. Messages kept arriving from other ships warning of the presence of icebergs in the main shipping lanes. The *Titanic*'s Captain Smith still seemed indifferent to these warnings.

It was well known that most of an iceberg's bulk floats below the surface so it was always important to keep a safe distance from the part one could see above water. Captain Smith may have been more concerned with the hope of gaining a new crossing record because, instead of slowing down to make sure that the ship kept well clear of icebergs, he maintained a speed of twenty-two knots, about 25 mph, a high speed for ships at that time. Shortly before ten o'clock in the evening the seventh ice warning of the day arrived, telling of a huge mass of ice less than eighty miles directly ahead. An hour later an urgent message was sent to all ships in the area from a ship, the *Californian*, twenty miles away, which had stopped its engines because of an eighty-mile stretch of ice directly ahead. At the same time, the *Californian'* sradio operator tried to call the *Titanic* but, finding that he was met with a blunt "Keep out" response, decided to retire for the night.

Close to midnight, as the *Titanic* pushed ahead, lookouts in the crow's nest, high up on the foremost mast, spotted an iceberg off the right side of the ship, almost directly ahead and towering sixty feet above the water. The warning signal was triggered. The engine room was ordered to stop the ship and then go full speed astern, but the warning came too late. Even as it began to swing away toward its left side, the ship hit the iceberg below the surface. The crew felt a bump and heard a scraping sound. They concluded that nothing serious had happened but the first officer as a precaution decided to close all the watertight doors below the waterline. The elapsed time from the moment of sighting until the watertight doors were closed was about half a minute.

The ice had gashed a series of openings in the steel side of the ship and water was pouring in. Within ten minutes, fourteen feet of water filled the forward part of the ship. All five compartments were flooded and, after another ten minutes, water rose to twenty-four feet above the keel. Captain Smith and the managing-director of the shipyard that built the ship, Thomas Andrews, were by now on the bridge assessing the damage. Andrews knew that the ship could only stay afloat for a little more than one hour if five compartments were flooded and he told Smith so. Distress signals were immediately sent out and preparations made for abandoning ship. The bow area was already sinking. Twenty-five minutes after the first sighting of the iceberg, Captain Smith gave orders that the lifeboats be made ready.

The captain knew that the lifeboats could only carry 1,178 out of the 2,227 on board even if every boat was filled to capacity, and he was anxious to avoid panic. Rockets were fired aloft and the *Californian*, which was still nearby, saw the rockets but the ship's operator had retired for the night soon after getting the earlier rejection from the *Titanic*. He had been at his station for sixteen hours. The *Californian* tried to make contact using light signals but, when that failed, it made no further attempts. Several other ships received the radio signals but they were all some distance away.

About an hour after hitting the iceberg the first lifeboat was launched, but inadequate planning together with passenger apathy saw it leave with twenty-eight people instead of its capacity load of sixty-five. Even as this boat was being lowered into the water many passengers felt it was safer to stay on the ship. They refused to believe that the *Titanic* would sink despite the abandon ship order. Other lifeboats too left with partial loads, one with forty-two, a second with thirty-two, and a third with thirty-nine. Much later, when the tally of survivors was examined, there were questions. Why did one boat leave with seven, two members of the crew and five who were mostly from first-class cabins? Was it impossible for passengers from down below to reach the boats in time because of the barriers that separated third from first class sections of the ship?

Approximately two hours after it had hit the iceberg the *Titanic* was

Figure 41 *Titanic* lifeboats on their way to the *Carpathia*.

listing heavily to port, its bow close to the water. People found it hard to keep their balance and panic was setting in. As one of the last boats was being launched and was already almost full, a group of passengers tried to jump in. An officer in the boat had to fire two warning shots to hold them back. As another boat was being loaded the crew linked arms and formed a chain around the boat, allowing only women and children to get on board. Captain Smith walked around, thanking various ones for the work done then headed for the bridge to go down with his ship, a long-standing maritime tradition. In the final moments many jumped off the ship. By hanging on to pieces of wreckage or, in a few cases, by being taken on board a lifeboat, some of these survived.

The *Carpathia*, a ship that was sixty miles away, received the distress messages and headed for the location of the *Titanic*, arriving shortly after 4:00 A.M. long after the *Titanic* had completely disappeared. For several hours the *Carpathia* took on board those in lifeboats as well as survivors from the sea, thus succeeding in rescuing 711 who were taken to New York. One thousand four hundred and ninety lives were lost, the worst ever tragedy at sea. Many were lost because they were unable to cope with the near zero temperatures. Ships from Halifax, Canada, were dispatched to pick up bodies. One hundred and ninety were recovered and these were interred in Halifax. Many years later, in 2001, some of these remains were exhumed in attempts at identification, using DNA techniques.

A British public inquiry was conducted as soon as the survivors were able to attend. They were delayed for some time in order to answer questions from the U.S. Senate. The inquiry was held in London and it centered on possible navigational negligence on the night of the disaster. Was the ship traveling too fast? Were officers attentive to the various warnings of ice? Why was it that the total number of survivors was far less than the total capacity of all the lifeboats? Were the third class passengers held back and locked below decks in order to allow those in second and first class to escape? The inquiry exonerated the captain and crew in words like the following: while the collision with an iceberg could have been avoided it was not a direct result of negligence on the part of either Captain Smith or any member of his crew.

Captain Rostron, *Carpathia'* sskipper, was commended by members of both U.S. and British authorities for his courageous efforts to reach the *Titanic* in time to save her passengers. In pushing his ship to its limits and dashing through treacherous waters he was seen as a true hero. The captain of the liner *Californian*, on the other hand, was regarded as almost a villain because he did not do all he could to save lives. Almost immediately after the public inquiries were completed dramatic changes were made in the rules regarding icebergs and lifeboats. The International Ice Patrol was instituted, ensuring constant watch on errant icebergs, and winter shipping lanes were moved farther south. Twenty-four-hour radio watch was required for all ships and sufficient lifeboats to accommodate everyone became mandatory.

These outcomes from the U.S. and British formal inquiries concentrated on the shipping errors and loss of life, but beneath all of these and only lightly touched on by the investigators lay some serious social issues. Not least of these was a tradition of class distinction when filling lifeboats. While the owners of the *Titanic* denied that any such practice existed, it was well known among other ships of that time. When the liner *Republic* went down, four years earlier, the captain told the passengers as they approached the lifeboats, remember women and children first, then first class passengers followed by all the rest. Whatever might have been the unspoken rules on the *Titanic*, the reality was blatant discrimination.

Out of the first class women passengers, 3 percent lost their lives, while 16 percent of second class women drowned, and in steerage, the lowest class, 45 percent of the women died. The barriers set up to keep the different classes of passengers from mixing became death traps. Steerage passengers were seen climbing out on whatever protrusions they could access on the sides of the ship in order to reach a deck above the water. When the last lifeboat was launched and the ship's officers were convinced that all women had been accounted for, dozens suddenly appeared from steerage sections. Such was the pathetic lack of organization for coping with an emergency. Two women from steerage were stopped as they walked toward one of the boats on the first class deck and ordered to go down to their own deck to board there, something that was quite impossible at that stage.

This traditional class distinction appeared again in New York as the *Carpathia* brought survivors ashore. Survivors' stories became headlines in newspapers but they were almost all from first class passengers. The horror of more children from steerage being drowned than men from first class was hardly noted. Investigators from both members of Congress and the British authorities ignored the steerage passengers. It was a similar story among the media representatives, at least for a time. Then questions began to surface about how some important men survived while a hundred women were lost. By exposing so many of these habits of class distinctions, the *Titanic* put an end to many of them. It destroyed much of an era of privilege that looked inappropriate, even indecent, in the light of the unfair treatment accorded people on that night of April 15, 1912.

Seventy-three years later, Robert Ballard and his team from Woods Hole Oceanographic Institution, Boston, discovered and photographed the wreck of the *Titanic* as it lay on the seabed at a depth of two miles, three hundred miles south of Newfoundland. Ballard's wish was that all who followed him would respect the site and not interfere with it. He felt it was a gravesite that ought to be left undisturbed. Interest in the wreck, however, was too strong for others to accept that recommendation. Two years after Ballard's discovery, a French expedition, backed by money from the United States, went to the site and recovered artifacts. The French submersible *Nautile*, used by the expedition, dived more than thirty times and spent about two hundred hours on the ocean floor.

Approximately nine hundred artifacts were discovered, many of them objects that no one knew had been aboard the ship. New light was cast on the *Titanic* and the condition of the wreck. There was a cache of Spode china with blue and gold patterns that caught historians of the *Titanic* by surprise. A bag stuffed with jewelry, U.S. banknotes and gold coins was also recovered. Some of the important navigational and communication instruments were also salvaged, such as the ship's telegraph, operated by a system of wires and pulleys. There were many other interesting objects including sterling silver knives, forks, and spoons, cut-glass carafes, white ceramic egg dishes, a bottle of champagne, a teapot, and a jar of skin cream.

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66

Katmai, Alaska, volcanic eruption

June 6, 1912
Mount Katmai, west of Kodiak Island

Volcanic ash in volume greater than the sum of all other volcanic eruptions in Alaska was ejected and devastated every place within miles of the eruption

The largest twentieth century eruption anywhere on Earth occurred in Alaska, on June 6, 1912, creating the Katmai Caldera and the Valley of Ten Thousand Smokes. Volcanic ash, in quantities more than from all other historical eruptions in Alaska combined, devastated areas hundreds of miles away. An ominous cloud rose into the sky above Mount Katmai, reached an altitude of twenty miles, and within four hours ash from this huge volcanic eruption began to fall on the village of Kodiak, one hundred miles to the southeast. By the end of the eruption, the ash cloud, measuring thousands of miles across, shrouded southern Alaska and western Canada, and sulfurous ash was falling on Vancouver, British Columbia, and Seattle, Washington. On June 7, the cloud passed over Virginia and by June 17, it had reached Algeria in Africa.

During the three days of the eruption, darkness and suffocating conditions caused by falling ash and sulfur dioxide gas immobilized the population of Kodiak. Sore eyes and respiratory distress were rampant, and water became undrinkable. Radio communications were totally disrupted and, with visibility near zero, ships were unable to dock. Roofs in Kodiak collapsed under the weight of more than a foot of ash, buildings were overwhelmed with ash, and many structures were burned. Novarupta, mean-

Figure 42 W. A. Hesse taking moving pictures of Katmai Volcano in 1912.

ing "new eruption," is a volcano that sits below Mount Katmai and that shared in the eruption, an event that was ten times more powerful than the 1980 eruption of Mount St. Helens. More than three cubic miles of volcanic material was ejected over two and a half days. The 1815 eruption of Tambora, by comparison, displaced about seven times as much material. The 1883 eruption of Indonesia's Krakatoa displaced twice as much. Magma from underneath Mount Katmai area was drained away, leaving a collapsed caldera that measured four square miles in surface area.

Several villages were abandoned forever and much animal and plant life had been decimated by ash and acid rain. Bears and other large animals were blinded by ash and starved when large numbers of the plants and small animals they lived on were wiped out. Millions of dead birds that had been blinded and coated by volcanic ash littered the ground. Aquatic organisms, such as mussels, insect larvae, and kelp, as well as the fish that fed upon them, perished in ash-choked shallow water. Alaska's salmon-fishing industry was devastated, especially from 1915 to 1919, because of the failure of many adult fish to spawn. Augustine is a good example of the frequency of volcanic eruptions in and around Cook Inlet, but Mount Katmai, a 6,000 foot peak, is an example of quite a different kind: as the world's largest twentieth century eruption it is certainly Alaska's worst ever within historic times. Mount Katmai and its sister mountain, Novarupta, are about ninety-five miles southwest of Augustine and three hundred miles southwest of Anchorage, within what is now known as Katmai National Park and Preserve. When the eruption happened, after centuries of silence from both of these mountains, more than three cubic miles of ash and small particles were blown into the sky, giving rise to a new name for the area—"Valley of Ten Thousand Smokes." Villagers from Katmai and other nearby communities moved away to a safer location.

The Katmai area was permanently changed by the eruption. Enormous quantities of hot, glowing pumice and ash flowed over the terrain, destroying all life in its path. Trees up slope were snapped off and carbonized by the blasts of hot wind and gas. For several days after the explosion ash, pumice, and gas created a haze that darkened the sky over most of the Northern Hemisphere. When it was over, more than forty square miles of lush green land lay buried beneath volcanic deposits as deep as seven hundred feet deep. For two full days, people in nearby Kodiak could not see a lantern held at arm's length. Acid rain caused clothes to disintegrate on clotheslines as far away as Vancouver, Canada. In the valleys of Knife Creek and the Ukak River, innumerable small holes and cracks developed in the ash deposits, permitting gas and steam from the heated groundwater to escape. A ship moored in Kodiak harbor at the time of the eruption gave this account of events. Five inches of ash fell everywhere, choking all wells and streams on shore. Visibility dropped to fifty feet and after about two more hours, at a time when the sun would have been shining brightly, pitch darkness set in and continued into the morning of the next day. Decks, masts, and lifeboats were all covered with a fine, yellowish-colored dust.

Avalanches of ashes could be heard sliding down the neighboring hills and sending out clouds of suffocating dust. The crew on ships kept working continually with shovels and hoses to try to get rid of the ash. The amount on the ground of Kodiak averaged one foot in height. Like other gigantic events of this kind, where ash and other materials are flung high into the upper atmosphere, the effects of Katmai's eruptions were felt far and near. There were over 40,000 square miles of the surrounding area covered with ash to an average depth of two inches. Smaller amounts of ash fell on Juneau, more than seven hundred miles to the southeast and still less on Seattle, about 1,500 miles to the south. Some ash particles reached far enough into the atmosphere that they were caught in global circulation patterns and provided spectacular red sunsets for months. In terms of the original volume of molten rock released, comparisons can be made with other major events. On this basis, there were three cubic miles of magma ejected from Katmai, thirty times greater than the volume of magma released in the 1980 eruption of Mount St. Helens. Even the 1991 eruption of Mount Pinatubo, the second largest of the twentieth century, was less than half the size of Katmai's.

In 1916, a National Geographic Society expedition led by Robert Griggs visited Mount Katmai and found a two-mile-wide crater where its summit had been before 1912. Nearby, the expedition discovered a newly formed lava dome they called "Novarupta" and huge flows of volcanic ash filling what they named the "Valley of Ten Thousand Smokes" for the numerous plumes of steam rising from the still-hot ground. Griggs' descriptions of these spectacular features helped persuade President Woodrow Wilson to create Katmai National Monument (now Katmai National Park) in 1918. In the 1950's, volcanologists discovered that the great Alaskan eruption of 1912 was not really from Mount Katmai, as previously thought, but from a new vent at Novarupta. The eruption removed so much molten rock (magma) from beneath Mount Katmai, however, that a cubic mile of Katmai's summit collapsed to form a two-mile-wide volcanic depression, a caldera, now a lake eight hundred feet deep. Despite the fact that the eruption was so close to the Continental United States and comparable in magnitude to that of Krakatau of 1883, it was hardly known at the time because the area was so remote from the world's main population centers.

Almost a hundred years after it happened, researchers are paying attention to Katmai because it is near the Arctic Circle and its impact on climate appears to be quite different from that of volcanoes in lower latitudes. When a volcano erupts anywhere, it does more than spew clouds of ash locally and shadow a region from sunlight so that it cools for a few days; it also blows sulfur dioxide, a gas irritating to the lungs and smelling like rotten eggs. If the eruption is strongly vertical, it shoots that sulfur dioxide high into the stratosphere as far as ten miles above the Earth. In the stratosphere, sulfur dioxide reacts with water vapor to form sulfate aerosols. Because these aerosols float above the altitude of rain, they don't get washed out, they linger, reflecting sunlight and cooling Earth's surface. A condition of this kind can create a kind of nuclear winter for a year or more after an eruption. In April 1815, for instance, the Tambora volcano in Indonesia erupted. The following year, 1816, was called "the year without a summer," with snow falling across the United States in July. Even the smaller, June 1991, eruption of Pinatubo in the Philippines cooled the average temperature of the northern hemisphere summer of 1992 to well below average. However, both of these eruptions, as well as Krakatau, were tropical events. Katmai and Novarupta are just south of the Arctic Circle.

Using a NASA computer model at the Goddard Institute for Space Studies (GISS), Professor Alan Robock of Rutgers University and colleagues found that Katmai's effects on the world's climate would have been different. The stratosphere's average circulation is from the equator to the poles, so aerosols from tropical volcanoes tend to spread across all latitudes both north and south of the Equator, quickly circulating to all parts of the globe. Aerosols from an arctic eruption tend to stay north of 30°N; that is, no further south than the Continental United States or Europe. These aerosols would mix with the rest of Earth's atmosphere only very slowly. This bottling up of arctic aerosols in the north would make itself felt, according to the findings of GISS, in India. According to the computer model, the Katmai blast would have weakened India's summer monsoon, producing an abnormally warm and dry summer over northern India. Why India? Cooling of the northern hemisphere by Katmai would set in motion a chain of events involving land and sea surface temperatures, the flow of air over the Himalayan mountains and, finally, clouds and rain over India. This is an unusual and rather complicated conclusion from Robock's research and it only became clear when the supercomputers were employed in the calculations.

To check the results of his study, Robock and colleagues are examining weather and river flow data from Asia, India, and Africa in 1913, the year after Katmai. They are also investigating the consequences of other high-latitude eruptions in the last few centuries. The fact that the stratosphere in high latitudes is shallower than at the tropics means that even small eruptions near the North Pole may deposit more aerosols than bigger events in the tropics. Furthermore, they would remain in circulation longer as happened with Katmai. Indians will need to keep an eye on Arctic eruptions. There is yet another consideration: even years after an eruption, volcanic ash deposited within two hundred miles of the eruption site would be remobilized by windstorms and blown high into the atmosphere, renewing the hazards for people and machinery. Fish and wildlife would be devastated as they were after the 1912 eruption, wreaking prolonged havoc on Alaska's now large and economically important fishing and tourism industries.

The chance of another Katmai-scale eruption occurring in any given year is small, but such cataclysmic volcanic events are certain to happen again in Alaska. Within five hundred miles of Anchorage, volcanologists have identified at least seven deposits of volcanic ash younger than 4,000 years that approach or exceed the volume of ash ejected by Katmai in 1912, including a thick layer of ash erupted from Hayes Volcano, only ninety miles northwest of Anchorage. Of the numerous volcanoes scattered across southern Alaska, at least ten are capable of exploding in a 1912-scale eruption.

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67

Omaha, Nebraska, tornado

March 23, 1913

A mile-wide twister in the city of Omaha

This tornado took the lives of ninety-six people, destroyed six hundred homes, and damaged more than 1,100 others

On the evening of Easter Sunday, March 23, 1913, a tornado storm of multiple parts passed through Nebraska and hit Omaha. It was close to a half mile wide and it stretched back as far as forty miles. This storm marked the darkest day in Nebraska's history as far as weather extremes are concerned. It started in Sarpy County, ripping its way northeast through Ralston, where seven people were killed. The twister then cut across Omaha and killed ninety-six people, destroyed six hundred homes, and damaged more than 1,100 others. The tornado followed the path of Little Papillion Creek as it entered the city before moving through the west side of town alongside the Missouri Pacific Railroad, destroying the small workers cottages in that area. This storm was so strong that steel train cars were pierced by pieces of shattered lumber from the demolished homes.

Easter Sunday began under cloudy skies in Omaha in1913. Rain threatened but never fell on the city, and by noon the skies had brightened to the point where the sun began to peek through. In the afternoon the skies darkened again as a massive storm system moved into the area from western Nebraska. At 5:45 P.M. the tornado touched down near Kramer, and then raced northeast to reach the outskirts of Omaha by 6 P.M. By the time the funnel cloud reached Dewey Avenue it was five blocks wide. When it reached Farnham Hill it followed a shallow valley through this upscale neighborhood. Even the large mansions of Farnham were unable to cope with the winds and many houses were torn to pieces. Others were later found chopped in half, pipes and supports dangling in space. At 24th and

Figure 43 Omaha, Nebraska, at 24th and Lake Streets, after the tornado in 1913.

Lake Streets a large crowd was enjoying a show at the Diamond Moving Picture Theater. The tornado flattened the building. Other brick structures in this small commercial district took similar hits, and this became the place where most of the casualties occurred. A streetcar running down 24th Street encountered the tornado near this area. Thanks to the quick actions of the streetcar's operator, every passenger survived. Later, people who saw the wrecked streetcar called it the streetcar of death because they were sure that no one had survived, given the immense amount of damage it had sustained.

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68

Texas hurricane

August 4, 1915
Galveston on Galveston Island

A storm surge of twelve feet inundated the business district of the city to a depth of six feet and killed 275 people

A monstrous hurricane formed near the Cape Verde Islands on August 4, 1915, and moved just south of the Greater Antilles, reaching the Texas coast near Galveston on August 16. In Galveston many people, with memories of the 1900 hurricane still fresh in their minds, left town as soon as it was clear that the storm would hit Galveston. Storm surges of twelve feet were seen at Galveston, inundating the business district to a depth of five or six feet. Many houses were demolished and all beach houses were washed away. Overall this hurricane, one that was a category 4 hurricane as it touched down, caused a great deal of destruction in its path, leaving 275 people dead and causing $50 million dollars worth of damage.

In Galveston, with strong winds, tides nine feet above normal, and a storm surge of sixteen feet, the ten-foot-high seawall built after the 1900 hurricane was unable to withstand the volume of water. It was partly damaged and this led to severe flooding in different parts of the city and the removal of twenty-five feet of the beach close to he seawall. Close to three hundred homes outside the seawall were destroyed. Despite the damage done to it, the seawall did achieve widespread protection for the city as a whole as evidenced by the low death toll compared with 1900. The devastation occasioned by the powerful hurricane of that year, the deadliest of its kind anywhere in the United States in modern times, led to the massive reconstruction of the whole city. Recovering from the 1900 storm involved building a seawall and raising the island's elevation significantly above sea level. In effect, the plan involved changing the entire natural environment of the city. The people of New Orleans must have often wondered why the same thing was never contemplated for their city. They have the same problem as Galveston, living on territory that in places is barely above sea level.

The challenge of raising an entire city began with a decision to raise its elevation by seventeen feet and surround the whole uplifted area with a ten-foot seawall. On the ocean side of this wall the land would slope down to the water on a slope of one foot for every 1,500 feet. To get the required quantities of sand, sixteen million cubic yards, enough to fill more than a million dump trucks, Galveston's ship channel was dredged and the sand was piped into the city in a slurry form. Quarter-mile sections of the city were marked off and protective walls erected around them. The theory was that, as the water drained away, the sand would remain as a hard surface. Before any work could be initiated, every building had to be raised and all service lines, sewer, water, and gas lines, had also to be raised. Even some gravestones had to be raised. The wall went up in stages year by year and the 1915 hurricane, with the same strength as the hurricane of 1900, was the first real test of the wall and the elevated interior. After leaving Galveston, the weakening 1915 storm took a turn to the northeast and passed Houston as a category 1 hurricane before dropping to tropical storm status later that day. In Galveston a series of fires broke out after the storm's passage and relief aid was slow because the causeway that connected Galveston to mainland Texas had been badly damaged by the hurricane.

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69

Pleasant Valley, Nevada, earthquake

October 3, 1915
Pleasant Valley, south of Winnemucca

Pleasant Valley was thinly populated and the main impact of the quake was geological, creating a twenty-mile scarp at the base of the Sonoma Mountains

The largest earthquake in Nevada's history up to 1915 occurred on October 3, 1915, and was centered in Pleasant Valley, south of Winnemucca. This earthquake had a magnitude of 7.1 and it was followed by several aftershocks that disturbed a large part of northern Nevada. It destroyed or seriously damaged many adobe houses in Pleasant Valley. Most of the damage was confined to the towns of Kennedy, Lovelock, and Winnemucca. The earthquake was felt over a very wide area, from Baker, Oregon, to San Diego, California, and from the Pacific coast to beyond Salt Lake City, Utah. A scarp four to fourteen feet high and more than twenty miles long was formed parallel to the base of the Sonoma Mountains. It broke the surface in four different places for a distance of thirty-seven miles. The largest offset of the ground was nineteen feet of vertical movement.

This earthquake occurred along a fault on the eastern side of Pleasant Valley, about forty miles southeast of Winnemucca, in the north-central part of Nevada. This location of the epicenter was almost uninhabited and, therefore, property damage was less than might have been expected. Damage was confined mainly to an area within forty-five miles of the Pleasant Valley Fault. The combined length of the scarps was thirty-five miles, the average vertical displacement six feet, and the maximum dis-

Figure 44 Pleasant Valley, Nevada, earthquake, 1915. Tobin Range, looking east. The white line at the base of the mountains is a fault scarp from the 1915 Pleasant Valley earthquake.

placement eighteen feet. Several northwest-striking segments of the scarps had a right-lateral component of displacement, generally less than three feet.

At Kennedy, two adobe houses were destroyed, mine tunnels collapsed, and concrete mine foundations were cracked. At Winnemucca, adobe buildings generally were damaged, and several multistory brick buildings lost their coping and parts of upper walls; many chimneys were demolished above the rooflines. In addition, water tanks were thrown down at Battle Mountain, Kodiak, Lovelock, and Parran. Damage occurred on several ranches at the southern end of Pleasant Valley. An adobe house was shaken down, a masonry chicken house and a hog pen were destroyed, and houses were displaced from their foundations. There was a large increase in the flow of springs and streams throughout northern Nevada and cracks formed in unconsolidated materials for considerable distances.

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70

Mattoon, Illinois, tornado

May 26, 1917
Mattoon, southeast of Springfield

Mattoon was responsible for the deaths of 121 people in the town of the same name and the destruction of 2,000 of its homes

The Mattoon tornado of May 26, 1917, which caused 101 deaths, injured 638, and did $55 million in property damage, was one of two worst tornadoes the state ever experienced. The other of these tornados was the deadliest in the United States, the Tri-state tornado of 1925. The 1917 tornado was a powerful F4 and tore Mattoon apart, killing 101 persons, injuring 689, and leaving more than 2,000 homeless. The business section of Mattoon experienced the worst amount of damage. The storm, traveling from east to west, devastated the entire northern half of the town, leaving no building standing in a section several blocks in width. The Mattoon tornado was the world's longest-lasting tornado, lasting for over seven hours and traveling 293 miles, spreading death and destruction along its path from Missouri through Indiana and then to Illinois. It was also the thirteenth deadliest tornado in U.S. history. Charleston and Mattoon are vulnerable to many disasters, including tornadoes and, because of their locations in what has come to be known as tornado alley, they must always live with capricious weather.

At 7 A.M. on May 19, 1917, a trough of low pressure lay west of Illinois. The isobar of 29.60 inches enclosed an elongated area extending from western Lake Superior to eastern Kansas. The center of this area was at St. Paul. Southerly winds and mild temperatures were general in the Mississippi Valley as far north as Minnesota. By 7 P.M. the center of the low-pressure area lay north of Lake Superior. Thunderstorms had occurred over northern and central Illinois, and winds were west at Springfield and northwest in all of western Illinois. At Springfield the wind veered from southeast to southwest and later to west and northwest. It was evident that the tornado developed at the time of the wind shift. In the aftermath of the tornado, Mattoon and Charleston took up the task of recovering dead bodies, nursing the injured, and housing and feeding the homeless.

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71

Halifax, Nova Scotia, Canada, explosion

December 6, 1917

Two ships collided in the narrow entrance to Halifax Harbor

The explosion that ensued was one of the world's greatest prior to the arrival of atomic bombs. It shattered the port of Halifax and surrounding area. The death toll was 1,600, while 9,000 others were injured, and 6,000 homes were destroyed

Two ships were approaching Halifax harbor on the morning of December 6, 1917, one arriving, loaded with ammunition, and the other on its way to Europe with a load of coal. Some confusion existed between the two ships, in spite of the fixed rule about how to pass, over whether to pass on starboard or port sides of the ships, which caused a collision in the narrow entrance to the harbor. The incoming ship, the *Mont Blanc*, had just come from New York and was about to add some coal to its cargo in Halifax before sailing for the war zone in Europe. The usual red warning flag that is always flown on a munitions ship was missing. The captain did not hoist it because he feared it would make his ship a special target for lurking German submarines. The ships collided and set off a gigantic explosion. Within minutes the whole surrounding area was shattered.

There were other reasons for some carelessness on the part of the outgoing skipper. His ship, the *Imo*, had been delayed and he was anxious to leave with his load of coal for Belgium. Traffic was heavy in the narrow channel because this was December and in a northern country like Canada there were only a small number of daylight hours available. Ships and tugs alike always wanted to get out of the channel before dark. Captain Le Medec of the *Mont Blanc* signaled a port passage to the *Imo* as the ships approached

Figure 45 A building damaged by the Halifax explosion, 1917.

each other. The *Imo* captain replied, suggesting a starboard passage, then sailed on without waiting for a reply. One of the sacred rules of navigation is that you do not act, in a case like this, before the other side agrees.

A few minutes later the *Imo'* sprow cut into the *Mont Blanc* ahead of the main hold where all the TNT was stored. Captain Le Medec tried to swing his ship around in a desperate effort to avoid the collision. He knew what could happen if his ship were to be hit but in the narrow channel it was impossible to get away from the other ship. A drum of solvent was broken open in the collision and a spark ignited it. As the liquid ran down into the hold the fire spread to the huge quantities of TNT. The *Imo* captain backed his ship away and beached it.

Years later a man who lived close to the harbor reflected on the event of December 6, 1917. He lived to tell the tale and he remembered wondering at the time why two ships could come so close to each other without trying to avoid a collision. He noticed that the *Mont Blanc* tried to swing away but it was too late. One moment after the collision it was clear that the munitions ship was about to explode. Halifax harbor is only half a mile wide so the amount of space available for altering course was minimal. The tide carried the *Mont Blanc* toward a pier on the south side where a telegraph operator was on duty.

He watched the ship come closer and closer and he knew about its lethal cargo. Instead of running away he stayed at his post, sending out warning signals, and just before the explosion he shouted a goodbye. His body was found later in the evening. The power of the explosion swept away churches, factories, and every other kind of building. Nothing was left standing. Fires broke out all over the place and shells and other ammunition rained down on people with some of it exploding in the process. Terror-stricken men and women and children, all of them covered with black soot and bleeding from numerous cuts from flying pieces of glass, were the common sight everywhere.

When the *Mont Blanc* exploded it just vanished in a cloud of smoke—blast of air and debris rose a mile high. Devastation was everywhere within a one-mile radius. Some bodies were thrown half-a-mile on to the shore. A thirty-foot tsunami erupted and, carrying rocks scooped up from the seabed, destroyed all the piers together with their contents. The tragedy was all the worse because of the war. Large numbers of military personnel and supplies were assembled at the harbor, awaiting transportation to Europe.

Two further complications made circumstances especially difficult for victims. The worst blizzard in living memory had just hit Halifax and temperatures were well below freezing. Many victims who were trapped in buildings froze to death. The second crisis was a forced evacuation because of the danger of fire at the munitions' stores. Out of a total population of 50,000, about 1,600 lost their lives, a further 9,000 were injured, and 6,000 lost their homes. It was the most violent human-made explosion prior to the appearance of atomic weapons. The blast shattered windows one hundred miles away. Damage amounted to $35 million, an enormous sum at that time. Subsequent investigations concluded that the captains of both ships were to blame for what had happened but only minor penalties were given. The city of Halifax had to be completely rebuilt.

Halifax was not the only place in North America where accidents involving munitions occurred both during World War I and in the years immediately afterward. On May 18, 1918, in a suburb of Pittsburgh, an explosion shattered the neighborhood around the factory of the Aetna Chemical Company, a manufacturer of TNT. The accident was triggered by an error in the part of the factory where various chemical components of TNT were being mixed. Workers nearby heard a low popping sound, something that would normally be ignored, but those familiar with the manufacturing process reacted immediately. They knew that in a matter of seconds the whole building would explode. A few managed to escape but most died. By the end of the day 241 were dead or missing and four hundred others were injured. The first building to explode was the one in which chemicals were being assembled.

As the building went up in flames it set off the next building in the complex and so the fires and explosions continued like a series of gigantic firecrackers until, within a few minutes, the whole neighborhood was wrecked. Heavy machinery, walls, roofs, and rafters were shot into the air, to descend minutes later on those trying to escape the inferno. Ambulances were dispatched to the scene from every hospital in the Pittsburgh area while company guards and local police set up a barrier to protect people from the burning factory. A morgue was set up near the factory and a train arrived to supplement the work of the ambulances by bringing the injured to hospitals. This train could only come to a point four miles from the accident scene because tracks had been covered with debris so the injured had to be carried to the train. All telephone and telegraph lines had been severed so there were no means of communication with places beyond the factory area, resulting in delays in getting help for the injured.

Eight years after the TNT explosions at the Aetna Chemical Company, on July 10, 1926, a lightning strike hit the depot at Lake Denmark, New Jersey, where the entire U.S. Navy's store of munitions was kept. Everything was blown sky-high in one gigantic explosion. It all happened during a thunderstorm in the late afternoon of July 10. A lightning bolt struck one of the storage units where TNT was kept and started a fire. It could have been contained but the officer in charge had been assured that the protective system in place would prevent damage from any lightning strike. The result was that the little fire mushroomed quickly into a catastrophe. The lightning-arresting system which had been installed for just such an event, for some reason failed.

Lake Denmark's Naval Ammunition Depot was located about thirty miles west of the Hudson River in New Jersey. The navy's entire supply of munitions was stored here and ships came up the Hudson River for supplies. They were then transferred by rail from the depot to the ships. In those years the fleet was concentrated on the Atlantic Coast so this location was accessible at all times. The army also had a munitions supply depot alongside the navy's depot. In all there was a complex of 180 buildings, including some manufacturing. Because of the huge quantities of explosives kept at this center and because of the frequency of summer thunderstorms in this part of New Jersey, a lightning-arresting system had been installed.

On July 10, 1926, near a storage unit that housed a million pounds of high-intensity TNT, a lightning bolt struck. That should not have been a problem as the lightning rod had been installed within a few feet of that location. For reasons that were never clear, something failed to work because within a few minutes a small fire appeared and almost at once a fire alarm rang out across the whole complex. One officer half a mile away from the fire looked out of his office window in time to see a huge white flash. He ducked down under the window and lay on the floor, knowing that the blast from the explosion would momentarily smash into his building and demolish it. A few seconds later that was what happened.

One after another high-explosive rounds exploded and fires sprang up. The entire area within half a mile of the arsenal including all the buildings was destroyed with all surface objects swept away into the distance. Of the 180 buildings that comprised the arsenal only sixteen survived. For about ten hours, fires and explosions continued unabated and none of the fires went out during that time. Not until the following morning were the flames finally doused. Residents as far as fifty miles away heard and to some extent felt the blasts. When it was all over damage added up to more than $150 million. Thirty lives had been lost and two hundred others injured.

The countryside was all torn up around the arsenal, leaving it like an old-style battlefield. Deep craters were torn out of the sandy soil. Steel girders were thrown a mile from the blast site. A large piece of a charred wooden beam was found on a farm three-and-a-half miles from the blast site. New Jersey's governor together with its two senators requested that the whole arsenal be moved from the state. Both the general public and the media supported the governor. The War Department was so moved by the event that it thought it had been the world's worst explosion. It certainly was the worst explosion in U.S. history up to that time.

The navy was rightly blamed for not taking adequate safety precautions. The lightning-arresting system clearly was inadequate and the high concentration of explosive material in so small a space was, to say the least, unwise. There was severe criticism of the navy from the U.S. government, both for the cost of the tragedy and for the dangerous position in which it placed the navy. Two years after the explosion the Department of Defense Explosives Safety Board was established. It was instructed to provide oversight on all aspects of explosives, including maintenance, transportation, and storage. Never again would so high a concentration of munitions be found in one place. Arsenals were subsequently placed in low population density areas across the country.

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72

World-wide flu pandemic

1918–1919

Flu pandemic affected the whole world with first reports coming from Spain

The disease spread from places where there were high concentrations of soldiers. It spread all over the world and took the lives of thirty million people

In the last year of World War I, the world was hit with a flu pandemic, the H1N1 virus. It would prove be the deadliest disease in human history. Far worse in the total number of fatalities than the black death scourges of the Middle Ages or the total number killed in World War I, counting both military and civilian casualties. In less than six months of 1918, thirty million people worldwide died from this flu and most of those who died were young. Many insisted that the total number of deaths was far greater than thirty million. Even worse than the number of deaths was the speed with which it spread and the terrible nature of the illness that people experienced. Common symptoms were severe coughing accompanied with bleeding from different places and the skin turning blue because of the lack of oxygen in the lungs. For large numbers of sufferers the painful end came within a few hours as their lungs became filled with fluid and they suffocated.

Wherever people are crowded together, especially in the terrible conditions of World War I, in frontline trenches or on troop ships from the United States, conditions are ideal for the spread of a flu virus. Because the outbreak occurred at a critical point of the war, when it seemed for a time that German forces might succeed, strict secrecy about the spread of the disease was maintained by American and allied governments. The German government was equally secretive and the post-war publication of documents from that time revealed that the German army was being decimated by flu outbreaks. It was because of this secrecy that the name "Spanish Flu" came to be its popular name. Spain was not involved in the war so they freely reported on their experiences of the flu and, because they were the first to report on it, everyone assumed that it had originated in Spain. Reports of the spread of the disease came in from all over the world. It traveled as quickly as a bushfire to the countries of Europe, to the United States, and to Asia. It is likely that the total number of deaths in Asia, given the high concentrations of people in many regions, was as great as the total number of deaths in Europe and North America combined.

In the United States there were half a million deaths from the flu pandemic, all within a period of six months. Most of these were recorded as deaths from pneumonia, the outcome that in most cases led to death. Another half million of soldiers from service in both Europe and the United States were hospitalized and a large number of these died, as many as had died in combat for the whole period of the war. In Britain 200,000 died from the same pandemic flu and, as happened everywhere else, they all died within the same months of 1918 and the beginning of 1919. The course of the disease, just as had been the experience of others with diseases in earlier centuries, was always the same: because the strain of the destructive virus was new, and people therefore had no existing immunity with which to counter it, death rates were high. As immunity was built up among all the sufferers, the death rate decreased and finally reached the low level that is recognized as normal for any flu. In places around the world where population density was very low, and where because of their isolation there had never been exposures to the kind of flu we experience every year, the impacts were devastating. Whole Inuit villages in Northern Canada were wiped out, and on the Island of Samoa in the South Pacific a quarter of the population died.

By October, across the United States, as the numbers of dead mounted, a near panic atmosphere appeared. Theaters, movies, bars, and a host of other places were closed down. Even schools, churches, and public campaigns to raise money for the war were shut down. Laws were introduced that required everyone to wear a face mask in public. Stiff fines were imposed on those who sneezed or coughed in public without covering their mouths with handkerchiefs. With our current knowledge of viruses we can conclude that these precautions would not have stopped the spread of the 1918 flu but it was all that seemed possible to people of that time. The Catholic Charities of Philadelphia hired several horse-drawn wagons with which they searched alleys and tenements for the bodies of abandoned victims. The city morgue had no space for the bodies so they had to be placed in mass graves, and without caskets too since Philadelphia, like many cities, had run out of them. Police departments suddenly found their work greatly eased. Crime had dropped to half what it was a few months earlier. The problem was quite different for the generals in charge

Figure 46 Demonstration at the Red Cross Emergency Ambulance Station in Washington, D.C., during the influenza pandemic of 1918.

of the army. This was a time of conscription, not the volunteer army of today, and those in charge of the draft and preliminary training before going overseas had to decide what to do.

Field Marshall General Crowder, in charge of the draft and training, was aware that crowded conditions in training camps were a recipe for the rapid spread of the flu. He knew what had happened earlier in 1918 at Camp Funston in Kansas, with the members of the Tenth Division, when soldiers in large numbers fell sick and many of them died. The officer in charge on that occasion wrote to the governor of Kansas, telling him that he had 1,440 admissions to hospital a day, that is to say about one a minute, and asking him to realize the strain that all of this was putting on his nursing and medical staff. General Crowder also knew that several other camps had, more recently, experienced a rash of flu infections. Following consultations with both President Wilson and the army leaders in Europe, Crowder decided to defer the training of 142,000 registrants who were due to begin on October 7, and wait for the end of the flu pandemic before bringing them to camp for training. Settling the question of training camps was easier than the one that President Wilson now faced. The army in Europe wanted more troops in order to capitalize on the successes they were experiencing but medical authorities urged him to stop the mass shipment of troops until the flu abated. Death rates on troop ships were running higher than the numbers that died in battle. Wilson accepted the advice of Army Chief of Staff General March, and decided not to suspend troop shipments. Fortunately, the end of the war came in less than a month after the President's decision.

In 1918 little was known about viruses and almost nothing was available to provide an adequate cure. Almost eighty years later, with concerns mounting that another flu pandemic could hit the world, scientists set about recreating the 1918 virus so that it could be tested out on lab animals to measure its strength. First they had to find a human body that had died as a result of the 1918 flu. They found one in Alaska that had been frozen in the Arctic permafrost soon after death so scientists were able to extract samples of lung tissue from it. The overlapping gene sequences were pieced together from this sample to give the full genome sequence and it was at that point that scientists became fairly certain that some ancestor had originally infected birds and the virus had moved from there into humans. A report from 1918, that was only investigated after 1998, confirmed this conviction. A veterinarian who was studying hog cholera in Iowa at that time discovered that the epidemic he was dealing with in pigs had symptoms that were identical to those he observed in the victims of the pandemic flu. He said in his report that whatever was caus-

Figure 47 Emergency hospital during influenza epidemic, Camp Funston, Kansas.

ing the flu in pigs must be very similar to the flu affecting humans. Today, with all our understanding of viruses, experts are convinced that the pandemic flu of 1918 was indeed a mutation of one that had been resident in pigs. When the recently-reconstructed 1918 virus was tested in mice it was found to be extremely virulent, creating 40,000 more particles in a lung than happens with ordinary flu. All the mice that were tested with the 1918 virus died within six days. Samples of the virus are now stored in a secure vault at the Center for Diseases in Atlanta, Georgia, but fears exist over the risk of it getting into terrorist hands.

In 2005, the United Nations General Assembly called for immediate international mobilization against an avian flu that had already transferred into humans and, by early 2005, killed sixty-one people in Southeast Asia. There were fears that this virus could become a pandemic and be as destructive as the flu of 1918, a similar bird to human virus and the cause of the deaths of thirty million people worldwide. This new bird to human virus could be worse than the 1918 flu because, while there is much greater knowledge on how to cope with it, there is at the same time far greater and more frequent travel around the world. Finding a vaccine for a new type of virus, one that might change as it moves from bird to human, and then have it available in huge quantities at short notice is a huge challenge. An examination of what happened in Central Africa in the past few years illustrates the problem. Within a year, an outbreak of the deadly Ebola virus took the lives of more than five hundred people in the Congo. The source of the virus was unknown for some time then, in December of 2005, a team of scientists found the virus in three species of fruit bats in the Congo. These bats were part of the human food chain in the Congo and it seemed likely that the transmission from bird to human occurred in this way. The possibility of a similar bird or bat to human transmission in Asia has raised concern everywhere. Especially since the 1918 virus, though unknown at that time, was a transfer from bird to humans.

The United States is not the only country that reconstituted the 1918 virus. The director and staff of the U.S. Federation of American Scientists' Working Group on Biological Weapons are far from being satisfied with the level of security presently provided in Atlanta. They say that the risk of theft by a disgruntled, disturbed, or extremist lab employee at the facility is so great that it comes close to being inevitable. They have proposed raising the level of security to the highest possible. In 2003, they point out, a SARS virus escaped accidentally from a lab in Singapore and a year later there were two escapes of the same virus from labs in Beijing. The avian flu virus was found in thousands of birds in Asia and in smaller numbers in many other countries, presumably carried worldwide by migrating birds. The detailed gene sequences of this virus are well known. It is defined as the virus H5N1 and it is one that has never before been experienced by humans except for those who died from it in Asia. There are therefore no antibodies in humans that could fight off infections from this virus, as is the case year by year when more familiar strains of flu viruses appear.

Dr. Andrew Fauci of the U.S. National Institute of Health is the United States watchdog for tracing the behavior of the H5N1 virus, monitoring it regularly as samples are collected from time to time, to check any mutations that develop and to give warning if any evidence of transfers from human to human are found. To date this has not yet happened. Soon after the first human death from H5N1, Fauci's lab developed a vaccine that would be able to protect humans. It had to be tested out on mice before it was safe to be administered to humans and Fauci discovered that the dosage needed to protect test animals was far greater than required for traditional flu attacks. Thus the various difficulties associated with responding to the United Nations appeal remained: how to produce enough vaccine in a very short time. That is, once the right mutation is present for creating a pandemic, how to cope with breakdowns in social organizations and institutions if large numbers of people die, and how to equip and protect adequately the care givers in hospitals so that the damage can be minimized.

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Mona Passage, Puerto Rico, earthquake

October 11, 1918

Offshore between Puerto Rica and Dominican Republic

It was wartime. World War I was still being fought. The death toll was 116 and damage costs four million dollars

On the morning of October 11, 1918, Puerto Rico was visited by one of the most severe earthquakes it had ever experienced in modern times. It was later identified as having a magnitude of 7.5. The earthquake was followed, almost immediately, by a tsunami that broke upon the shore, drowning 116 people and destroying native huts. Property loss amounted to $4 million. In the northwestern part of the island, where the damage was greatest, a number of people left their dwellings and went to the hills, partly because of the unusual strength of the earthquake and partly because of the aftershocks that were almost continuous for two days.

The governor of Puerto Rico requested the secretary of war to investigate conditions throughout the island, to assess the damage and to assure everybody that the danger was over. An intensive one-month search of the territory was carried out, including the islands of Vieques and Saint Thomas. The epicenter was finally located deep in the northeast part of the sea passage between the island of Mona and the international border between Dominican Republic and Puerto Rico, a stretch of water known as Mona Passage. Everything that could throw light on the earthquake was carefully examined. The experiences and observations of a large number of persons were collected. Some of them had felt the shock in Santo Domingo and some had experienced the shaking on the Island of Vieques. The meteorologist in charge of the weather bureau at San Juan collected information for the investigating group through his many observers. Information was also gained through correspondence with persons where the shock was felt. The earthquake occurred in daytime. Puerto Rico is accustomed to shocks of mild to moderate intensity and this may explain the close agreement that was discovered in descriptions of the shock. Most observers say that the earthquake began as a pronounced vertical vibration, which was followed by horizontal oscillations. In regard to the directions of movements, they were mainly east to west.

The earthquake began suddenly without warning. There were no preliminary vibrations of any kind. Furthermore, no evidence of earthquakes of any kind had been felt over the previous eight months. The first shock was felt in San Juan shortly after ten in the morning. It lasted for a full two minutes, first as a series of vertical motions, accompanied by creaking of the timbers in wooden building, then latterly as horizontal shakings sufficient to cause nausea and evident in the swinging to and fro of electrical fixtures. A second shock followed about five minutes after the first one and a third one after a further five minutes. Both of these were of short duration, less than a minute each. In some of the churches, as at Arecibo and Mayaguez, places that are one hundred miles apart, columns supporting arches between the nave and the aisles were crushed as though they had been subjected to strong vertical compression. At a house near Mayaguez, wooden columns supporting a porch roof jumped up and down, and after the earthquake a shoe was found between the base of the column and the floor of the porch. The tower of the Arecibo church was badly cracked and tilted toward the east. Nearby, a steel smokestack was bent in an easterly direction. The cracks in the brick roof of the municipal building ran chiefly in a north-south direction and, at a place four miles south of Arecibo, books in a concrete vault were thrown from the shelves on the northwest wall but not from the other shelves. At the southwest corner of Puerto Rico the surface of the ground moved in waves as if it had been part of the ocean.

A great wave from the sea, now understood as a tsunami, following the earthquake of October 11, was highest near the northwestern part of Puerto Rico. It was seen almost immediately after the earthquake. Wherever the wave appeared on Puerto Rico or on its neighboring islands, observers reported that the ocean first withdrew from the land, in places exposing reefs and stretches of sea bottom never before visible during low tides, and then the water returned, reaching heights that were high above normal. At some places the main wave was followed by one or more smaller ones and, especially in shattered bays, the water continued to ebb and flow for some time. At the Boqueron Lighthouse the keeper, who was up in the tower when the earthquake began, immediately started down the stairs, and as he went down he noticed that the water along the shore had already begun to recede. It returned quickly and his measurements show that the height reached by the water, not counting the wash of the wave, was about fourteen feet above sea level. Southwest of the lighthouse, where the land is lower, the water was reported to have reached inland for a distance of three hundred feet into a grove of coconut palms. The lighthouse keeper had the impression that the wave came from the northwest. Near Point Agujereada the limestone cliffs are about 330–400 feet in height, and their base is a narrow strip of beach. Several hundred palms were uprooted by the wave, and the beach was turned into a sandy waste. In this vicinity a few small houses were destroyed and eight people reported to be drowned. People visiting this district soon after the earthquake estimated the height of the wave at eighteen feet.

As the seat of the disturbance was under the ocean it was impossible, in 1918, to determine its exact location, but it was estimated as being near latitude 18° 30′ north and longitude 67° 20′ west, or roughly ten miles west of Boqueron Lighthouse. The sea wave was highest along the northwest coat of Puerto Rico and decreased progressively in all directions. Submarine cables were broken at several places within the area bounded by parallels 18° 25′ and 18° 35′ north and meridians 67° 15′ and 67° 30′ west. The seismographic records of the earthquake do not fix the position of the origin with a high degree of accuracy. This is not to be wondered at when we remember that an error of one second in the record time of arrival of vibrations at the various stations in eastern North America would correspond to a difference of six miles in the distance from the point of origin. The errors seem to have balanced because together they identified the location as being in the northeastern part of the Mona Passage. As has already been mentioned the limitations of the technology in use in 1918 are reflected in the reports that were given by observers. The interpretation of the cause of the earthquake is one example of these limitations: severe earthquakes are the result of the sudden relief of stress that slowly accumulated in the rocks on the sea floor.

The tsunami that accompanied the earthquake had a different origin. Research conducted on the ocean floor around the island of Mona many years after 1918 revealed underwater landslides that dated back to 1918. The small portion of the earth's crust beneath Puerto Rico, in contact with the much bigger North American Tectonic Plate, was seen to have tilted at the point of contact, presumably due to interactions between the two. Gigantic slabs of limestone were released by these interactions, some of them as big as fifty miles wide, and the result of the displacement of water they caused gave rise to the tsunami. The damage it caused was greatest on the low-lying coastal areas and, as has so often been seen in the actions of tsunamis, the retreating wave because it carries so much debris and rocks is often more deadly than the first incoming wave. The Columbus Memorial stood on the western beach. It was demolished and a 2,500 pound limestone block from the wreckage was carried inland for more that three hundred feet. The island of Mona experienced the tsunami in the form of a twelve-foot wave that washed away a pier.

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Vancouver Island, Canda, earthquake

December 6, 1918

West Coast of Vancouver Island west of Port Alberni

This one had a magnitude of 7 but its activity was unrelated to the subducting plate. Earthquakes are common in this area and fortunately this one was intra-plate and, while felt over a very large area, caused no casualties and did minor damage to buildings

This earthquake of magnitude 7 occurred on Friday, December 6, 1918. Its epicenter was near the west coast of Vancouver Island at a depth of ten miles, and was felt very strongly at Estevan Point Lighthouse and at Nootka Lighthouse on the southern tip of Nootka Island. There was some damage done to the Estevan Point Lighthouse and to a wharf at Ucluelet. This earthquake awakened people all over Vancouver Island and in the greater Vancouver area. It was felt in northern Washington State and at Kelowna, in the interior of British Columbia. Due to sparse population, no injuries and little damage resulted from this earthquake. Other than broken dishes and some instances of cracked plaster on central Vancouver Island, the only damage reported was to the Estevan Point lighthouse. Its steel reinforced concrete tower cracked for its full length in several places, and parts of the glass lens were smashed.

There is an average of one earthquake in southwest British Columbia every day. Nearly all are too small to be felt, but a damaging earthquake occurs somewhere in the region about once every twenty years. The largest earthquake in this century had a magnitude of 7.3. It hit in 1946 and was centered beneath Vancouver Island. Were this earthquake to occur today under Vancouver, damage would be in the billions of dollars.

Recently, scientists have recognized a history of infrequent, but great earthquakes on the fault separating the subducting Juan de Fuca and North America plates. The last great earthquake in 1700 AD affected the entire coast from northern California to southern British Columbia. The 1918 earthquake appears to be a crustal intraplate event occurring in the lithosphere of the America Plate, resulting from the complicated interaction of the Explorer, Juan de Fuca, and America plates.

The major tectonic boundary separating the Pacific and North American lithospheric plates lies near the west coast of North America. The San Andreas and Queen Charlotte transform faults dominate this boundary. However, in the region between northern Vancouver Island and northern California, the oceanic Juan de Fuca and Explorer plates lie between the major plates and are being subducted beneath North America. These two smaller plates act independently of the two bigger ones, the Juan de Fuca moving under the North American Plate at approximately an inch and a half a year. While major concerns over earthquakes in this region tend to focus on subduction motions, it is important to note that this 1918 one was not of this type. Instead it was a crustal, intraplate earthquake. Rather than being directly associated with the subducting Nootka fault zone, it was linked to the stress in the continental crust as the North American Plate interacts with the Explorer and Juan de Fuca plates.

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Kelud, Indonesia, volcanic eruption

May 1, 1919
Eastern Java, southwest of Surabaja

The eruption expelled a lake on its surface, throwing mud and pyroclastic flows from the heated water all over the surrounding agricultural areas and killing 5,000 people

On May 1, 1919, the volcano Kelud, on the island of Java in Indonesia, erupted. It was its deadliest strike of the twentieth century. The eruption expelled the lake at the summit, approximately 5,000 feet above sea level. Mud and pyroclastic flows from the heated waters of the lake swept over the surrounding agricultural areas of Kediri and Blitar. They traveled as far as twenty-five miles from the volcano, destroying 40,000 acres of farmland. Three million people live within fifteen miles of the volcano and more than 5,000 people were killed on the day of the eruption. A hundred villages were destroyed. Kelud is a small volcano when compared with Indonesia's others but, because of the lake at its summit and the frequency of its eruptions, it has been the source of many of Indonesia's deadliest eruptions.

The 1919 eruption prompted the creation of the Volcano Survey of Indonesia with its first task being how to drain the lake waters from Kelud. There had been earlier attempts because of the known frequency of Kelud's eruptions. In 1905, the local Dutch administration arranged for a dam to be built at the foot of the mountain in order to divert flows into the nearby river Badak. When the 1919 eruption occurred, this dam proved to be ineffective. It was taken away by the heavy mudflows that occurred. After this very destructive eruption, authorities decided to dig a tunnel and so prevent a repeat of the 1919 tragedy. Extensive engineering work started in September 1919 and was finally completed in 1926. A tunnel, a thousand feet in length, had been excavated through the walls of the crater by that time. It lowered the elevation of the water by two hundred feet and thus reduced considerably the volume of water that remained. Unfortunately, successive eruptions in 1951 and 1966, though much weaker than the 1919 event, destroyed the drainage system that was in place and raised both the elevation and the volume of the summit lake. The reconstruction of the drainage system was initiated immediately after the 1966 event and it succeeded in limiting the volume of water in the lake to a manageable level.

Indonesia has a chain of 129 active volcanoes extending eastward for 4,000 miles from the northern end of Sumatra. Several eruptions of these volcanoes have been catastrophic in the past, as in the cases of Tambora in 1815 and Krakatau in 1883, both in terms of the loss of human life and the partial or total destruction of infrastructure and economy. Millions of Indonesians are currently living on volcanoes and civil infrastructures are progressively developing on their slopes. Due to the economic and demographic pressures that exist in Indonesia today, it is clearly not possible to prohibit settlement of population around these active volcanoes. The soil is incredibly good. One of the challenges for Indonesia is how to use and manage this land resource as well as to minimize the risk to humans and long-term economic effects of future eruptions. The relatively inconspicuous 5,000-foot-high Kelud *stratovolcano* contains a lake in its crater at the summit that has been the source of some of Indonesia's most deadly eruptions. More than thirty eruptions have been recorded from it over the past thousand years. In 1556 its mudflow from an eruption was responsible for 10,000 deaths. The ejection of water from its lake during Kelud's typically short, but violent, eruptions creates pyroclastic and mud flows that lead to fatalities and destruction. These events have claimed more than 15,000 lives since 1500 and caused widespread destruction.

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Florida/Gulf of Mexico hurricane

September 14, 1919
Florida Keys and Corpus Christi, Texas

After causing major damage in the Florida Keys this hurricane devastated Corpus Christi

The hurricane of 1919 was one of the deadliest and perhaps strongest storms of the twentieth century. With winds reaching at least 110 mph and wave heights as high as sixteen feet, the great storm made landfall in the Corpus Christi area on September 14, 1919. Local people were influenced by the widespread belief that the city was protected from severe damage of hurricanes by the barrier islands. Even when stories reached them just ahead of the storm, of incredible damage from a hurricane in the Florida Keys, little was made of the possibility of a Texas landfall. Before September 14 had passed into history the terrible reality was evident to all: debris was piled up as high as sixteen feet in downtown Corpus Christi and the official total of dead was 287. Many believed that the accurate figure was in the range of 600–1,000 because city officials wanted to downplay the severity of the event.

The storm was first detected near the Lesser Antilles on September 2, 1919. It traveled to the west-northwest and hit the Dominican Republic and the Bahamas, where it reached peak strength as a category 4 hurricane. The storm's center grazed the Florida Keys on September 9 as a category 4 hurricane on the Saffir-Simpson Hurricane Scale, killing several hundred people before making its way into the Gulf of Mexico. The barometric pressure of the hurricane after leaving the Keys, as taken by a ship, was 27.37 inches, making this hurricane one of the most intense in U.S. recorded history. It was certainly the most intense to strike Key West in all of the twentieth century. As it moved into the Gulf something strange happened. All indications at the time pointed to the hurricane curving into the Louisiana coastline on September 13. On the basis of that prediction the Weather Bureau seemed to have ignored what was going on for a time. It is difficult to understand what happened subsequently unless this was the explanation.

With the advantages of radar, satellite, and weather balloon reports, it seems to be almost inconceivable today that we have not always had the luxury of tracking hurricanes hour by hour. Inconceivable as it may be, none of these technical resources were available to forecasters in 1919, but what was available, limited though it was, failed them. The Weather Bureau lost the hurricane in the Gulf soon after it had left the Keys. With no ship reports and only sporadic observations along the coastline, the Weather Bureau began a desperate attempt to find the hurricane center. Coastal offices sent special observations by telegraph every two hours to the Washington headquarters. By midnight on September 13 the storm's center was still missing as far as the forecasters were concerned. They sent a message to Corpus Christi urging everyone to take all possible precautions against a hurricane, especially if high winds, high tide, and low barometer readings were observed.

Finally, at 9:30 A.M. on September 14, the Meteorologist-In-Charge of the Corpus Christi Office issued a statement to get people out of low-lying areas at once. Police, city, and Weather Bureau officials began to notify the public. By 10:30 A.M. they knew that the hurricane was near. Shortly thereafter, wires to Port Aransas went down, isolating the city of Corpus Christi. Rockport did receive later advisories, and the last one gave an accurate if not cryptic analysis, this is the worst hurricane in history. The first two deadly effects, the storm surge and wind, weakened and then tore away at buildings close to the coastline. But with the track and strength of the hurricane, a seiche developed along the bay front region of Corpus Christi. A northeast wind developed and, as it veered to the east, it strengthened the seiche. creating an even greater height in the storm surge. Water reached twelve feet in the downtown district, and even higher in the narrow inlet into Nueces Bay.

No one can give a reliable estimate of the strength of the hurricane when it made landfall. Wind data at the Corpus Christi Weather Office was lost when the anemometer was destroyed. One nearby town reported wind gusts of 170 mph. Damage all along the coast was both catastrophic and deadly. In the North Beach area of Corpus Christi only two buildings survived and both of them were severely damaged. Crude oil had been spilled everywhere and despite the harm done it ensured a lower rate of disease than might otherwise have occurred because the oil preserved dead bodies from quick decay. The personal stories of survivors are quite extraordinary. One woman was found exhausted at the beach, tarred and feathered. She had become immersed in oil while drifting on debris. Her head rested on a feathered-down pillow that had come from somewhere. Another woman was washed ashore with her dog. Three times she had slipped off the raft on which she rested and three times her dog pulled her back on to it. One of the people forced to evacuate Corpus Christi was Bob Simpson, who would later become head of the National Hurricane Center and one of the designers of the Saffir-Simpson Hurricane Scale.

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Humboldt, California, earthquake

January 22, 1923
The coast of California near Humboldt Bay

This whole coastal area experiences greater damage from earthquakes and tsunamis than anywhere else on the Californian coast because of the influence of the Gorda offshore tectonic plate. There was widespread damage of buildings but no casualties

A 7.2 magnitude earthquake struck California off the coast of Humboldt County on January 22, 1923. Houses were severely damaged at Ferndale, Petrolia, and Upper Mattole. Many chimneys were downed and water lines were broken. At Pepperwood, one house was shaken from its foundation and split apart, and another was twisted from its base. Chimneys also were knocked over at a number of places. Several landslides occurred. The impact of the earthquake was felt all the way from Siskiyou County on the Oregon border south to San Francisco, three hundred miles away, and eastward to Nevada County. It was also observed on several ships at sea. Many aftershocks occurred in the Petrolia and Upper Mattole regions. A small tsunami was recorded.

The North Coast of California and adjacent offshore area is the most active seismic region in the continental United States. The size, location, and frequency of past earthquakes give an indication of what to expect in the future. The instrumental record of earthquakes on this coast extends back only into the early 1900s. However, it is possible to learn about older earthquakes from written accounts in newspapers, church logs, and diaries. From these accounts, seismologists can reconstruct the pattern of ground shaking and estimate the location and magnitude of early earthquakes. Since 1853, more than sixty earthquakes have caused some damage to North Coast communities. The majority of these earthquakes have been centered offshore in the southeastern portion of the Gorda Plate offshore from Crescent City and Eureka.

These earthquakes recur frequently, causing some damage to communities, particularly in the Cape Mendocino area, almost every two years. Since the early 1990s there has been the highest level of regional earthquake activity of the twentieth century. Nine earthquakes of magnitude 6 or larger have struck the coastal and offshore areas. Seven earthquakes were close enough to coastal communities to cause at least moderate damage. Damaging earthquake activity was not restricted to the coast. Klamath Falls, Oregon, experienced its strongest earthquake in historic times. West of Eureka an earthquake with a magnitude of 7.3 occurred in 1922. This potentially damaging earthquake was felt from Eugene, Oregon, all the way to San Francisco. In 1994, the area around Eureka experienced its largest earthquake since 1932. It caused an estimated $5 million in property losses. In that same year there was the Mendocino Fault Earthquake, the largest ever recorded along this fault. It was felt as extensively as the Eureka earthquake of 1922.

A major reason for the recurrence of earthquakes in north coastal California right up to the present time is found in the behavior of the Gorda Plate, offshore from the stretch of coast between Crescent City and Eureka. This smaller tectonic plate is gradually breaking apart under the stresses it is experiencing from much larger plates. In 2005, for example, an earthquake of magnitude 7 was recorded in this coastal area and, because of its size, it was feared that tsunamis would be triggered. It turned out that the quake was caused by undersea pieces of the Gorda Plate jerking violently past one another in a sideways motion known as strike-slip, not the kind of motion that would create big tsunamis. A subduction motion of the Gorda Plate beneath the North American Plate would be a much more dangerous event. The fundamental action that is compressing the Gorda Plate is the northward movement of the Pacific Plate as it slides parallel to the San Andreas Fault. A strike-slip movement close to the coast could give rise to a tsunami and places such as Humboldt Bay and Crescent City would be the victims of the waves within half an hour.

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Kamchatka, Russia, earthquake

February 3, 1923
The Peninsula of Kamchatka, Russia,
in the Northwest Pacific Ocean

This region of Russia is well known as a source of powerful earthquakes and equally powerful tsunamis. In the case of the 1923 earthquake the tsunami began as a twenty-five-foot wave and within half a day it reached Hawaii and California, causing damage and disruption there

On February 3, 1923, an earthquake of magnitude 8.3 struck the east coast of Kamchatka, Russia, generating a twenty-five-foot tsunami that raced across the Pacific to Japan, Hawaii, and California. Local government documents show that this tsunami, at its origin, flooded low-lying coastal areas that were covered by thick snow. The unusual process of tsunami run-up without loss from ground friction is a result of the smoothing of the ground by ice. It was concluded that the tsunami flooded snowfields and deposited an extensive sheet of sand. A mixture of snow and seawater flooded over the area and caused damage to vegetation. Kamchatka is notorious for triggering earthquake tsunamis, and historical documents show that they have repeatedly caused considerable damage over the past two centuries. The tsunami from the 1923 earthquake caused an eight-inch rise in sea level at San Diego and a four-inch rise at San Francisco.

The Pacific Plate's behavior is the key to the Kamchatkan earthquakes and tsunamis and its history is clearly illustrated in the evolution of the Hawaiian-Emperor Chain, a series of volcanic mountains stretching 4,000 miles across the North Pacific from Hawaii to a subduction zone at Kamchatka. The chain also provides a concrete illustration of sea floor spreading. The Pacific Plate, over millions of years, moved northwards and then northwestwards, first at a rate of three inches per year, then four inches, over the last seventy million years. Volcanic mountains in the chain older than seventy million years were carried down into the Kamchatka subduction zone and, as a subduction zone, every earthquake of the size of the 1823 quake carried the likelihood of a major tsunami.

The Kamchatka Peninsula is one of the most tectonically active regions of the world, and has historically experienced a number of large tsunamis. Assessing tsunami records is important for long-term tsunami prediction and for mapping the likely hazards. In the case of Kamchatka, historical records of tsunamis are too short to develop a predictive chronology of events. The way to obtain long-term data is to study paleotsunamis, that is, to identify, map and date prehistoric tsunami deposits. These deposits also provide a proxy record of large earthquakes. Paleotsunami research became an active field of investigation in the late 1980s. Evidence of strong modern and pre-historic earthquakes and tsunamis has been found and studied in Japan, North America, and a number of other localities. At Kamchatka, studies of tsunami deposits began about 1990. Preliminary results suggest that the period from 0 to 1000 AD was particularly active. The combined record of tsunami deposits and of numerous marker tephra on Kamchatka offers an unprecedented opportunity to study tsunami frequency. It is possible to examine both the average frequency of events as well as the changes in frequency through time.

Some examples since 1923 of major earthquakes at the Kamchatka-Kuril-Islands (KKI) site provide good illustrations of the power of the tsunamis that follow. These outcomes are giving rise to increased efforts by national governments around the Pacific to anticipate and deal with tsunamis. In November of 1952, an unusually big quake occurred at KKI. It had a magnitude of 9 and it triggered Pacific-wide tsunamis in all directions toward the south and east. New Zealand experienced waves three feet high, Peru and Chile had lower wave heights, and Alaska and California had wave heights of four to five feet. The area that suffered most from this tsunami was Hawaii. Altogether there was one million dollars worth of damage. In Oahu, boats and piers were destroyed and at the Big Island a bridge linking an outlying island to Hilo was shattered. The year 1958 saw another major earthquake from KKI, this time one of magnitude 8.3. Five years later there was an earthquake of 8.5 magnitude and, in 2002, another of magnitude 7.5. In November of 2006 there was one of magnitude 8.3 and, this time, the preparations that are described in the following paragraph were in place. The Pacific-wide tsunami alert was received in good time. This time Crescent City of California received the strongest hit. Two docks were damaged and several boats were tossed on to dry land. Waves were three feet above normal and they persisted for twenty minutes.

The U.S. National Tsunami Hazard Mitigation Program has representatives from the National Oceanic and Atmospheric Administration, the Federal Emergency Management Agency, the U.S. Geological Survey, and the states of Alaska, California, Hawaii, Oregon, and Washington. The program addresses three major tasks: hazard assessment, warning guidance, and mitigation. The first two tasks, hazard assessment and warning guidance, are led by physical scientists who, using research and modeling methods, develop products that allow communities to identify their tsunami hazard areas and receive more accurate and timely warning information. The third task, mitigation, is handled by emergency organizations that use their experience and networks to translate science and technology into user-friendly planning and education projects. Their activities focus on assisting federal, state, and local officials as they plan for and respond to disasters. They also provide information for the public that is deeply affected by the impacts of both the disaster and the pre-event planning arrangements that have to be made.

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Tokyo, Japan, earthquake

September 1, 1923
Close to the city center

An earthquake of magnitude 7.8 with its epicenter close to the city destroyed most of Tokyo and burned down what was left. Death toll was 150,000 and an additional million were left homeless

On the first day of September 1923, Tokyo was hit with a powerful 7.8 strength earthquake. It was centered south of Tokyo, at that time a city of 2.3 million, the world's fifth largest. Many aftershocks followed. As had happened with the San Francisco earthquake, seventeen years earlier, the main destruction came from outbreaks of fire. Open cooking utensils spilled their coals on to wooden kitchen floors. When flames appeared there was no water available to quench them as the piping had been severed when the earth shook. Thousands of fires soon sprang up, rising gradually to a firestorm as they easily jumped over the narrow streets to ignite the next row of wooden homes. When the fires finally died down and conditions in Tokyo and the areas nearby were assessed, about 150,000 had died and a million were left homeless.

Tokyo, the city known as Edo in earlier centuries, became the administrative capital of the country about four hundred years ago under the control of the Tokugawa family who extended the city's territory by reclaiming land at the mouth of the Sumida River. Unconsolidated ground, that is to say the filled land on which new areas of the city were built, is a dangerous place when an earthquake strikes as was seen during the 1906 San Francisco earthquake. The shaking transforms such land, turning it into a kind of jelly that cannot support the buildings standing on it. In 1868, Tokyo came under a new form of government, one that brought the Emperor from Kyoto to Tokyo to take his place as ruler of the whole country. Under this new regime the city flourished, bringing it to its high population. The filled land, however, remained as it had been in earlier years, so liquefaction and destruction of many buildings in this part of the city became additional features of the earthquake.

Rebuilding the Kanto area west and south of Tokyo was a major undertaking. To compound the problem, the Prime Minister of Japan had died suddenly and his successor had not yet taken office, nor identified his cabinet, so various members of the previous government had to take responsibility for the restoration work. The first thing they did was to declare martial law. It was the only way to cope with the widespread destruction and the raging fires. Fortunately there were many individuals and agencies, both locally and in many other countries, able and ready to help. Reconstruction went ahead with remarkable speed, perhaps because Japan is so used to earthquakes that it reacts with predictable speed when a big one hits. Streets were laid out in the same patterns they held before the earthquake, often semi-circular and always narrow in order to provide space for the hundreds of thousands who needed housing. Such an arrangement was bad from the point of view of future earthquakes or outbreaks of fire but the damage done was so great that the needs of people outweighed the advantages of making the city better prepared for the next earthquake.

The Philippine Plate moved about ten feet in a northwestward direction as the fault slippage occurred, and numerous ground fissures, land uplift, and areas of subsistence were seen. Parts of Sagami Bay were uplifted twenty-five feet and then slowly, over a four-week period, sank back to within five feet of their original elevation. At the same time, parts of Sagami Bay subsided by more than six hundred feet. This amount of subsidence could not be explained on the basis of the fault slippage. Following subsequent examination of the sea floor geologists concluded that the earthquake had triggered mudflows and enormous quantities of sedimentary material had been carried out of the bay into deeper water. It was also concluded that the shaking from the earthquake had compacted much of the unconsolidated material on the sea floor. The great depths of six hundred feet could have been formed in such ways. A few minutes after the earthquake occurred, a tsunami that reached heights of forty feet swept across the Boso Peninsula on the east side of Tokyo Bay, causing a large number of deaths.

The earthquake was directly responsible for many of the deaths in and around Tokyo as buildings collapsed on people. However, it was fire that killed the largest number of people. Everything happened at noon when midday meals were being prepared over open charcoal braziers. As thousands of these hibachis were knocked over on to wooden floors a mass of fires broke out and there was no water to extinguish them because the city's water mains had been severed. People poured out on to the streets for safety, taking as much of their personal possessions as they could carry, but safety eluded them. The mushrooming fires, aided by a strong wind, turned into a firestorm and streets became deadly traps. On the east bank of the Sumida River police and firemen designated a park that had been an army clothing store as a safe place for anyone. About 40,000 people crowded into it. At four o'clock in the afternoon this place was hit with a firestorm and most of the 40,000 were killed.

At times in the past Japan has been suspicious of the value of western technology for the construction of earthquake resistant or earthquake proof buildings. On more than one occasion they noted that the simple wooden buildings used by farmers were able to withstand the shaking from an earthquake much better than brick or concrete structures. During this terrible disaster of 1923, one building that had been designed by an American architect stood firm when everything around it collapsed. The architect's name was Frank Lloyd Wright and the building he had designed was the Imperial Hotel, still today a landmark in downtown Tokyo. The interesting thing about this man was his adoption of Japanese ideas in his work, ideas that later would be known as organic architecture. Wright had designed the Imperial by floating it on a bed of piles that had been sunk into the ground. He then reinforced the walls with steel bars and divided the whole structure into sections each of which could move independently during an earthquake. At noon on September 1, 1923, two hundred dignitaries were having lunch in the Imperial to celebrate its opening. The luncheon ended abruptly as the earthquake stuck but the Imperial Hotel stood firm.

Japan has always been prone to earthquakes because it stands on the Eurasian Tectonic Plate, and is subjected to pressure from another two, the Pacific and the Philippine plates, both of which are continually sliding under it. The southern Kanto region has had two shocks of magnitude 7.8 or more during the past one thousand years. One of these was this 1923 earthquake, the other arrived in 1703. Both occurred along the Sagami trough, a northeastern boundary of the Philippine Plate. Although they both occurred in nearly the same region, the 1703 earthquake was significantly different in the distribution of coastal uplift and tsunami height as can be seen at the present time in the height of the marine terraces along the southern Kanto region. Both of these earthquakes are interpreted as the result of low-angle faulting with a thrust component at the plate boundary. The southern Kanto region has been uplifted at different times over the past six thousand years.

Major uplifts have been associated with earthquakes like those of 1703 and 1923. The recurrence rate of these is estimated at between 800 to 1,500 years. Thus it is unlikely that major earthquakes like those in 1923 and 1703 will occur in the future. It is a very different story when we examine the western end of the Philippine Plate. It is located on the other side of the Island of Honshu, to the west of Tokyo, around Suruga Bay, in a segment of the plate known as Tokai. Here there is a record of frequent earthquakes. This segment is subducting beneath the Eurasian segment. The last earthquake happened in 1854 and, prior to that, in 1707. Both of these were of magnitude 8.4. At earlier stages, in both 1605 and 1498 earthquakes of similar magnitude, that is to say around 8, hit the region. All of that amounts to four massive earthquakes within 350 years but at irregular intervals. Because of these statistics Japanese geologists now talk about the coming Tokai twentieth century earthquake. They do not know when it will arrive but they feel the chances of one in this century are very high indeed.

When writing about present activities in the Tokai Segment they title their reports "The Earthquake of 20xx." Japan has been making preparations for it for the past twenty-five years. They know that it will be extremely destructive when it arrives because the subduction zone within which it moves is very long. They also expect it to be stronger than the 1923 quake. They point out that past earthquakes in Tokai occurred every 110 years plus or minus thirty-three years. In the year 2006 it was 152 years since the last earthquake and the region was overdue for another on the basis of past statistics. In 1978, the local legislature adopted a large-scale earthquake countermeasure act and a year later declared the Tokai segment to be "An area under intensified measures against earthquake disaster." There is also persistent public education designed to show the expected effects of the coming Tokai Earthquake. Japanese geologists often refer to it as worse than Kobe, the devastating 1995 quake in the city of that name.

The endless battle with earthquakes in Japan creates an outlook and a pattern of research unmatched in any other country. The Tokai Segment, for example, receives continuous attention. Both its depth and the height of the land above it are measured regularly and more detailed measurements are made of one part of the segment where the two plates are locked. This is the part that will one day give way and cause an earthquake. Historical studies of past Tokai tsunamis enable geologists to assess their impacts from the wave records. Unlike so many western countries, Japan has maintained accurate records of past earthquakes as far back as 1700. One expert made a prediction in 1999 based on the collection of measurements available at that time. He said in 1999 that there is a 40 percent chance of another Tokai earthquake before the year 2010. Other experts have said that, when the Tokai Segment gives way, there is likely to be 6,000 deaths, another 20,000 serious injuries, and one million buildings damaged. He also said that large areas would be shaken at a level of 7, the highest intensity level in the Japanese intensity scale.

One disturbing prediction says that the greatest shaking from the Tokai earthquake will occur close to the site of a major nuclear power station, the Tokai-mura power station. This was not a consideration in 1923 but it soon became one in the years following World War II as Japan greatly expanded its industrial base and needed lots of energy. Japan lacks significant domestic sources of energy except coal and must import substantial amounts of crude oil, natural gas, and other energy resources, including uranium. Japan's nuclear output nearly doubled between 1985 and 1996, as Japan attempted to move away from dependence on oil following the 1973 Arab oil embargo. The Japanese government is committed to nuclear power development, but several accidents in recent years have aroused public concern. During the past few years, public opposition to Japan's nuclear power program has increased because of a series of accidents at Japanese nuclear plants, including a March 1997 fire and explosion at the Tokai-mura reprocessing plant. Other problems for Japan's nuclear power program have included rising costs of nuclear reactors and fuel, the huge investments necessary for fuel enrichment and reprocessing plants, several reactor failures, and the question of nuclear waste disposal. Regardless, Japan plans to increase the proportion of electricity generated from nuclear to 42 percent within the next decade. Japan ranks third worldwide in installed nuclear capacity, behind the United States and France.

Over four decades have passed since Japan's first commercial nuclear power plant began operation in Ibaraki Prefecture in 1966. As of today the nation has fifty-two reactors operating around the country with a total output of 46,000 megawatts. Nuclear power accounts for approximately one-third of the country's total electric power output. As an island country, it is impossible for Japan to exchange energy with neighboring countries through power transmission lines or pipelines. Japan is also energy scarce, depending on foreign countries for about 80 percent of its energy resources. These conditions are completely different from those of Europe or the United States; therefore, the government of Japan concludes that it is rational to continue making the fullest possible use of nuclear power generation as one of the mainstays of the nation's energy supply. Nuclear power generation contributes to improved energy sufficiency and to the stability of the energy supply, in addition to playing an important role in reducing Japan's carbon dioxide emissions.

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Charlevoix, Quebec, earthquake

March 1, 1925

Eastern St. Lawrence Valley, Canada, near the city of Quebec

The shock was felt six hundred miles away, including much of New England. Damage to buildings was substantial but there were no casualties

On March 1, 1925, an earthquake of magnitude 6.7 rocked the lives of thousands of people in eastern Canada. The location was Charlevoix-Kamouraska and the depth of the quake was six miles. The shock was felt six hundred miles away. The main quake was followed by a series of aftershocks caused by the readjusting of the earth's crust. The earthquake was widely felt and caused damage, especially to unreinforced masonry buildings, along the St. Lawrence River, near the epicenter, and at Quebec City, Trois-Rivières, and Shawinigan. The St. Lawrence Valley represents an enormous break in the earth's crust. About 350 million years ago an enormous meteorite collided with this fracture zone, in the Charlevoix area, further weakening the earth's crust. In fact, the most seismically active area in eastern Canada is the Charlevoix-Kamouraska area. In 1663 and 1925, the largest earthquakes ever recorded in Quebec were centered in this particularly vulnerable area.

There is a distinctive feature about earthquakes in eastern Canada in that the crystalline rocks of the Canadian Shield transmit seismic waves very effectively. They die out much more slowly than waves produced by earthquakes in areas such as the West Coast. Thus, damage and shaking occur at greater distances from the epicentre. This explains why, on November

25, 1988, an earthquake of magnitude 6 centered in the Saguenay, was strongly felt in Quebec City and as far away as Washington, D.C., six hundred miles from the epicentre. Objects were shaken off shelves, a power failure followed and minor damage was done to some buildings in the Lower Town of Quebec City. For many people who had never experienced an earthquake before, it was an unsettling and even frightening event. Although the earthquake did not cause any direct casualties, uneasy feelings were widespread among the population. Numerous earthquakes have often occurred in eastern Canada. Some of them had significant geological effects such as surface faulting, liquefaction, submarine slumping, rock avalanches, rock falls, landslides, railroad embankment slides, and one tsunami. These earthquakes had a strong psychological and social impact on people, mainly due to their lack of preparedness for them.

The probability of an earthquake being centered precisely below the Quebec City area is low because very few such earthquakes have ever been recorded. But we are not immune to significant damage because if a major earthquake, like the one that occurred in 1925, were to be centered in the Charlevoix area, Quebec City would experience it. Although earthquakes of magnitude less than 5.5 do not generally do any damage, destructive effects are not related solely to the magnitude of the earthquake. The distance between the epicenter and built-up areas, the condition and type of construction in the area, and the nature of the ground are all factors that can have a significant impact on the extent of damage. Buildings constructed on rock are more earthquake resistant. In unconsolidated sediment, earthquakes are much more intensely felt. When earth fill is not well compacted and contains a great deal of water, it behaves like jelly. Some parts of Quebec City would be at greater risk than others. For example, the valley of the Saint-Charles River is filled with clay sediment, which tends to amplify seismic vibrations.

The previous occurrence of large earthquakes suggests that this part of Canada may be the site of a large earthquake in the future. The study of these past quakes helps to calculate a seismic hazard assessment for surrounding urban areas because it is known that the 1925 quake damaged buildings 150 miles from the epicenter. The National Building Code of Canada contains guidelines for the design and construction of new buildings and for the renovation of existing structures. These guidelines are intended to ensure that buildings are more resistant to the shaking that accompanies an earthquake. Throughout Canada, buildings that are constructed in the areas most susceptible to seismic vibrations must adhere to stricter standards. The higher the seismic hazard, the more safety factors must be taken into account. For example, the seismic hazard in the Quebec City area is ranked at four on a scale of 0–6 for ground acceleration.

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Illinois/Indiana/Missouri tornado

March 18, 1925

Three states were affected, Missouri, Illinois, and Indiana

The main locations hit in the course of the three-state rampage were Ellington, Missouri, southern Illinois, and Princeton, Indiana

Widely considered the most devastating and powerful tornado in American history, the Tri-State tornado ripped through Missouri, Illinois, and Indiana on March 18, 1925. In its 219-mile-long wake this tornado left four completely destroyed towns, six severely damaged ones, about 15,000 destroyed homes, and 2,000 injured. Most significantly, 695 people were killed, a record for a single tornado. It left a legacy that is evidenced by ghost towns, lost ancestors, and stories passed from generation to generation. It all began during an afternoon thunderstorm near Ellington in southeast Missouri. From there it crossed the Mississippi River about seventy-five miles southeast of St. Louis and then followed a northeast course as it plowed through southern Illinois and southwestern Indiana.

This tornado from southeastern Missouri was indeed the deadliest tornado in U.S. history, twice as deadly as the second deadliest, the 1840 Great Natchez Tornado. The track left by the tornado was the longest ever recorded in the world. Historians would recognize it as an example of the F5 on the Saffir-Simpson Scale. It formed part of a series of tornadoes that broke out in the spring of 1925—there were tornadoes at that time in Tennessee, Kentucky, and Indiana. In all, at least 747 were killed and 2,298 were injured during this outbreak. The Tri-State exacted its greatest toll on southern Illinois where it reached speeds of 60 mph. Although this part of its journey was over rural land, it tended to follow a string of railroads, placing several towns in its path. Thus 540 people died in southern Illinois in the following towns: Gorham, 37; Murphysboro, 234; DeSoto,

Figure 48 Ruins of the Longfellow School where seventeen children were killed during the Tri-State tornado, the longest-lived and longest path of any recorded tornado. It traveled 300 miles from SE Missouri to Indiana and killed over 600.

69; West Frankfort, 148. In addition, fifty-two people died on farms and small settlements within southern Illinois.

The vortex was first sighted in northwest Ellington, Missouri. It sped from there to the northeast, killing two and causing extensive damage as it passed through several smaller towns, killing eleven and injuring thirty-two in these places. The tornado crossed the Mississippi River into southern Illinois. It was there that the greatest number of deaths were registered, 613, the most ever for a tornado in a single state. Crossing the Wabash River into Indiana, the tornado struck and nearly demolished Griffin, devastated rural areas, impacted Owensville, then roared into Princeton, destroying half the town. It traveled ten more miles to the northeast before finally dissipating three miles southwest of Petersburg. The tornado's unusual appearance, that of a rolling fog, caught many people by surprise and preventing them sensing the danger in time. Additionally, there were downburst winds that widened the damage caused. In summary, over 15,000 homes were destroyed and damages added up to $16.5 million.

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82

Clarkson Valley, Montana, earthquake

June 27, 1925
Helena in Montana

People fled in panic when the quake struck. They had never experienced anything of this strength before. There were no casualties but damage amounted to $150,000

On June 27, 1925 an earthquake of magnitude 6.6 struck Montana near Helena. It was followed by several aftershocks. People fled in panic into the streets. Prior to the main shock a lightning storm had raged, six persons being knocked to the ground and stunned by bolts that struck in various parts of the city. Many years later everybody was still talking about this earthquake, wondering when and where the next one would hit, or picking up a new story about the last one. The quake on June 27 was really a brand new experience for Montana because it was a real earthquake, not one of the little baby quakes that had occurred in past years. The quake was felt at strengths of 2 to 3 from Seattle to the South Dakota line, from Spokane to Thermopolis and Casper, Wyoming, and as far north as Calgary, Alberta. The most severe damage occurred in the counties of Gallatin, Three Forks, Logan, and Lombard. Because no large cities were near the epicenter, property damage did not exceed $150,000. At Manhattan, the community high school and the grade school were both severely damaged, but reinforced concrete buildings were not affected. Many chimneys were toppled.

At Three Forks, walls of the schoolhouse bulged on all sides, and its foundation and basement were damaged. A church, whose walls were not tied together by an upper floor, also sustained heavy damage. Later shocks demolished the walls. Almost all masonry buildings showed cracks and damage, but because most of the buildings were of frame construction, they sustained only cracks in plaster and some fallen chimneys. At Logan, the poorly designed and constructed schoolhouse was damaged heavily. However, a large brick roundhouse sustained only a few cracks. As at Three Forks, most of the buildings at Logan were of frame construction and therefore sustained only cracks in plaster and destruction of chimneys. At Lombard, where the Chicago, Milwaukee, and St. Paul Railway crosses the Northern Pacific Railway, large boulders were dislodged. A huge rockslide blocked the Deer Park entrance to the Lombard Tunnel on the Chicago, Milwaukee and St. Paul Railway.

Cracks occurred in graded and filled roads but not in cuts or where the natural surface had not been disturbed. Approaches to many bridges settled by as much as one foot. One spring formed near Josephine and began to flow, but other springs and sources of water in the neighborhood ceased to flow. Landslides were reported to have hemmed in passenger trains loaded with vacationers. Pavements and buildings were cracked in many cities and some buildings were demolished. The Olympian, fast train of the Chicago, Milwaukee, and St. Paul railroad between Chicago and Seattle, is believed to have been stalled between two of the avalanches in the vicinity of Three Forks. Two other trains, one a Milwaukee train and the other a Northern Pacific, were hemmed in by the slides.

There were no reports of material damage to Yellowstone Park, and the quake is believed to have no connection with the avalanche in the Gros

Figure 49 Montana earthquake of June 27, 1925. Broken railroad track near Lombard.

Ventre River valley near Jackson, Wyoming early that week. Out of all the reports of panic and minor property damage there were none telling of any loss of life.

An earthquake insurance policy for $115,000 was written a day after the earthquake. It was taken out on behalf of the First National bank building in Missoula. According to Ira C. Watson of the Watson Agency, who wrote the policy, this was the first earthquake insurance policy ever written in Montana. Mr. Watson said there were other business blocks in the city upon which the owners were considering earthquake insurance and that other policies could be written over coming days. The railroad tracks were restored to service within a week. A length of track had to be installed to bypass temporarily the area blocked in Sixteen Mile Canyon near Lombard. Immediately after he returned from a conference, Governor Erickson arranged for some of his staff to form an executive committee to handle subscriptions for restoration work. Montana has a history of large, damaging earthquakes but relatively little is known about the faults that produced those earthquakes. Only the 1959 Hebgen Lake earthquake caused surface rupture and thus revealed the causal fault lines. The faults for other damaging earthquakes, including this 1925 one did not have surface breaks.

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83

Santa Barbara, California, earthquake

June 29, 1925

Santa Barbara and immediate surroundings

Damage was extensive and fortunately casualties were few, thirteen in all, because people were still at home when the quake struck

The Santa Barbara earthquake of June 29, 1925, hit the city area early in the morning when, fortunately, no one was outside and the railway was stationery at the terminal. Violent movements were registered on the rail cars, first from east to west and then from north to south. The Mission Creek Dam, the main source of water for the railway, was shaken by the initial shock and all the water ran away, effectively putting the railway line out of business. Those Santa Barbara residents who were not already awake survived the earthquake, as did their homes, but almost every chimney in the city crumbled. Several hotels partially collapsed and a few other buildings completely collapsed. Thirteen people were killed, many fewer than would have been had the earthquake occurred several hours later and they had been on their way to work or were traveling.

Commercial buildings did not ride out the earthquake as well as the residences. In the downtown area, along State Street, the rubble was so thick in the middle of the street that travel by car was impossible. In an odd twist of fate, by leveling much of Santa Barbara's commercial district, the earthquake proved a boon to Santa Barbara's businesses. City officials seized the opportunity that the earthquake gave them to enforce a stricter building code, requiring commercial buildings along State Street to conform to a Spanish-Moorish style of architecture. Thus, the 1925 earthquake is responsible for the distinctive architecture in the city that has made Santa Barbara a popular tourist destination for the years that followed. The area between Naples and Santa Barbara, a stretch of sixteen miles, was extensively damaged with a number of minor landslides having occurred, all of them toward the ocean side. The roundhouse at the Santa Barbara Terminal, a ten-foot brick structure with a wooden roof, was knocked down.

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84

Florida hurricane

September 18, 1926
Miami and Fort Lauderdale and places in between them

This hurricane was sixty miles wide and it reached Florida at 150 mph, causing a death toll between 325 and 800 and a damage cost of more than $100 million

During the night of September 18, 1926, Fort Lauderdale, Miami, and several coastal locations in between were hit by sustained winds of 150 mph from a hurricane that was sixty miles wide as it made landfall in Florida. The death toll was estimated to be from 325 to 800. Several hotels along the coast had their skylights and windows shattered, and the water rose four feet deep in their lobbies. In one instance, fearing that the walls might cave in, a building inspector ordered all women and children to move to another building farther back from the waterfront. The U.S. Weather Bureau in Miami said that no storm in previous history had done as much property damage.

In the early morning of September 17, the Weather Bureau in Washington issued an advisory about a very severe storm that was moving in the direction of Florida. Newspapers ran the advisory, but readers failed to take it seriously. By early evening the Washington Bureau was sending out hurricane warnings but again not many people took them seriously. In 1926 there were few avenues for warning people. Only a few people owned radios and could hear the warnings being broadcast on southern Florida's only radio station. All through the evening and night the barometer kept falling, flood waters were rising, and gale-force winds were being experienced all along the coast. Then, soon after midnight, September 18, the hurricane made landfall with tremendous force, knocking out all electrical power and overturning many buildings. People waited in the darkness.

Figure 50 Miami's new drydock, results of hurricane, Sept. 18, 1926.

Skylights and windows in hotels were shattered, and the water rose four feet deep in the lobbies. In one hotel, fearing the walls would cave in, a building inspector ordered all women and children to move to another building farther back from the waterfront.

The storm had been born near the Cape Verde Islands off Africa on September 6, 1926. It moved across the Atlantic and into the Caribbean and was reported off St. Kitts on September 14. Two days later it had moved into the Bahamas, and by September 17, it began to take aim at southern Florida where it arrived early on September 18, as a category 4 hurricane. As the eye of the hurricane passed over Miami, hundreds of survivors crawled out of their places of refuge, thinking that the storm was over. Thus, when the second half of the storm roared over the town, dozens were washed away. The storm crossed Florida before making a second landfall along the sparsely populated Alabama coast, still a powerful category 3 hurricane. Most of the coastal inhabitants had not evacuated, partly because they had not received the warnings and partly because the city's relatively new population knew little about the danger that a major hurricane posed. Some tried to leave the barrier islands in the lull before the rear of the hurricane arrived, only to be swept off the bridges by the storm. Farther inland, Lake Okeechobee experienced a high storm surge that broke a portion of the dikes, flooded the town of Moore Haven, and killed many. Two years later, in the deadly Lake Okeechobee Hurricane, more than two thousand lives would be lost in this same area.

Most of the 200,000 people living in the storm's projected path were new to Florida, lured here by the easy money of a land boom. Having never seen a hurricane, they had little knowledge of a storm's destructive force. Striking some twenty-five years before hurricanes were named, the 1926 storm became known in southern Florida as The Hurricane or The Big Blow, a title it retained for sixty-six years until Hurricane Andrew arrived.

The lure of the land boom was premature. The wild real-estate boom had collapsed. Millionaires at the end of 1925 had become poor folks by the middle of 1926. Many citizens skipped monthly payments and tax bills and, as a result, lost their homes. Businesses closed down. The sun still shone, but its rays bounced off the bleaching skeletons of unfinished buildings, especially in Miami where damage was far more severe than anywhere else. A storm surge of sixteen feet was experienced there, gutting homes and offices and devastating the harbor. The damage toll soared to over $100 million in 1926 dollars. If a similar hurricane occurred today the damage bill would be more than $100 billion.

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85

Lompoc, California, earthquake

November 4, 1927
Offshore from Lompoc, west of Santa Barbara

All places within fifty miles of Lompoc suffered damage and a tsunami from the earthquake was recorded on the tidal gauges at San Francisco and San Diego

An area offshore, west of Lompoc, California, experienced an earthquake of magnitude 7.1 on November 4, 1927. The most severe damage occurred north and west of Lompoc. Chimneys were wrecked in several towns in these areas, including Guadalupe and Arroyo Grande, all places within fifty miles of Lompoc. There were sand craters and cracks in numerous buildings where water-soaked soil had weakened foundations. The Southern Pacific Railroad tracks, running close to the coast west of Lompoc and near Vandenberg Air Force Base, were thrown out of alignment. A tsunami from this earthquake was recorded on the tide gages at San Francisco and San Diego.

Late in the morning of November 4, the captain of a ship at sea a few miles west of Point Arguello was startled to discover great quantities of dead or stunned fish floating on the surface of the ocean. He was unaware that he was viewing the aftermath of an earthquake that had struck underneath him a few hours earlier that day. Other signs of trouble had come an hour after midnight on the fourth when residents of a coastal community were awakened. Others soon followed because of the strength of the earthquake, powerful enough to awaken most of the inhabitants of Lompoc. Several other ships at sea were shaken. At the Roberds Ranch southwest of Lompoc ten to twenty sand blows appeared. These sand blows occur when shaking from an earthquake causes the pore pressure of water trapped between sand particles to suddenly increase. The result is a fountain of water and sand coming straight out of the earth. The Lompoc office of the Los Angeles National Trust building had all of its furniture and equipment broken and scattered around the rooms. Hundreds of residents of Lompoc, probably recalling the recent earthquake damage in downtown Santa Barbara, hurried to downtown Lompoc to check on buildings.

This was one of the largest Californian earthquakes of the twentieth century and a great deal of interest persisted about it for a long time, particularly questions concerning its epicenter. The quest for this location was heightened because the earthquake was the third largest occurring offshore of California since 1900 and because, over the years, many questions remained unanswered about the earthquakes and tsunamis that had been reported from areas offshore from coastal locations around Santa Barbara. Some indications of the range of opinions about the Lompoc epicenter were documented in 1977, fifty years after the earthquake, each no doubt influenced by the growing body of information and technological expertise that had accumulated over the years. The earliest estimate had placed the epicenter more than forty miles west of Point Arguello and others had followed with a range of alternatives closer to the coast. Still later reassessments of the epicenter placed them along a fault, defined as the Hosgri Fault, stretching for a hundred miles along the coast but with ruptures that may have triggered earthquakes farther west of the defined fault.

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86

St. Francis Dam failure

March 12, 1928
Part of the Los Angeles aqueduct system

This dam, part of the Los Angeles aqueduct system, was constructed on a fault. The dam failure caused the deaths of five hundred and it also changed the course of the Santa Clara River

Shortly before midnight on March 12, 1928, the St. Francis Dam, part of the Los Angeles aqueduct system, collapsed and released twelve billion gallons of water, destroying a swath of land all the way to the ocean and killing five hundred people in its path. The dam had been constructed on a fault, a common geological feature in that part of the country. Unfortunately no geological investigation was made before the dam was built. The collapse of this dam, built by the city of Los Angeles, is a classic example of the neglect of scientific expertise. At that time engineering projects did not consult geologists prior to selecting dam sites.

The accident that followed, California's second worst, next to the San Francisco earthquake of 1906, became a landmark in the history of dam construction. Some have called it America's greatest civil engineering failure of the twentieth century. Never again, in the multiple-fault, earthquake-prone state of California would a major dam be built without a prior, extensive, geological assessment. The St. Francis Dam was a curved, concrete, gravity dam in San Francisquito Canyon, two hundred feet high, with a span of six hundred feet across the mouth of the canyon, and a dike along one side of the canyon. It was built to provide an additional 38,000 acre-feet of water storage for the Los Angeles aqueduct system. Behind the dam, the second biggest in a chain of storage basins, were twelve billion gallons of water, enough to meet the needs of the city of Los Angeles for more than two months. The catastrophic failure that occurred on March 12, 1928, happened as the dam filled to full capacity for the first time. Only much later, in the light of better knowledge of the geology of the Los Angeles area, was a full explanation provided for the failure of the dam.

The architect of the dam was William Mulholland, chief engineer of the Los Angeles Bureau of Water and Power. He had a history of success in the years before 1928 with a variety of projects that were designed to provide both water and hydroelectricity for Los Angeles. It was he who planned and supervised the construction of a 233-mile-long aqueduct that came through the Sierra Nevadas and brought water and electrical power to Los Angeles. Early in 1928 he was working on a very ambitious plan to bring water from the Colorado River across 250 miles of deserts and a series of tunnels to Los Angeles. Thus, when he proposed building the San Francisquito Dam, his plan was enthusiastically welcomed. He was a trusted man, and he was allowed to go ahead with construction of the dam even in the face of warnings from geologists. He ignored their warnings and the local laws of that time allowed him to do this. What he was told by geologists, however, proved to be the cause of the disaster that followed on March 12: they had pointed out that the type of rock under the dam was too weak to sustain the weight of the dam and, furthermore, the dam site was a major geological fault.

Figure 51 St. Francis Dam flood, March 12–13, 1928, Los Angeles County, California. St. Francis Dam before the 1928 failure.

Figure 52 St. Francis Dam flood, March 12–13, 1928, Los Angeles County, California. Taken from the same location, showing the remains of the dam and reservoir floor. The dam failed at 1:58 P.M. Monday, March 12, 1928, according to the water storage recorder on the dam. Twenty minutes prior to that time, the water was slowly dropping in the reservoir indicating that leakage was increasing. The flood destroyed the power house about one mile below the dam at 12:04 A.M. March 13, 1928. The left (west) abutment of the dam was entirely swept away.

For about a week before the failure of the dam, farmers in the surrounding area reported leaks and their quantity and volume seemed to increase day by day. On the morning of March 12, one man observed an unusual amount of water escaping through cracks at the dam's base. This report was immediately brought to Mulholland's attention. He inspected the location and pronounced it safe. Rain had been falling steadily since March 6 and the level of water in the dam had reached the maximum possible, to the point of overtopping. Either the water release mechanism had failed to operate or it had never been installed. Close to midnight, while most of the residents of the Santa Clara Valley were asleep, billions of gallons of water swept down the Santa Clara River. There was no time for local residents to escape. Houses were crushed, farms turned into seas of mud, and cars tossed around like toys. A wide swath of land, in places as wide as sixty miles, was cleared of everything as the water cascaded along a seventy-five-mile-long path to the ocean. Five hundred people had been killed and damage estimates reached $20 million.

This failure represents but one of a number of important dam failures that occurred in the 1920s and 1930s, when American civil engineers were pushing the limits of a technology that was still in its infancy. Like most major engineering failures, looking back on it one can see that considerable long-term societal benefits resulted from the public outcry that followed the disaster. One immediate action was the establishment of a dam safety agency, the first of its kind anywhere. This new organization required geological assessments of dam sites before the design stage, including a normalization of uniform engineering criteria for testing of compacted earth. Foundation material of this kind is still in use worldwide. All the Los Angeles Department of Water and Power dams and reservoirs were assessed in the light of the St. Francis experience and one of the outcomes was an extensive retrofit of the Mulholland Dam. Mulholland's reputation as an outstanding engineer ended suddenly in the wake of the failure of the St. Francis Dam.

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87

Lake Okeechobee hurricane

September 16, 1928
Lake Okeechobee, west of West Palm Beach

This deadly hurricane with its 150 mph winds and wall of water caused the deaths of 2,500 in Florida and overall a death toll of 4,075

The hurricane San Felipe Segundo, named after the saint's day on which it did so much damage to Puerto Rico, but better known as the Okeechobee Hurricane, was the first recorded hurricane to reach category 5 status. It remains the only recorded hurricane to strike Puerto Rico at category 5 strength, and one of the ten most intense ever recorded to make landfall in the United States. In South Florida at least 2,500 were killed when storm surge from Lake Okeechobee breached the dike surrounding the lake, flooding an area covering hundreds of square miles. In total, the hurricane killed at least 4,075 people and caused around $100 million in damages.

The Okeechobee Hurricane struck the Leeward Islands, Puerto Rico, and the Bahamas, before reaching Florida on September 16, 1928. In Guadeloupe, about 1,200 people were killed, and in Puerto Rico where the storm hit directly at peak strength, three hundred died and hundreds of thousands were left homeless. The storm was first observed nine hundred miles to the east of Guadeloupe on September 10, by a ship, the most easterly report of a tropical cyclone ever received via ship radio. A ship in the Virgin Islands later reported the pressure of this storm as being at 27.50, a rare low value, and hence the identification of a very powerful storm. After leaving Puerto Rico, the hurricane moved across the Bahamas as a strong category 4 hurricane. It continued to the west-northwest, and made landfall in southern Florida on the evening of September 16 with winds in excess of 150 mph. The eye passed near West Palm Beach and then directly over Lake Okeechobee.

In September 1928, only about 50,000 persons lived in southern Florida. The land and real estate boom was already beginning to fade, although many subdivisions and new communities were still being built. The Great Hurricane of September 1926 had already sounded a loud alarm to the new residents about the vulnerability of their new homes. Lake Okeechobee is about seven hundred square miles in extent, making it the second-biggest body of fresh water that is entirely within U.S. borders. It is quite shallow and, prior to land reclamation around 1910 in the Everglades south of the lake, water drained out of it at its south end. A dike of packed soil, six feet high, was built around the south side of the lake to restrain water in times of heavy rainfall. Draining the Everglades with a view to the development of farmland in it began around 1910, and migrant workers from the Caribbean along with local sharecroppers were employed to work the new land. Several new towns began to appear along the shores of the Lake. On September 16, as the storm approached, residents of these towns heard about it but did not pay much attention to what they heard. Once again, as had happened before, the Weather Bureau forecasters were convinced right up to the afternoon of the sixteenth that the storm was going to move northwards and avoid hitting Florida. Their warnings finally came too late for people to evacuate danger spots.

By September 16, Lake Okeechobee already had a high level of water due to heavy rains over the previous week. By the evening of that day, as the hurricane's eye passed over the lake's southeast corner, accompanied with 120 mph winds and a wall of water that had swept inland with it, the six-foot dike disintegrated and homes were crushed. Waves of debris carried everything before them. Some survived by hanging on to floating remains of homes, most drowned. The aftermath was as difficult as the terror of the storm. Bodies in that hot climate had to be buried quickly but that was not easy in a place where the water table was so close to the surface. People said that they could not keep the coffins in the ground. But something had to be done with the 2,000 bodies that were there. Some were sent to West Palm Beach where a steam shovel dug a mass grave for the white victims. The bodies of hundreds of black farm workers were buried in a cemetery for blacks. Days later a much bigger grave was dug on higher, sandy soil for 1,000 victims, but still there were many more awaiting burial. They were finally burned in a mass cremation.

News of the disaster was slow to reach the outside world. The nearest city of any size to Lake Okeechobee was West Palm Beach, forty-five miles away, and it was busy coping with its own disaster. All communication lines had been severed. Newspapers across the country a couple of days later reported on the terrible tragedy of a storm that had hit Florida's east coast, unaware of the much greater tragedy farther inland. Migrant workers were not included in census records and there was a general callousness toward their welfare. No one seemed to care about the number of blacks who might have died. When the Red Cross reported that more than 2,000 blacks had lost their lives, state officials changed its total, fearing that such a large number might scare off visitors and endanger the tourist industry. The reality was that this was the second-worst hurricane disaster in the nation's history up to that time, second only to the Galveston Hurricane of 1900. For years after 1928 farmers cultivating land south of the lake came across human skeletons.

The hurricane's path turned northeast as it crossed Florida, taking it across northern Florida, eastern Georgia, and the Carolinas on September 19. It then moved inland and merged with a low-pressure system much farther north around Toronto, in Canada, by September 20. Everyone now knows the potential of Lake Okeechobee. Hence, in the three decades after the storm, the U.S. Army Corps of Engineers constructed a 150-mile dike around the lake. In places, the dike was forty-five feet high and 150 feet wide. Built out of mud, sand, grass, rock and concrete, and named after President Herbert Hoover, the dike has withstood a handful of hurricanes, though none as powerful as the 1928 storm. In the event of a powerful hurricane, to take pressure off the dike, water can be pumped in large volume out of the lake through two wide canals into the sea. Many people have concluded that the site is safe no matter how powerful the next hurricane might be and they have built homes close to the lake. Farms and ranches have also appeared. The dike and the flood control structures have encouraged people to develop 700,000 acres of sugarcane and other market crops. The whole area is sometimes called the nation's winter vegetable basket.

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88

Stock Market Collapse

October 24, 1929
Wall Street at the south of Manhattan Island

Black Thursday received its name because it was on that day that the Stock Market began to crash. Investment in the Stock Market was quite small in 1929 compared with the present time but the conditions surrounding the market at that time were the reasons for its collapse

Thursday, October 24, 1929, is remembered as "Black Thursday," the day that the New York stock exchange began to crash. Close to thirteen million shares were traded in the panic selling that took place on that day. It was not the biggest day of volume but the level of trading and the downward trend created fear and confusion, elements that are the greatest enemies of the market. The bigger day of selling came later, on Tuesday, October 29, when more than sixteen million shares were sold. It was the most devastating day in the history of the New York stock market. One story from later in the day, perhaps apocryphal, is that someone offered to buy a large number of shares for a dollar each and because there were no offers he got them all.

Newspapers across the country told the story in their headlines, next day, October 30, in words like the following: stock prices virtually collapsed yesterday; billions of dollars of market value were wiped out; from every point of view it was the most disastrous day in Wall Street's history. New York bankers, the people to whom investors looked for hope in the crisis, like all others, saw little prospect of recovery for the foreseeable future. Black Thursday had indeed been a turning point. Stocks began to lose their value rapidly, beginning on October 24. By the close of business on that day four billion dollars had been lost. It took exchange clerks until five

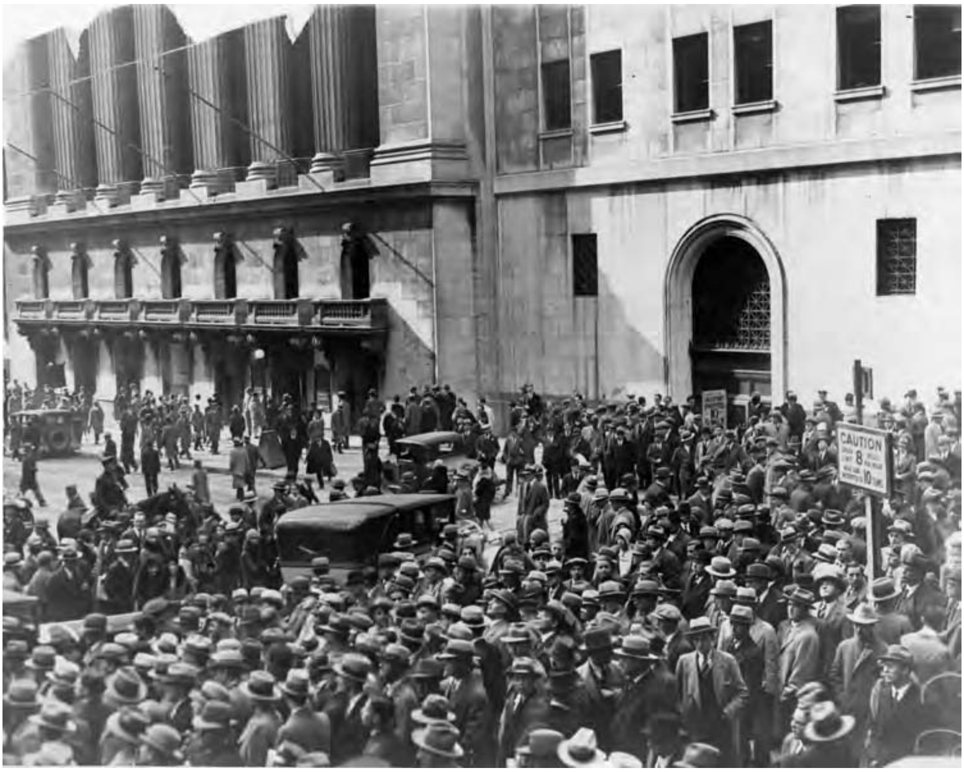

Figure 53 Crowd of people gather outside the New York Stock Exchange following the crash of 1929.

o'clock next morning to complete the paper work. By the following Monday, the realization of what had happened began to sink in, and a full-blown panic was evident. Thousands of people, many of them ordinary working people, saw their recently acquired wealth disappear. In that last week of October the total value of stocks dropped by $15 billion.

The crash heralded the end of a long period of economic growth, often referred to as the "Roaring Twenties." There was a rapid increase in industrialization coupled with a rash of new technologies. The Ford "Model A" car came out in 1927. Radios were everywhere and sound movies were breaking all records about the same time. Most of all there was a spirit of optimism about the future. Wages were high and consumer spending was also high. The stock market caught the attention of more and more people as its values kept on climbing. One feature that caught the attention of more thoughtful people was the strength of a widespread desire to get rich quickly with a minimum of effort. It was a distorted understanding of the American dream that anyone can get to the top if he or she tries hard enough, and it became very evident in the Florida real estate boom of the mid twenties.

Large tracts of land in Florida were being subdivided into building lots and sold for a 10 percent down payment. The people who bought these lots had no intention of living on them. They had become convinced that Florida's warm climate would attract an endless number of people from the cold northern states and this demand would continue to raise the value of the lots they had bought. Within a few weeks they could sell for a good profit what they had bought with borrowed money. As long as this continued and everyone profited from recurring sales there was no incentive to ask questions about how such a trend could continue indefinitely. The optimism of the time failed to see the risks in the speculative bubble with which they were involved. The first sobering reassessment came with the 1926 hurricane that killed hundreds and tore roofs off thousands of houses. Then, within two years of the first explosion of demand, the number of buyers from the north steadily decreased. By 1928 it was all over and defaults had multiplied.

The boom and bust experience of Florida did not have a lasting influence on the get-rich-quick outlook. The new prospective bubble that appeared on the horizon was the stock market. The familiar Dow-Jones Industrial Index, often known as the Dow, had risen rapidly, from 100 in 1924 to 150 in 1926, then to 200 in 1928. These numbers might seem insignificant when we see more than 10,000 as the Dow's value today, but

STAGE | BROADWAY | SCREEN

VARIETY

PRICE 25¢

VOL. XCVII. No. 3 NEW YORK, WEDNESDAY, OCTOBER 30, 1929 88 PAGES

WALL ST. LAYS AN EGG

Going Dumb Is Deadly to Hostess In Her Serious Dance Hall Profesh

A hostess at Roseland has her problems. The paid steppers consider their work a definite profession calling for specialized technique and high-power salesmanship.

"You see, you gotta sell your personality," said one. "Each one of we girls has our own clientele to cater to. It's just like selling dreams in a store—you have to know what to sell each particular customer.

"Some want to dance, some want to kid, some want to get soupy, and others are just 'misunderstood husbands'."

Girls applying for hostess jobs at Roseland must be 21 or older. They must work five nights a week. They

Hunk on Winchell

When the Walter Winchells moved into 304 West 58th street, late last week, June, that's Mrs. Winchell, selected a special room as Walter's exclusive sleep den for his late hour nights. She shushed the Winchell kidlets when her husband dove in at his usual eight o'clock the first morning.

At noon, Walter's midnight, his sound proof room was penetrated by so many high C's he awoke with but four hours of dreams and a grouch.

DROP IN STOCKS ROPES SHOWMEN

Many Weep and Call Off Christmas Orders — Legit Shows Hit

MERGERS HALTED

The most dramatic event in the financial history of America is the collapse of the New York Stock Market. The stage was Wall Street, but the onlookers covered the country. Estimates are that

Kidding Kissers in Talkers Burns Up Fans of Screen's Best Lovers

Talker Crashes Olympus

Paris, Oct. 29.

Fox "Follies" and the Fox Movietone newsreel are running this week in Athens, Greece, the first sound pictures heard in the birthplace of world culture, and in all Greece, for that matter.

Several weeks ago, Variety's Cairo correspondent cabled that a cinema had been wired in Alexandria, Cleopatra's home town.

Boys who used to whistle and girls who used to giggle when love scenes were flashed on the screen are in action again. A couple of years ago they began to take the love stuff seriously and desisted, but the talkers are reviving the ha ha for film osculators.

Heavy loving lovers of silent picture days accustomed to charming audiences into spasms of silent ecstasy when kissing the leading lady are getting the bird instead of the heartbeat. The sound accompaniment is making it tough.

Such a picture romancer as John Gilbert is getting laughs in place

Figure 54 The famous cover of *Variety*: "Wall St. Lays An Egg."

the important thing to note about the 1920s was the rate of growth, doubling in four years. In fact it accelerated rapidly after 1928, jumping from 200 to 350 within a year. That should have given some warning to investors but they failed to see the danger. Buying on margin became the popular activity in these years of rapid growth. It meant that you could buy stock at one tenth of its value using borrowed money. Borrowing money was no easier then than now but people thought that the high gains in the market would justify a high rate of borrowing. You then paid back over time what you borrowed, including interest, but as you did so the increased value of your stock more than paid for the cost of borrowing.

It all looked so perfect that many thousands who never previously paid any attention to the stock market began to invest. They borrowed all they could, withdrew all their savings, even mortgaged their homes, and bought stock. A more useful measure of the times can be gained from the prices of individual stocks rather than the Dow. One mining company had a share value of $50 in 1924. By 1927 it had jumped to $274 and two years later to $575. If one could pick the right place in which to invest, people thought, enormous wealth could be secured. The Marconi Company's shares jumped from $4 in 1927 to $28 a year later but one comment from the president of the company, warning everyone that shares were running too high, should have alerted investors to the volatility of the market. For that one remark the company's shares dropped to $7 within two days.

By the summer of 1929 interest in the stock market was at a fever pitch. The nation had never seen anything like it since the days of the nineteenth century gold rushes. Stock prices had jumped 78 percent since 1928. At lunchtime all traffic came to a standstill as thousands crowded into the New York Stock Exchange. New office blocks appeared almost every week to cope with demand. Anyone could buy stocks even if he had no money. Brokers were glad to loan money because they were sure that the rising value of stocks would more than cover their risk. Ships sailing for Europe were fitted with tickertape and brokerage offices so people could speculate in the course of the voyage. The enormous amount of unsecured consumer debt created by speculation left the stock market fragile. Some economic analysts warned of an impending correction, but their warnings were largely ignored. Banks, eager to increase their profits, speculated dangerously. Finally, in October 1929, the buying craze began to slow down. Many took note of the extremely high rate of growth and pulled back, but for most it was too late to change course.

Before long the Federal Government decided it had to step in to establish control mechanisms such as the Securities Exchange Commission to make sure that fraud, overpriced stocks, and unrealistic levels of risk would never again ruin the stock market. At the same time the loss of so much wealth led to a massive downturn in the national economy and the first signs of the Great Depression surfaced. It lasted for ten years and the causes of this long period of economic stagnation are varied. Production of products had outrun demand. In the enthusiasm of the good times, manufacturing firms and investors had anticipated a certain high demand and designed production levels accordingly. It seems strange that the memories of the late 1920s did not last long. The intensity of the failures of that period should have alerted everyone to the unpredictability of the stock market, but in less than sixty years a similar collapse occurred.

In 1987 there was a crash very much like that in 1929. Again it happened in October and it was a Monday, a "Black Monday," that led the crash.

In some ways, the 1987 crash was much worse than the 1929 one—508 points on the Dow, the biggest drop ever, compared with 124 points in 1929. In percentage terms the market lost 23 percent of its value in 1987 against 25 percent in 1929. The important differences, however, are the effects of the various controls instituted after 1929. There was no worldwide economic crisis in the wake of the 1987 crash, just a temporary slowdown before a rapid rise soon after, one that continued throughout the 1990s.

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89

Grand Banks, Nova Scotia, earthquake

November 18, 1929

At the edge of the continental shelf, three hundred miles southeast of Newfoundland

The slump was triggered by an earthquake of magnitude 7.3, 150 miles south of the Island of Newfoundland, Canada, at the edge of the relatively shallow continental shelf

On November 18, 1929, a major earthquake occurred 150 miles south of Newfoundland, Canada, along the southern edge of the Grand Banks. This magnitude 7.3 event was felt as far away as New York and Montreal. Damage on land was concentrated on Cape Breton Island in the northern part of Nova Scotia where chimneys were overthrown or cracked. Highways in Nova Scotia were blocked by landslides. Aftershocks, some of magnitude 6, were experienced in both Newfoundland and Nova Scotia. A tsunami that was triggered by the earthquake caused extensive destruction on the coast of Newfoundland and killed a number of people.

Dense coastal settlements along the south and east coasts of Newfoundland have long been a feature of this part of Canada because of the fish resources provided by the banks. The Grand Banks is the largest of them. They mark the seaward limit of the continental shelf and they constitute the most extensive area of banks anywhere along the North American coast. Because they are shallow they serve as a rich habitat for fish as they are constantly being enriched by nutrients from both the southward-moving cold Labrador Current and the northward-moving warm Gulf Stream. In recent years, with the increasing use of bigger and bigger fishing vessels and their use of trawl nets with which to scour the sea bottom, over fishing has almost destroyed some stocks of fish and local residents have had to find alternative livelihoods.

The earthquake's epicenter was 6,000 feet below sea level and the landslide it caused was multi-faceted. It constituted a massive submarine slump involving a number of small landslides, adding up in aggregate to more than two hundred cubic miles of debris. The many smaller slides were spread out over a distance of seventy miles along the edge of the continental shelf. As the smaller landslides were coalescing into one big mass they formed into a mixed current hundreds of feet thick. This current as part of the whole overall landslide swept down slope at the edge of the continental shelf at a speed of fifty feet per second, cutting twelve transatlantic cables in numerous places as it moved. About 80,000 square miles of the seafloor was covered with sediment to a depth of ten feet. It was one of the biggest turbidity currents ever identified either historically or in the geological record.

The main story from this earthquake was the tsunami that followed. It was felt along the eastern seaboard as far as South Carolina and across the Atlantic in Portugal. Approximately two and a half hours after the earthquake the tsunami struck the southern part of Newfoundland as three main pulses, causing local sea levels to rise as high as twenty-two feet. At the heads of several long narrow bays the momentum of the tsunami carried water as high as eighty-five feet. This giant mountain of water claimed a total of twenty-eight lives, twenty-seven of them drowned and a young girl never recovered from her injuries and died a few years later. This was Canada's largest documented loss of life directly related to an earthquake, although oral traditions of First Nations people record stories of entire villages being destroyed by tsunamis.

More than forty local villages in southern Newfoundland were affected, where numerous homes, ships, businesses, livestock, and fishing gear were destroyed. Also lost were more than 280,000 pounds of salt cod. Total property losses were estimated at more than $1 million. Many buildings were lifted off their foundations and they floated away. The ferocity of the tsunami was not restricted to the land; it also tore up the seabed. This destruction of the seabed was believed by many to be the dominant factor in poor fish catches during much of the Great Economic Depression that followed in the years of the 1930s. The provincial capital of Newfoundland, St. John's, and the rest of the world did not immediately know of the devastation caused by the tsunami. The only telegraph line from the Burin Peninsula had, coincidentally and unfortunately, gone out of service just prior to the earthquake. When word did finally get out, help came quickly. A relief committee of the government, including doctors and nurses, arrived at communities on the south coast of Newfoundland on the afternoon of November 22. Recovery assistance was also provided by the Red Cross.

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Ukraine catastrophe

November 1932
A terror famine in the old Soviet Union killed
more than ten million people in the Ukraine

Stalin's systematic slaughter by famine and control of movement of more than ten million people was the worst mass atrocity in Europe before World War II

In November 1932, Joseph Stalin launched a campaign of terror against the farmers of the Ukraine to force them into joining a system of collective farming. The peasants, especially the owners of small farms, often referred to as the kulaks, opposed the plan for collective farming, so Stalin decided to starve them into submission by taking away their grain, their main source of food. Millions died from starvation in the year that followed.

In the aftermath of the Communist Revolution of 1917, peasants seized land from the owners of the big farms and Lenin allowed them to do this. He saw a period of small-scale free enterprise as a useful intermediate stage on the path to dictatorship. This stage went on for some time and farmers continued to work their land for profit. After Lenin died, Stalin came to power and, by the end of the 1920s, he decided it was time to abolish all private ownership of land and establish collective farms. This decision was part of a much bigger plan to double the nation's industrial output, a plan that was fully realized by 1932 at a time when the Western World's economies were in disarray due to the collapse of the world's stock markets. Stalin's plan required total control of the country's agricultural resources so that he could get adequate food supplies for the busy industrial cities at low prices, not the prices charged by the farmers.

The focus of his plan was the Ukraine where the best agricultural land of the nation was found and where he soon encountered the strongest opposition. The small-scale farmers, the kulaks, were determined to retain possession of their farms, and when they saw that Stalin was determined to create collective farms they decided to resist. They killed off all their stock for food and held back as much of their grain crops as they could. In less than a year these moves began to starve the cities of their food supplies and Stalin's drive for industrialization was threatened. In the two or three years before 1932 about twelve million new workers had joined the industrial enterprises around Moscow and farther east and most of these additional workers came from rural areas. Stalin felt he had to take drastic action.

Tensions between Russia and Ukraine have a long history. Historically, they were separate countries and after the Communist Revolution of 1917, which was a Russian revolution, Lenin was determined to make sure that Ukrainians supported the new dictatorship in Moscow. As early as 1918 a quarrel involving some Ukrainian farmers led to a response along the following lines from Lenin: These kulaks must be mercilessly suppressed. Find a hundred of their richest and hang them. Publish their names as a warning to others. Stalin's campaign took forms far worse than Lenin ever envisaged and it became even more violent after an incident in the Kremlin during the November 1932 anniversary celebration of the 1917 revolution. In the course of the evening his young wife, Nadezhda Alliluyeva, criticized Stalin publicly, an unthinkable act in that society at that time.

The reason for her criticism arose from her contacts with students who had been forcibly sent to the Ukraine to help with collectivization. Stalin had permitted her to study textiles at a technical school and there she met students returning from the Ukraine. She reported what she heard to Stalin—the mass terror, starvation, the bands of orphaned children begging for bread, even cannibalism. One student reported that he had to arrest two men who were selling corpses. Alliluyeva was anxious to do what she could to alleviate the suffering and when she saw that her husband was not interested she criticized him in front of his closest colleagues. She did not know that Stalin was well aware of all that was happening and had deliberately instigated it. He told her she had been collecting gossip, that these stories were all lies. Determined to prevent news of the atrocities reaching the rest of the country he immediately arranged for the execution of all the students who had been working in the Ukraine.

Alliluyeva knew at once that she had violated the code of secrecy surrounding Ukrainian matters when she spoke out in the Kremlin. Shortly afterward she was found dead, shot either by her own hand or that of another's. The evening's celebration ended abruptly. Later, all who had been in attendance were shot except for one young woman who happened to visit the party for a short time on an errand, unknown to Stalin, and who was able to leave quickly after the news of Alliluyeva's death. Many more executions followed. Stalin's whole character seemed to change. He acted in the most violent way against the slightest opposition from anyone. He intensified the campaign against the kulaks in a way that can best be described as extermination.

Stalin's drive to complete collectivization of farms was speeded up. The slightest opposition meant either instant death or banishment to Siberia. The quantity of grain to be given to the government was suddenly doubled at a time when the existing quota was at the starvation level. What was left for the people of the Ukraine was insufficient to sustain life. Any who tried to hold on to grain and hide it were also killed. Military units assisted by the secret police searched homes and the areas around them and shot anyone found guilty. These military units also guarded the government's quota of grain, stored locally in elevators. Within one month of the incident in the Kremlin, Stalin instituted a new passport system in order to keep tight control of everyone living in the Ukraine, especially to prevent starving peasants going elsewhere in search of food. Those who tried to leave without permission were shot.

Other rules accompanied the passport decree. Not only was a Ukrainian unable to leave his territory to look for the essentials of life, he was not permitted to leave the collective farm and seek work in the big industrial enterprises without permission from the local party official. The high death rate and the large numbers that had been banished to Siberia left the collectives with a shortage of labor. No party official would allow a worker to leave for the city. Alongside the needs of labor were the demands from Stalin to maintain secrecy about the devastation that had occurred and these demands were best met by isolating the Ukraine. Both the Ukrainian peasant as well as the former kulak, the owner of a small farm, had become serfs with no rights and no ownership of anything, just like the old days under the czar.

The *New York Times* reporter in Moscow in 1932, Walter Duranty, described the passport laws as popular and valuable in his dispatches to the United States. While he recognized that Westerners would see them as a shocking infringement of individual rights and freedom, in his view the Soviet worker sees them as a vigorous step toward the improvement of living conditions. Duranty, in his reports, stressed the value of the passports for preventing large numbers of agricultural workers leaving their communities. That was exactly why they were introduced by Stalin, but Duranty failed to include the real reason, to prevent starving peasants finding food. In his reports to the *New York Times* he goes so far as to identify some of these people. He lists some as class enemies, such as kulaks who are opposed to the good work being done by the government. This was the kind of reporting that gave him a Pulitzer Prize, yet at that very time he knew that many millions had already lost their lives due to the forced famine.

Duranty blamed the famine stories of 1932 on people who were hostile to the Soviet Union and wanted to prevent the United States from recognizing the new Communist Government. Whatever may have been his motives in falsifying facts the results were very favorable to Stalin and he was duly rewarded with special privileges not granted other correspondents. His reports carried a lot of weight in the United States because of the newspaper he represented. When, a short time later, the United States recognized the Soviet Union as the authentic government of the country, Walter Duranty's news reports were described as enlightening and dispassionate. The worst case of falsification came later, in the 1940s, when Hollywood produced the film "North Star," a Soviet collective farm run by well-fed happy peasants.

In the reality of 1932, village after village saw their infrastructures taken away as part of Stalin's method of total destruction. Churches were set on fire because they were symbols of the old Russia, a relic of the past that might compete with the new Russia if left standing. Bureaucrats from the Communist Party were put in charge of huge farms, deciding what to plant and where, what machinery to buy and how to use it, all without any expertise. The only sources of wisdom for this work were either dead or in Siberia. The inefficiency of the new system and its new managers, especially in the short term while the collectives were being organized, meant less grain for the cities. Hence Stalin demanded higher quotas and the cycle of starvation and death deepened. Cannibalism appeared here and there.

Students from the Soviet School of Mines in Moscow and other colleges like the one attended by Alliluyeva were sent to assist in the collectives because there were no peasants to do the work. Each group was allocated to a particular village but, as they traveled through the Ukraine, they noticed that there were no people anywhere. Sometimes they would arrive at a place that the map said was a village but nothing was there, only some bricks and weeds. At one destination where they were expected to stay a group found only one young girl, the only survivor in the village. She was in a state of dehydration, barely alive, and beyond medical help. She was anxious to tell the students as much as she could. The only regular food they had for some time was a kind of pancake made from beet and cherry leaves. In other villages the students met similar devastation. Here and there they met individuals who were insane through hunger and were attacking anyone and everyone they met. Any student who reported in Moscow what he saw was immediately shot.

As hunger spread the violence increased. Whole villages were wiped out and their inhabitants shot at the slightest provocation. Hundreds of thousands were banished to Siberia to work in mines or forests. The slaughter could almost be termed a genocide because a whole ethnic group was seen as the enemy of the Soviet State. Millions died from starvation. The number is uncertain but many estimates give five million as the likely number, half of that number being children. It was similar to the Nazi Jewish Holocaust as far as numbers of people are concerned. The reason the West knew so little about this holocaust compared with the German one is due to Stalin's effective propaganda. No foreign correspondent was allowed to visit the Ukraine. He arranged special conducted visits for distinguished foreigners who were supportive of socialist ideas and made sure that they only saw what he wanted them to see. George Bernard Shaw, the well-known British playwright, was one of those. He returned to Britain and announced that reports of starvation and forced collectivization were, in his words, "nonsense."

Certain villages with model collective farms were set up for the special visitors where everyone was well fed and well housed. Edouard Herriot, twice premier of France and also a strong socialist, spent five days in the Ukraine and stated that there was no famine there. Sir John Maynard Keynes, one of the world's greatest economists of his time and an expert on Russian agriculture, visited the Ukraine and told everyone in Britain when he returned that reports of famines were totally unfounded. Sidney and Beatrice Webb, British social scientists, spent a lot of time in the Ukraine in 1932 and afterward published a massive volume on their research. In it the peasants are described as greedy and cunning, subject to drunkenness and laziness. They are seen to be hostile toward the good work of a government that only wants to see resources shared equally by all. With allies like these Stalin made sure that the West knew little about the terror-famine, the name given to the catastrophe by Robert Conquest in his book *The Harvest of Sorrow*.

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Nevada earthquake

December 21, 1932
An uninhabited area of Nevada southeast of Reno

There were no casualties from this quake but complicated faulting occurred along a stretch of forty miles

A major earthquake of magnitude 7.2 occurred in an uninhabited area of western Nevada on December 21, 1932, and thereof caused minimal damage to buildings. Two cabins, one of stone and the other of adobe were destroyed, and ore-treating plants and mines were damaged. The main shock was felt in and around the community of Mina where many chimneys were knocked down, walls fell down, and cracks appeared in the ground. Extensive and complicated faulting happened over an area forty miles long and four to eight miles wide with numerous rifts developing, each as long as four miles in length and more than three hundred feet in width. Significant vertical and horizontal displacements were common. Boulders were shaken from cliffs, landslides took place, and ground water fluctuated vertically. The earthquake was felt from San Diego to southern Oregon and several aftershocks followed.

An earthquake of almost identical magnitude occurred a few hundred miles northeast of Mina in 1915, and the results on the ground were quite similar to the 1932 one: scarps as long as forty miles and extensive vertical and horizontal displacements happened. There was also a third major quake prior to 1915, within the twentieth century, and again primary rifts and fault scarps were observed along with significant earth movements. It is of special interest that the horizontal direction of movement of the adjoining mountain masses in the 1932 quake is the same as those observed at Owens Valley along the eastern slopes of the Sierra Nevada Mountains and also the same as on the east side of the San Andreas Fault.

These similarities are reminders of the nature of the underlying geological structures that form the westernmost limits of the North American Tectonic Plate. From Florida to Alaska there are places in the United States that are today found together in one location but geologically they are quite different from one another. They carry the name terranes. Florida, all of it, may well have come from Africa, and several places east of San Francisco certainly came to that location from elsewhere. For example, the Marin Headlands north of San Francisco was recently identified by its fossils as coming from somewhere on the seabed of the Pacific Ocean. Similar stories describe the history of Alcatraz and Angel islands.

These are but a few of the many terranes found across the nation. Parts of Nevada, which is quite some distance inland, came from Asia. All along the west coast, from Baja, California to Alaska, terranes are everywhere. Two hundred separate ones have been discovered, some large and some quite small, some located as far inland as Utah and Colorado. Most of these terranes arrived between 100 and 200 million years ago and as a result of their arrival the continent was extended westward by three hundred miles. The sources of these new lands are unknown. Some came from ocean floors, some from islands, and some from other continents. These terranes now provide valuable clues about ancient rock formations that lie underground beneath more recent formations.

Locating the epicenter for the 1932 earthquake was difficult for the geologists who examined the area in depth in 1934. This can readily be appreciated since their work preceded the knowledge of tectonic plates by more than thirty years. When no clear center became obvious from the various reports collected, an area southeast of Reno was selected as the epicenter region. Years later, with present day technology, the epicenter was located northeast of Reno, a location that is more in keeping with the direction of surface movements that has already been noted. Overall this earthquake was the second most severe ever for Nevada in terms of the available knowledge of that time.

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Sanriku, Japan, earthquake

March 2, 1933

Northeast Honshu, Japan, in the Prefecture of Iwate

The offshore earthquake, though powerful, was barely felt on shore so no one was prepared for the tsunami that followed

The northeast coast of Honshu, Japan, in Iwate Prefecture, was hit with a powerful earthquake of magnitude 8.4 on March 2, 1933. It was followed by a tsunami that reached heights of seventy feet, causing catastrophic destruction to countless homes and ships and taking the lives of more than 6,000 people. An almost identical event occurred in the same location in 1896, causing the deaths of more than 26,000 people. The lower death rate in 1933 reflects, in part, the precautions taken after 1896 earthquake to cope with possible future earthquakes and tsunamis. It is also partially explained by the difference between the two causal earthquakes.

The 1896 event with the same name and a greater magnitude, 8.5, occurred on a reverse fault, as an interplate event, instead of the normal pattern, and this resulted in less shaking and slower initial speed. Its epicenter was ninety miles offshore, near an area of very deep water known as the Japan Trench, where the Pacific Plate subducts beneath the Asian Plate. Because of the nature of the fault, the impact on shore was much weaker than would normally be expected from such a powerful earthquake. Hence, people on shore paid little attention to the mild shaking they experienced so there was little expectation of a tsunami, even though this part of the Japanese coast experiences earthquakes frequently. Thirty-five minutes after the earthquake, the most devastating tsunami in Japan's history reached the shore at the same time as high tide. In some places the tsunami's wave reached a height of 125 feet. Everything in its path was totally devastated.

It was quite a different story with the 1933 event. The ground shaking was much more violent as the tsunami reached the shore about forty minutes after the earthquake. There were widespread cracking of walls and numerous landslides. Aftershocks followed, with the largest, occurring three hours after the main earthquake, having a magnitude of 6.8. These aftershocks continued intermittingly for about six months. Many different studies have been conducted on this tsunami. The results indicate that tsunamis became much larger in areas with a V-shaped bay, such as those on a ria coast. Later studies found that tsunamis in general become larger in V-shaped bays when the earthquake occurs relatively close to shore.

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Baffin Bay, Canada, earthquake

November 20, 1933

Off the east coast of Canada in Baffin Bay north of Iwate

This earthquake had a magnitude of 7.4 but the outstanding point about it is that this part of Canada's offshore in Baffin Bay is rarely hit with strong earthquakes

On November 20, 1933, the largest instrumentally recorded earthquake to have occurred along the passive margin of North America occurred in Baffin Bay. Coincidentally, it also was the largest known earthquake north of the Arctic Circle. In spite of its size, the 1933 earthquake did not result in any damage because of its offshore location and the sparse population of the adjacent onshore regions. The only known location that felt the earthquake was in Upernavik, Greenland. It was not felt in Thule to the north or in Disko Fjord to the south. One would have expected the earthquake to be felt in the closer northeastern coastal communities of Baffin Island but no reports were ever received.

The Baffin Island region continues to be active. In fact it is one of the most active regions in eastern Canada. Five magnitude 6 earthquakes have occurred here since 1933. The latest moderate-sized earthquake had a magnitude 4.8 and occurred on July 5, 2004. Analysis of seismograms of this earthquake shows strong evidence for strike-slip faulting, a condition that contrasts with the generally accepted belief that Baffin Bay is dominated by thrust faulting. The best-fitting solution consists of a large strike-slip sub event followed by two smaller oblique-thrust sub events. All of these occur at a depth of about six miles. An instrumental magnitude of 7.4 was determined for this earthquake. Preliminary analysis of subsequent large earthquakes in Baffin Bay finds additional evidence for strike-slip faulting in the region. The results for Baffin Bay, together with those for other passive margin earthquakes, suggest strike-slip faulting may be more prevalent in these regions than was previously believed.

It was believed that Baffin Bay was formed by seafloor spreading between sixty and forty million years ago, but more recent evidence suggests that the seafloor spreading began much earlier, around sixty-nine million years ago. It has been difficult to define the ocean-continent boundary owing to the thick sediments in Baffin Bay. There is evidence for faulting in the basement rocks and older sediments in Baffin Bay and for slumping, which could be seismically related, in the younger sediments. Although Baffin Bay is now known to be a very active seismic zone, considerably less was known about the 1933 event for a long time. Prior to the 1933 earthquake, the region was believed to be aseismic. Earthquakes of magnitude 6 and greater subsequent to1933 are noted in the International Seismological Summary and similar summaries, but it was only with the expansion of the Canadian seismograph network in the north during the 1950s and 1960s that these earthquakes could be put into any kind of regional context.

Estimates suggest that the earthquake catalogue for Baffin Bay has been complete above the magnitude 7.0 level since 1920, magnitude 5.5 since 1950, magnitude 4.0 since 1968 and is incomplete for magnitudes less than 4.0 for all time periods.

This contrasts sharply with the Charlevoix seismic zone in the long settled St. Lawrence Valley where the completeness years for the same magnitude levels are estimated to be 1660, 1900, and 1937, respectively, and where earthquakes of magnitude less than 0.0 can now be routinely located by a dense local seismograph network. Historical seismic activity is not uniformly distributed throughout Baffin Bay but is concentrated in northwestern Baffin Bay on the Baffin Island side of the 6,000 feet bathymetric contour. To date no one has been able to correlate the seismicity with particular geological structures or geophysical anomalies. It has been suggested that it is related to the stresses associated with post-glacial rebound.

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Bihar, India, earthquake

January 15, 1934
Nepal, six miles south of Mount Everest

This magnitude 8.1 earthquake ruptured the earth for a distance of 1,200 miles and killed 12,000 people

The 1934 Bihar-Nepal earthquake had a magnitude of 8.1 and caused 12,000 deaths in Nepal and India combined. The epicenter of the earthquake was in Nepal six miles south of Mt. Everest. It was the worst that ever occurred in that country. Its rupture length was estimated to be 1,200 miles. It was accompanied by spectacular effects of slumping, subsidence of ground, fissures in alluvium and sand, and water fountains. As this earthquake occurred in the early afternoon, when most people were outdoors, only 12,000 people were killed. Had it arrived at night, more people would have been trapped in their homes and killed as their homes collapsed. Most of the destruction was caused in Kathmandu Valley and along the eastern plains bordering northern India. More than 80,000 houses were damaged.

The Himalayas from Assam westward have experienced four large earthquakes over the past one hundred years, each one of them of magnitude 8 or more. There is evidence that even larger events have occurred in the past, and geodetic and seismic monitoring show that stress is accumulating now. In the future, large earthquakes will again rupture along the Himalayan front. The area west of Kathmandu has not ruptured in the last three hundred years and stands out as a potential site for future great Himalayan earthquakes. The Indian Department of Mines and Geology is collaboratying with many scientists from all over the world to understand the causes and effects of these devastating earthquakes, and to help mitigate the ensuing destruction.

About two hundred million years ago an ocean separated India from the rest of Eurasia. This sea was gradually consumed through the subduction of the oceanic floor beneath Tibet. Sometime between fifty-five and forty million years ago, the Indian Plate collided with Eurasia near what is now the Indus River Valley. Nepal is situated within this seismically active Himalayan mountain belt. The continuing northward motion of India at the rate of about four centimeters per year has created wide-spread deformation, giving rise to the world's highest mountains. Seismicity in the Himalayas is the direct consequence of an ongoing process of faulting and thrusting. Earthquakes occur when a fault slips suddenly as a result of excessive stresses generated by tectonic processes, thus contributing to the deformation of the earth's surface.

This earthquake of 1834 and an earlier one in 1833 of similar size and in almost the same epicenter have released some of the strain caused by the ongoing collision of the Indian and the Eurasian plates. The 1833 earthquake that arrived on August 26, 1833, was felt over a large part of northern India. It shook an area half a million square miles in extent in Nepal and Tibet. Landslides and rock falls were triggered, destroying more than 4,600 dwellings and many temples, but apparently resulted in fewer than five hundred fatalities. It is certain that the loss of life would have been far more severe had not the main shock been preceded by two large foreshocks five hours before the main shock so that people went outdoors in alarm. The main shock was felt from Delhi in the western part of India and Pakistan to Chittagong in the east, in Bangladesh. Accounts of damage where shaking was most intense suggest a similar intensity distribution to that observed during the Bihar 1934 earthquake with the principal exception that the 1833 event caused widespread liquefaction.

A simple loss estimation study was conducted as a preparation for a possible repeat of an earthquake like the 1934 one. Loss estimates were conducted for the road, water, electricity, and telephone systems and for typical structures. In addition, possible death and injury figures were estimated by looking at statistics from previous comparable earthquakes in other parts of the world. Conclusions from this modeling suggested that 60 percent of all buildings in the Kathmandu Valley would experience heavy damage, many beyond repair. Almost half of the bridges in the valley would be impassible, and 10 percent of all paved roads would have moderate damage, such as deep cracks or subsidence. Nepal's only international airport would be inaccessible. Ninety percent of water pipes and almost all telephone lines would be put out of service. Half of all electric lines would be knocked out. In the light of the increased population today, compared with 1934, the death toll would likely be 22,000 and the number of injured 25,000.

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Quetta earthquake

May 31, 1935
The city of Quetta in what is now Pakistan

Quetta is 5,500 feet above sea level and is located in a very mountainous area about fifty miles from the Afghanistan border

At 3 A.M. on May 31, 1935, the city of Quetta was devastated by a severe earthquake of magnitude 7.7, lasting about thirty seconds, followed by many aftershocks. This city, at 5,500 feet above sea level, is in Southwest Pakistan, about fifty miles from the Afghanistan border. It was razed to the ground by the earthquake and more than 30,000 people lost their lives. Quetta, in 1935, was part of India and was ruled by Britain. British military officials immediately arranged to clear away the debris of the earthquake so that ambulance convoys could transport the injured to local dressing stations. At the same time groups of soldiers began to dig out the victims who lay under the ruins of their homes. There was little contact with the outside world as the telegraph center had been destroyed so Quetta had to cope on its own with the disaster.

Before the earthquake, Quetta had been a British military garrison since 1876 in the area that was called Northwest Frontier. Twelve thousand soldiers were stationed there to cope with the conflicts that emerged from time to time with local warlords. Its name comes from a local dialect meaning "fort." In order to accommodate the soldiers their residences were constructed in a multi-storied fashion. When the earthquake struck, these buildings collapsed and many lost their lives as they came down.

When reconstruction began after the earthquake all buildings were single-storied. The officer in charge of the garrison was Lieutenant-General Sir Henry Karslake, an experienced frontier specialist. His quick action both in rescue work and in reconstruction prevented an outbreak of disease. May is a hot month in Quetta and bodies had to be buried before decomposition set in.

Within three hours of the earthquake, that is to say between 3 A.M. and 6 A.M. on May 31, Karslake had divided up the devastated area into sections, allocated a group of soldiers to each section and told them to do everything possible to save lives and help the injured. They rescued people from the debris, moved in supplies, kept law and order, ran medical services, and set up a refugee camp on the open ground. Much of the work was done before breakfast! Only a military organization could have done it. The dead were laid out on the side of the road and collected in carts for burial and a separate group of soldiers had earlier been given the task of digging graves. Rescue work went on steadily throughout the day. By 8 P.M. it was dark and everything stopped.

Long before the evening the men were totally exhausted. It had been a very hot day and they had worked continuously since early morning, for the most part with nothing to eat. They had to wear medicated pads over their mouths and noses owing to the danger of disease from dead bodies and the odor hourly became worse. The pitiful requests of the survivors, who could do nothing to help themselves, and the sight of the dead bodies added to the strain of the day's work. Christians were buried in one place, Muslims in another, and Hindus burned their dead at any convenient location. A major problem was the question of what to do with animals. The city was full of cows and water buffaloes, and most of them had calves. Karslake had the injured shot.

During the first day or two, when everything was disorganized, young people from local tribal areas came to Quetta. They knew that beneath all those bricks thousands and thousands of rupees and valuables were buried. The large majority of native people kept their money in a box under their beds rather than trust the banks. Martial law was declared, which meant looters could be shot on sight, and soldiers were posted on the outskirts of Quetta to stop thieves from coming in. By June 12 all British women and children had been moved to temporary accommodation elsewhere along with thousands of refugees and over ten thousand injured men, women, and children. Some were taken by air but most went by rail. In retrospect, the Quetta earthquake of 1935 represented a landmark in India's history. For the first time, serious and systematic efforts were made in the design of earthquake-resistant methods of construction. The use of reinforced concrete at different levels in buildings dates from the experience of the Quetta earthquake. This and other actions taken in 1935 became the model for earthquake response in all the other earthquake-prone regions of India.

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Labor Day hurricane

September 2, 1935
The Florida Keys

This storm's extremely high winds, high storm surge, record low pressure, and high fatalities earned it the name of the most powerful ever to strike the United States

The 1935 Labor Day Hurricane was the most powerful ever to strike the United States. It was not the most deadly in terms of fatalities but its extraordinary high winds, huge storm surge, and lowest barometric pressure ever recorded in the United States up to that time rank it as number one in intensity and destructive power. It was appropriately named "Storm of the Century." This category 5 event made landfall along the Florida Keys on Labor Day, September 2, 1935. People on the Keys were hit with 200 mph wind gusts, a storm surge of fifteen feet, and waves that carried everything before them.

It formed over the Atlantic and, after striking the Bahamas, it headed for Florida, reaching the Keys with sustained winds of 185 mph. Its central pressure was 26.35 of mercury, a level that was not surpassed until Hurricane Gilbert arrived in 1988. The population of Florida, including the Keys, was growing very fast in the mid-thirties. The disastrous outcome of the land grab of the 1926s had been forgotten. A railway line had been built at a cost of almost $50 million to link the Keys with the rest of the state. Large numbers of settlers and tourists kept arriving every year. By the summer of 1935 there were more than 12,000 residents there plus another 750 who were veterans, hired by the Federal Government to build a road linking the islands of the Keys.

Early on Sunday morning, September 1, the weather bureau, having noted that this storm had reached hurricane status, issued an advisory that it was going to move through the Straits of Florida and pass on into the

Gulf. Given the level of skills in meteorology at the time, and the limited number of stations relaying data to the bureau, this forecast was a reasonably estimate. By the evening of the day the advisory was extended to include all of southern Florida as well as areas along the west coast of the state. Very few people received this information. Those who did were the residents who had lived in the area for some years and were familiar with hurricanes. They were the ones who called the weather bureau frequently to get the latest information and shared it with others. They were also the ones who made all possible preparations to protect themselves from a strike. More recent arrivals, including the administrators of the veterans' road-construction project, decided to go with the earlier advisory that the storm would pass west south of the Keys.

The Bureau's estimate of the storm's location on Labor Day morning was out by almost three hundred miles. Furthermore, because they did not know at that time that it was a very narrow hurricane, less than ten miles across, they had little advance warning of the nature or direction of its forward winds. Before 11 A.M. the bureau decided to include the Keys as a place that might be hit. The Administrator of the veterans' project decided at that time to get a train backed down to the Keys on the one-track line to bring veterans away from the danger area. There were extended delays in getting this done. Because of the holiday no train was waiting and ready at the town of Homestead. It was after 5 P.M. before the needed train began to back down into the Keys. By 8 P.M. on Labor Day the storm struck. The train had not yet reached the middle Keys. Ten cars were tossed off the train by powerful waves that were surging over the islands. More than four hundred lost their lives.

Even today, with all the advances made in weather forecasting, a storm of the intensity of this Labor Day one would destroy every building in the keys. Few would survive. The only remedy in the face of an approaching hurricane is evacuation and this is the course consistently taken now especially since the total population of the Keys has risen to well over 100,000 when tourists are included in the total number. After striking the Keys, the hurricane continued up the west coast of Florida and landed again on the Florida Panhandle as a category 2 hurricane on September 4. It then passed over Georgia and South Carolina and back into the Atlantic Ocean off the coast of Virginia.

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Gainesville tornado

April 6, 1936
Hall County, Georgia, southwest of Gainesville

This tornado reached downtown Gainesville as a double-funnel storm that caused 203 deaths and $13 million worth of damage

Early in the morning of April 6, 1936, an F4 tornado landed in Hall County southwest of Gainesville, Georgia, destroying homes and infrastructure as it moved toward downtown Gainesville. A second funnel from west of the city joined it and together they hit the square in downtown Gainesville. Memories linger long in situations like these. One lady recalled, sixty years later, how dark the city had suddenly become in the middle of the day. She had never seen anything like it before and all she heard from the people around her was to take cover as quickly as possible. She had no idea what they meant. The tornado destroyed almost everything in the downtown area, killing 203, injuring another 1,600, and causing $13 million worth of damage.

President Franklin Delano Roosevelt, who was on his way from Washington, D.C., to Warm Springs, Georgia, stopped in Gainesville three days after the storm and witnessed the destruction. This city was a struggling community in 1936. Its economic base had been weakened as a result of the depression of the 1930s. The boll weevil, drought, and crop failure had destroyed so much farmland that many farmers sought jobs away from the farms. Unemployment levels were high. Weather was not on many people's minds. In the downtown area on the morning of April 6, 1936, about two hundred people reported for work at the Cooper Pants factory. People on the way to the courthouse and kids on the way to school began to fill the square. Had there been better warning systems in place, the people of Gainesville would have been more prepared for what happened because, on the evening of the previous day, an F5 tornado passed through Tupelo, Mississippi, one of many tornadoes that were moving in the direction of Gainesville, about two hundred miles farther east.

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Hindenburg crash

May 6, 1937
Lakehurst, New Jersey

As the Hindenburg came in to land at Lakehurst, New Jersey, it caught fire and, with hydrogen tanks in use, a huge explosion followed

In the evening of May 6, 1937, the German airship Hindenburg was approaching Lakehurst, New Jersey, preparing to land. The ground crew stood ready as the ship reduced its speed, dropped its landing ropes, and prepared to connect with the mooring mast. Suddenly there was a flash of light and before anyone could assess what was happening a gigantic fireball erupted and the whole ship was engulfed in flames. In a few minutes the Hindenburg was reduced to a smoking mass of flames and molten metal.

In 1937, Hitler was at the height of his power in Germany and the zeppelin *Hindenburg* was the biggest airship in the world. As flagship of Germany's lighter-than-air fleet Hitler wanted to use it in a regular service to the United States to demonstrate the benefits of this new mode of travel. The *Hindenburg* had made the Atlantic crossing several times in the previous year and this was its first trip in 1937. With its huge size, almost as long as the *Titanic*, and with enough width and height to provide lounges and dining rooms, it offered a new and luxurious style of air travel. Everyone knew that the gas used to hold the airship aloft was hydrogen, inexpensive to produce and very effective, except that it was highly flammable. A single match or a bullet could easily set off the kind of explosion that occurred at Lakehurst.

This may have been the reason for premonitions of doom that were expressed before the flight left Frankfurt. These concerns affected some people so much that they cancelled their plans to travel. Seven million

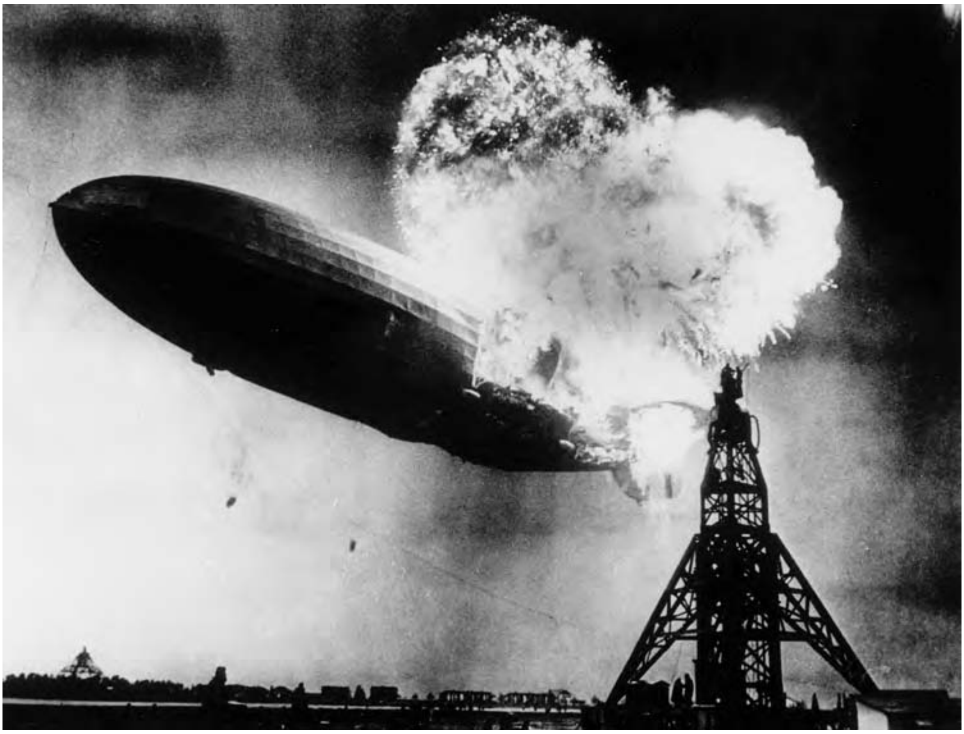

Figure 55 This photo, taken at almost the split second that the *Hindenburg* exploded, shows the 804-foot German zeppelin just before the second and third explosions send the ship crashing to the earth over the Lakehurst Naval Air Station in Lakehurst, New Jersey, on May 6, 1937. The roaring flames silhouette two men, at right atop the mooring mast, dangerously close to the explosions.

cubic feet of hydrogen was needed to hold the 242-ton ship in the air and the presence of this huge quantity of a flammable gas might also have caused fears. The much safer gas to use in zeppelins was helium, more expensive to produce than hydrogen but not flammable. Germany would probably have used helium had it been available. In the 1930s the United States had control of the world's supply of helium and was not willing to let a country like Germany have access to it because of all the military buildups taking place in Europe.

The debate over helium versus hydrogen was not an easy one to settle and most German authorities finally relied on years of experience with hydrogen-filled airships to support sticking to this gas. It was sixty times cheaper than helium to produce so that was a big factor even if there had been no problem with supply. Helium had only 90 percent of the lifting power of hydrogen, because it was a slightly heavier gas, and Germany was anxious to mount the biggest cargo possible. It even changed the passenger terminal city for the *Hindenburg* from Friedrichshafen to Frankfurt because the latter was a thousand feet lower in elevation. At the higher air pressure that this change provided the airship could carry an additional seven tons of payload. To avoid the risk of an explosion when releasing gas to allow descent, which had previously led to two explosions, stored water was used instead.

The *Hindenburg* was a new airship. Its first flight took place in 1936. It was a luxury, air-conditioned vessel with twenty-five two-berth cabins to accommodate its fifty passengers. Passengers could live aboard in a style of luxury unmatched in all earlier airships. It was like living in a first-class hotel. Along both sides of the passenger deck was the promenade with seats and with slanted windows that gave clear views of the landscape below. It was always a spectacular scene as the vessel was only 650 feet above the ground or sea level. Passengers boarded the ship via a retractable set of stairs as far as the lower deck, then by a staircase to the top deck. The *Hindenburg* could travel 8,000 miles without refueling at a speed of 80 mph.

The material used for the sides was cotton or linen as these were found to have better resistance to wind and rain than any other materials. A varnish and several coats of aluminum paint completed the outer shell. Everywhere inside the ship the lightest materials were used for framing, usually aluminum. The ship's brain was the control car, located on the bottom of the vessel close to the front. Two of the key officers always on duty were the rudder and elevator men. The former kept the ship on a fixed course while the elevator man watched four instruments dealing with horizontal and vertical shifts, elevation, and hydrogen pressure.

Hindenburg was the first of the zeppelins to allow smoking but the rules for smokers were strict. There was a revolving door that served as an airlock through which people passed to reach the smoking-room. Asbestos lined the walls of this room and no passenger could leave until the cigarette was extinguished in a water-filled ashtray. No one was ever seasick on this airship; its motion was so smooth that often passengers refused to believe it was in the air, quite a contrast to today's big planes. One popular game that related to the airship's stability saw people competing to see how long a pen or pencil could be stood on end without falling over. Ernst Lehmann was the captain, a man with long years of experience on zeppelins stretching back to World War I days. As the airship traveled across the Atlantic on its fateful final voyage everything seemed to go well. The weather was good so speed was maintained at 60 mph. This meant crossing the Atlantic in three days. At Lakehurst, New Jersey, there was some delay due to bad weather but the rain and wind had gone by the time the *Hindenburg* touched down.

No one was prepared for the chaos and destruction that followed the spark from somewhere as the nose of the *Hindenburg* approached the mooring mast. The landing ropes had been thrown down and ground crew was steadily drawing the ship to the ground. Suddenly the whole structure collapsed and fire was everywhere. Some jumped to the ground, others waited until the ship dropped farther down, risking getting incinerated in the process. One passenger called it a medieval picture of hell. Some had no chance of escape and were caught in the flames. The whole conflagration started and was all over in half a minute. Captain Lehmann, who ran back into the flaming fuselage more than once to rescue people, was so badly burned that he died soon after being taken to hospital. Thirty-six people lost their lives and many were injured.

The fire burned on long after the airship was a mass of tangled wreckage. Diesel oil from the engines kept it going. An attempt was made to rescue some of the mail and there was some success. People in Germany and across the United States received badly charred letters a few days later. Some looting occurred because the police did not cordon off the area for a few hours. The conclusion as to cause was simple, the ship was destroyed because it had hydrogen. Suggestions of sabotage were given serious consideration but were later dismissed. The fact that a storm had passed over the area just before the ship arrived gave confirmation to the idea that a static electrical charge had built up between the outside of the airship and any metal structures within.

It was discovered that the fabric cover, unique to the *Hindenburg*, was a poor conductor, thus allowing an electrical charge to build up. Immediately after this tragedy, the fabric of other airships was checked and, where necessary, changed to ensure good conduction. Other changes in the aftermath of the *Hindenburg* explosion saw hydrogen being removed and helium put in its place on all airships. At the same time, new regulations were put in place to anticipate electrical discharges. The electrical gradient between ship and ground was always thereafter measured at landing time. Perhaps if the *Hindenburg* had decided to get to ground first instead of the mooring mast the story might have been quite different because the size of the electrical charge would have been less. In any case, this one event changed the history of aviation. The zeppelin never regained an important role in air travel and production of new airships was stopped soon after 1937. Sixty-four years later, Friedrichshafen was once again in the news as a new eight million dollar, helium powered, zeppelin was built there for low altitude tourist trips around central and southern Europe.

Germany's alternative to the growing demand for luxury travel across the Atlantic in bigger and more luxurious liners came to a sudden end when the *Hindenburg* caught fire. A comparable shock had come twenty-five years earlier with the sinking of the *Titanic* and, as a result, new rules about safety were introduced at that time for all ocean liners. The demand for ways of moving from place to place greatly increased after World War II and, because there were large numbers of people leaving Europe for short or long stays at countries around the world, faster ways of traveling were demanded. In the final years of World War II, jet fighter planes came into use. Immediately after the war this type of plane was seen as the answer to faster modes of travel. By the early 1950s commercial travel by jet planes had started. Like all new developments in the technology of air travel there were risks of failures. To use jets in warfare was quite different from long distance usage with large numbers of people. The wartime machines were light and their length of time in the air on any one sortie was only a few hours.

It was a very different challenge to fly a big airliner on jet engines halfway around the world. Britain was a pioneer in this new way of air travel and in 1952 the De Havilland Company launched the first turbo-jet airliner, the comet. It was a thirty-six-seat jet and it could fly from London to Johannesburg, South Africa, at speeds of 500 mph. The British Overseas Airways Corporation (BOAC) adopted it at once and in less than a year comets were flying around the world. Other airlines were equally eager to buy these new jets and De Havilland soon had a waiting list of five for every comet that came off the assembly line. The trip from London to Singapore was one of BOAC's longest routes and comets were particularly welcome on it because they cut back substantially on the time taken. One comet was flying that route in 1953 and had stopped over in Calcutta en route. As it took off on May 2, 1953, to continue its flight to London everything seemed normal. Six minutes later communication with the control tower was lost. The plane had gone down less than ten miles from the airport and all forty-three on board were killed. This was BOAC's first fatal crash in five years and the fact that it happened to one of its newest planes was a big shock. Commentators insisted that some unusual weather much have caused the accident. One newspaper concocted a story of a downdraft meeting an updraft of air just where the comet was flying. Many believed it.

Another long-distance route flown by BOAC was London to Johannesburg so comets were popular there too. For eight months after the tragedy near Calcutta, nothing occurred to make BOAC change its activities. The comet continued to be enormously popular. Then, on January 10, 1954, a comet from London, one that had stopped over in Rome, took off from there to continue its journey to Johannesburg. There were thirty-five people aboard. These numbers seem small by today's standards but the 1950s were years that knew nothing about the jumbo plane or even smaller jets of the kind we know now. Jets were still quite new ways of traveling. An Italian fisherman saw this jet shortly after its takeoff while it was high in the sky, then watched it plummet down into the sea near the Island of Elba, about one hundred miles from Rome. BOAC immediately grounded all of its comets and proceeded to conduct a full scale inspection of its entire fleet.

Following a meticulous series of examinations, flights resumed in March of 1954 but within a few days another comet went down, this time on the London–Johannesburg route. Commentators and officials now began to ask big questions. Newspaper reports wondered about the basic safety of the comet, asking whether there might be something wrong in the design that no one had yet recognized. A major salvage operation was launched to recover the wreckage of the jet that went down off the Island of Elba and the results were very surprising. There was no evidence of fire, explosion, or engine failure. The only possible explanation for the crash was the condition of the fuselage. It had been ripped apart in several places.

Intensive tension and pressure tests on the materials being used in the comet's fuselage finally revealed what was wrong. The materials were inadequate for long distance travel at high altitudes. The jet's fuselage was fine for short-range military fighters at low altitudes but it could not cope with repeated pressurization, speed, and high altitude over long distances. The career of the comet came to an abrupt end two years after its debut. Some time later it was redesigned with better materials but by then other manufacturers like Boeing had captured the jet plane market and the comet was no longer the only choice available.

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Nanking massacre

December 13, 1937

Nanking, the capital of China at the time of the massacre

In violation of international agreements that Japan had signed Japanese soldiers assaulted China. Nanking, the capital of China at that time, was the scene of their greatest and most brutal actions

On December 13, 1937, the Japanese Army, as it continued it's assault against China, in knowing violation of an international agreement, reached Nanking, the Chinese capital, and began to loot, rape, torture, and murder all over the city. Soldiers who surrendered were shot or bayoneted and homes were looted, often in full view of the commanding officers. The atrocities committed were so barbaric that they rank among the worst of the twentieth century.

In the years before World War II, Japan began its series of military conquests in China. It was led by a group of officers who had either forced or persuaded the rest of Japan's leaders to take these steps. Some who opposed their plans were killed. It was a reckless venture and a violation of an agreement that Japan had signed regarding international relations. The militarists responsible for all that happened subsequently were completely indifferent to this agreement. They not only attacked China, beginning with the conquest of Manchuria in 1931, but they ignored virtually every known rule of law for dealing with civilians and prisoners during war.

The Tokyo War Crimes trials, the Asian equivalent of the Nuremberg trials of the Nazi war criminals, began in 1946 and exposed the details of what had gone on over the previous years. Its rationale for the indictments it handed down was the UN War Crimes Commission Report of a year earlier. In this report blame for all the atrocities was laid on both the government in Tokyo as much as on the commanders in the field. The following are a few extracts from the damning indictments that were listed: "Inhabitants of countries which were overrun by the Japanese were ruthlessly tortured, murdered, and massacred in cold blood. Torture, rape, pillage, and other barbarities occurred. Despite the laws and customs of war as well as their own assurances, prisoners-of-war and civilians were systematically subjected to brutal treatment and horrible outrages, all calculated to exterminate them."

Nowhere were these acts of bestiality more violently executed than in Nanking. On December 13, 1937, advance units of Japanese soldiers captured the city, China's capital. The defenders, against the advice of General Chiang Kai-shek who commanded the Chinese Army, tried hard to hold out against the invaders but lost. As soon as they entered the city the Japanese launched an orgy of cruelty and destruction. Women of all ages were raped, by individuals and by groups, then killed, as many as 20,000 in all. Soldiers who surrendered were shot, beheaded, or bayoneted. Others were mutilated and killed in other ways, often in the most bestial ways imaginable. Altogether about 300,000 died in these ways.

For the weeks following December 13, 1937, Japanese rapes and massacres continued. There were atrocities against civilians and mass executions. The enormity of the scale and nature of these crimes was documented by survivors and recorded in the diaries of Japanese soldiers. Nanking had been a city of 250,000 but as people retreated westward from the Japanese advance the city's population swelled to a million by December of 1937. On December 13, as the city fell, a large number of refugees tried to escape across the Yangtze River but were unable to get away because all the boats were missing. Some tried to swim but they were all shot by Japanese soldiers, some in the water, most at the river's bank. Altogether 50,000 died at that location in a few hours.

In the streets, about 100,000 refugees or wounded soldiers were huddled, and they became targets for tank and artillery gunners. Dead bodies covered the streets. They became "streets of blood" in the course of a two-day massacre. Many Chinese soldiers moved around inside the city and changed into civilian clothes but that made little difference to their fate. Anyone who was suspected of being a soldier was arrested. They were all sent outside the city in groups numbering from several thousand to tens of thousands and shot by machine guns. Any who were still alive were bayoneted. Gasoline was poured on some and they were burned alive. Numerous atrocities occurred all over the city, mainly on civilians. Japanese soldiers invented and exercised inhumane and barbaric methods of killing, including stabbing, striking off the head, and drowning.

A group of concerned foreigners formed an international rescue committee and established a safety zone for refugees within the city. Japanese soldiers ignored the rights of the foreigners and frequently entered the safety zone where they arrested young men. Every time they did so, the men they arrested were executed on the site. All the storehouses were emptied and everything else of value was seized, including jewelry, coins, and antiques. There was an organized burning of buildings throughout the city. Nanking, once a beautiful historical center, was burned to ashes. The best that can be said about all this horror is that it conforms to some of the worst practices in wars from the ancient past. Citizens and soldiers alike were often terrorized by successive acts of such brutality and cruelty that they remained passive and submissive. The conquering army could thus proceed with its mission without having to worry about resistance from the conquered.

Women who did not readily submit to their rapists were tortured afterwards before being killed. The only ones who were allowed to live were the so-called "comfort women," prostitutes who were forced to accompany the soldiers on their campaigns. After World War II, some survivors from this group successfully sued the military authorities. The brutal rape scenes of Nanking are matched by others since that time. Gang sexual assault and rape with murder was commonplace during the Bangladesh war of independence in 1971 and is described by Susan Brownmiller in her book, *Against our will: Men, women and rape*. Some aspects of the rapes of Nanking left scars for a long time. No Chinese woman from that time ever admitted that her child was the result of rape. The whole subject of Chinese women being impregnated by Japanese rapists remained so sensitive that it has never been thoroughly studied.

Rape victims finally received the recognition they deserved in the Bosnia Civil War of the 1990s. In that conflict Serbian soldiers singled out Muslim women and girls and raped them as violently as did the Japanese in China. For the first time in history there was a declaration by an international tribunal that these sexual crimes alone constituted a crime against humanity. Three former Serbian soldiers were indicted on this charge in March of 2000. The things they did were just the same as those committed in Nanking, but fortunately their evils were raised to the highest level of international crime. Information about the Japanese activities was poorly circulated at the time but sufficient was known in western countries, especially in the United States, and thus strong condemnations were sent to Japan.

On one occasion, the Japanese officer in charge invited sailors from a Japanese boat that was anchored on the Yangtze River to witness the mass executions. A memorial building now stands on the spot where many of these mass executions took place. For decades, Japanese authorities denied that anything extraordinary had happened. One eyewitness account did reach the Western World and was published in the *New York Times* in December of 1937 but the details were few. Not until the War Crimes Trials were held in Tokyo in 1946 was the full account recorded. Many who witnessed the terrible events told their story at that time.

There is one puzzling aspect of Japanese activities at Nanking that may relate to a friendship from an earlier time between Sun Yat-sen, the Chinese revolutionary, whose memorial is in Nanking, and General Matsui who commanded Japanese forces when they captured the city. Sun Yat-sen had previously visited Japan on more than one occasion and met with General Matsui. They became good friends and shared the same ideals for many of the problems of East Asia. Japanese Emperor Hirohito took a detailed interest in all aspects of the country's military exploits but his focus on Nanking was intense. Could it be that he knew of the friendship between Matsui and Sun Yat-sen and was afraid that it might prevent his orders from being carried out?

Whatever the reason might have been for the Emperor Hirohito's involvement in the fighting at Nanking, the records of the war show that he decided to interfere by appointing his uncle, Prince Asaka, as commander of all forces at Nanking. Matsui was not replaced but his authority was taken away because Prince Asaka had greater status. The first thing Asaka did was to send sealed orders to all the officers under his new command ordering them to execute all captives. A note accompanying his orders told the officers to destroy the orders after reading them. Asaka knew that what he had commanded was wrong and that it was a flagrant violation of all international agreements for dealing with captured soldiers. He stayed on in Nanking until February 10, 1938. Matsui left the city soon after Asaka arrived.

The Rape of Nanking was the phrase used at the Tokyo trials to describe the atrocities that occurred there and the witnesses to what happened were many. Dr. Wilson, a native of Nanking who had been educated in the United States, saw his hospital filled to overflowing with patients who had received bullet or bayonet wounds, and women who had been sexually molested the morning after the Japanese captured the city. This scene was repeated every day for the following several weeks. An older official from the Chinese Ministry of Railways described the scene in street after street. There were bodies lying everywhere, some badly mutilated. It was no use counting them. There were far too many. All of these personal reports were given to the prosecutors in the presence of the Japanese officers who were on trial.

Hsu, a member of the Chinese Red Cross, gave help in burying the corpses to avoid an epidemic. He counted as many as 43,000 then left off counting. The bodies had their hands tied with either rope or wire so he could not follow the Chinese custom of loosening anything that was tied before burial. Several survivors of mass killings testified how they were able to feign death by falling and getting covered with those beside them who were just shot. Many of those had to endure thrusts from bayonets, a common Japanese practice to make sure that there would be no witnesses to their atrocities. An American professor of history, Miner Bates, at the University of Nanking told of numerous killings for each of which there was no provocation or apparent reason.

Bates also told of thirty college girls at his university being raped two days after the Japanese entered the city and a further eighteen three days later in different parts of the campus. All the other women were in a state of hysteria. Furthermore, his campus was next door to the Japanese Embassy so Japanese officials in the embassy must also have been aware of what was happening. Prosecutors asked Bates for the name of the officer in command of the Japanese troops at that time. General Matsui was the answer, the man now standing in the court along with Koki Hirota, Japan's foreign minister at that time. For most of the time during the Tokyo trials defense lawyers were silent in the face of damning personal testimonies but this time, because Matsui and Hirota were importance defendants it was different.

When Bates told the prosecution that he had sent reports of the atrocities to the Japanese Embassy, William Logan, who was defending the accused, immediately inquired if Bates' reports had been sent to Tokyo. Bates assured him that they were sent but he was then asked how he knew. Bates informed him that he had received detailed accounts from the U.S. Ambassador in Tokyo, describing discussions he had had with Hirota over these very reports. There were numerous additional personal testimonies added to these, many of them so gruesome that only the barest details should be recorded. The randomness and the cruelty of the ways that people were tortured before being killed all pointed to a deliberate policy, not just the actions of a few depraved individuals.

On the basis of massive amounts of evidence, twenty-eight Japanese officers were prosecuted for mass murder, rape, pillage, brigandage, torture and other barbaric cruelties upon a helpless civilian population. Eyewitnesses gave testimonies of the atrocities. Of the twenty-eight men, twenty-five were found guilty. Of the other three, two died during the trials, and one had a mental breakdown. Seven criminals were put to death by hanging, sixteen were sentenced to life imprisonment, and two had lesser sentences. Of the seven who were hanged, four were executed for their involvement in the Rape of Nanking. Quite apart from the decisions at the trials, about one thousand officers committed hara-kiri suicide, in the days following Japan's defeat. This form of suicide was a Japanese national tradition in the wake of failure.

Matsui pretended all through the trials that nothing more than a few incidents had happened. When asked if Prince Asaka, uncle of the Emperor Hirohito, had anything to do with all the crimes he strongly defended him. In fact, all of the emperor's household was exempted from prosecution, despite extensive evidence of their involvement. This was a firm policy of the countries conducting the trials. On the night before he was hanged, Matsui changed his mind about Nanking. In his words it was a "national disgrace." He went further and said that the real culprit for all of it was Prince Asaka. Over the years that followed the trials, Japanese citizens maintained a denial of the massacre. During the war, because of the strict control of news, civilians knew almost nothing about atrocities. They heard only about heroic war figures.

The facts released during the Tokyo War Trials shocked the whole country. Many books were written on the subject. At that time, there was no public government denial of the massacre, but there was not any official public acceptance of responsibility either. From the 1960s to the 1980s deliberate efforts were made to deny the horrors of Nanking. A highly controversial history textbook for schools was published in 1982. The Rape of Nanking was described as action in response to resistance from the Chinese Army. The nations of Asia were enraged and their anger made Japanese authorities reconsider the contents of the book.

By the 1990s, a different version of history made its way into school texts. These books now refer to the "Great Nanking Massacre," in which Japanese soldiers conducted a rampage of looting, burning, and raping against international condemnation, and killed those who surrendered. Media sensitivity in North America has also changed since the 1930s. The reports that were published by the press and in magazines in 1937 would not be acceptable today because they might generate destructive hatred against the perpetrators. Press reports on Rwanda, a similar event of mass murder, toned down the horror of the actual event. By contrast, the following are the kinds of reports carried in the Western press and journals in 1937 regarding Nanking: it was his job to complete the butchery of the Chinese defenders. He lined them up in batches and shot them all. It was a tiresome business killing them. Japanese sailors watched the executions.

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VOLUME 2

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New England hurricane

September 21, 1938
Long Island, New York, and Providence, Rhode Island

Wrong assumptions about the course this hurricane would take led to inadequate preparations for its arrival in New England. Consequently there was extensive destruction

On the afternoon of Wednesday, September 21, 1938, a hurricane slammed into Long Island at 150 mph bringing along in its wake a storm surge of thirty feet or more. On Long Island's southern beach, as residents tried to cope by putting up shutters and fastening windows, they suddenly found their homes swamped by thirty feet of water. Some homes just exploded. In Rhode Island, the city of Providence, unprotected from the wind because of its location east of Long Island, fared worse than most places. It is located thirty miles from the ocean at the head of a funnel-shaped sea inlet. The storm surge, trapped by the narrowing passage, rose far beyond the thirty feet that was experienced elsewhere and destroyed everything in it path. About half of the six hundred deaths from the storm happened in Rhode Island. Overall, this hurricane was the deadliest U.S. natural disaster in all of the sixty-seven years prior to the arrival of Katrina.

The hurricane was born in the Caribbean as a tropical storm four days earlier. It traveled westward and forecasters warned Floridians to expect its arrival three days later. On its way through warm waters it gathered strength, arriving off the southeast coast of Florida on the morning of September 20 as a category 5 hurricane, the strongest possible. It stretched across five hundred miles of ocean and its 150 mph winds had already torn up coconut palms on the Bahamas. As it neared the coast of Florida weather forecasters observed the telltale signs of the storm curving north-

Figure 56 Island Park was destroyed by a breaker with a reported height of 30–40 feet. A sturdy washing machine is all that remains of a destroyed home.

wards, the path taken by so many storms before, and they gave a sigh of relief. Predictions now indicated that there would be no landfall either in Florida or anywhere else along the coast before it veered out to sea and faded away in the colder water of the northern Atlantic. In 1938, all weather decisions affecting Florida were made in Jacksonville and, on this occasion, forecasters at the weather bureau there decided that this storm would behave like most of its predecessors that took similar paths. Little attention was paid to weather conditions farther north along the coast, a risky omission since this hurricane was a category 5, the highest and most powerful type.

Weather forecasting skills in the United States were far below those of Europe at this time, particularly those of Norwegians who had developed a system of air mass analysis for predicting weather conditions. In the United States, predictions were based on measurements on the ground at each place, temperature, wind speed, air pressure, and so on. Norwegian scholars had discovered that the atmosphere is not a single undifferentiated mass of air but rather consists of different masses of air each defined by specific humidity and temperature levels, some extending as far as six hundred miles from side to side. It's the interactions between these different air masses that create all of our weather patterns. Any hurricane approaching a high-pressure air mass will move away from it because hurricanes are low-pressure zones. Low-pressure air masses will attract hurricanes. Had U.S. weather forecasters taken account of these things, the devastation could have been avoided as can be seen today by examining the environment of September 21, 1938, in and around New York.

There were thunderstorms over New York and muggy conditions over Long Island. Heavy rain had been falling in Connecticut and Massachusetts and there was a risk of flooding there. A low-pressure system covered the area from New England to the Carolinas. A warning had been received from a ship off the coast of Florida that air pressure within the hurricane was lower than had ever previously been known in the Atlantic at that time of year. One additional anomaly was the surprising location of the Bermuda high air mass. It had migrated to a position ten degrees of latitude father north than its usual position. The combination of the Bermuda high preventing the hurricane from moving out into the Atlantic and the attractiveness of the low that had covered the New England area for days alerted one young forecaster to issue a warning but he was overruled by a senior staff member who insisted that hurricanes rarely reach New England and there was only a chance of 1 percent of one coming at that time. It is true that the last time one hit this area was in 1815 but the United States has sometimes seen hurricanes with a 1 percent chance of hitting a particular place reaching that same spot twice within one month of the same year.

Figure 57 Waves striking seawall give appearance of geysers erupting.

The observations of the young staff member at the Washington, D.C., branch of the Weather Bureau, the agency that took over from the branch at Jacksonville, were the ones that should have been heeded. The general conditions all along the coast were very different from the usual pattern. The low pressure area extended all the way from east of the Great Lakes southward as far as Cape Hatteras and it was stationary in that extended location on September 20 as the hurricane began to move northward from the coast of Florida. The winds circulating this area of low pressure were strong because of the extent of the low pressure, and they were warm as they swept air along with the hurricane from within the warm Gulf Stream. By midnight on September 20, two developments had occurred, both of which were probably not observed by the Weather Office in Washington, D.C. Had they been aware of them, warnings would have been issued long before the late morning of September 21. The two developments that accelerated the hurricane to a speed of 60 mph and also pulled it toward the northern coast were the attraction of the big low-pressure area and the "extra push" from the warm air that circulated northwards around this low-pressure area.

At 2:30 in the afternoon of September 21 the hurricane made landfall on Long Island. It had traveled from the Carolinas at 60 mph and, though unknown to the forecasters, the positions of the main air masses ensured that it would travel northwards in a straight line and be drawn on to shore by the low pressure air mass that lay over all of New England. Within a short time of its arrival community after community across Long Island, in Connecticut and in Rhode Island were knocked out. All power was lost and there was no way by which any one location could share its experiences with another. Conditions were made worse by a general indifference to any possibility of a hurricane reaching this part of the country. They had heard of the hurricane throughout the previous day and assumed that what the forecasters had predicted was going to happen. Even when a radio warning of an approaching hurricane suddenly came with the afternoon weather forecast of September 21 people ignored it till tragedy struck. In some places winds reached more than 180 mph and in others more than 230 mph.

The city of Providence was hardest hit because its physical location raised storm water levels very high and also because it was more exposed to open sea. Cape Cod, too, experienced extensive damage and a number of deaths because of its exposure to open sea but other areas of both Massachusetts and Connecticut had some protection from storms because of the shelter provided by Long Island. Nevertheless, a shoreline city like New London was no match for the fury of the hurricane. Winds and floods combined to leave it in ruins. In and around Jamestown and Newport, Rhode Island marinas, beach pavilions and buildings of all kinds were demolished. Farther north in Providence yet another unusual feature of this city was the source of trouble, its arcade, an old indoor shopping mall that became a wind tunnel for the hurricane. People became toys to be tossed around anywhere and everywhere. Many of them were seriously hurt with flying pieces of glass.

In summary, thousands of boats, cars, and buildings were destroyed in the short three-hour rampage of the storm and virtually all telephone lines were knocked out of service. Some creative individuals were able to make use of the cables linking New York and Boston with the cities of Europe so these two U.S. cities were able to send messages to each other. Recovery of something approaching pre-storm conditions was long and difficult. Not only were thousands of homes washed away or damaged beyond repair; in addition shorelines and other land areas had been washed away, making rebuilding impossible and property titles meaningless. In one or two locations in Rhode Island there was one redeeming feature: a barrier beach had been opened up in several places, a change that local people had long hoped for because it would ease access for small craft. The final assessment of damage included 680 deaths, about 2,000 injured, another 4,500 homes destroyed, an additional 15,000 damaged, and 60,000 people made homeless. Total value of damage was estimated at $400 million in 1938 currency.

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Imperial Valley, California, earthquake

May 19, 1940

The Imperial Valley is located in southern California

The Imperial Valley experienced an earthquake of magnitude 7.1. The population of the Valley was only 40,000 at the time, so casualties were few and most of the damage occurred in buildings and irrigation canals

The Imperial Valley of California, near El Centro, located about ten miles from the Mexican border, was hit with a magnitude 7.1 earthquake on May 19, 1940. The earthquake took nine lives from a region that, at the time, had a population of about 40,000, and caused $6 million worth of property damage, including the effects of a strong aftershock near Brawley. Damage to other centers such as El Centro and Holtville was much less. In addition, there was extensive destruction to the structures and canals of the Imperial Irrigation District (IID) with ground displacements as large as 10–14 feet.

The Imperial Valley earthquake of 1940 is particularly important to the history of California because it was the first earthquake to provide documented evidence of surface rupturing since the 1906 San Francisco quake. Furthermore, it provided detailed local accounts of the kind of shaking motion that accompanied the event. Not until the San Fernando earthquake of 1971 were comparable records available. Soon after the Imperial Valley earthquake occurred, all available manpower and machinery were brought in to repair the Alamo and Solfatara canals of the IID. Although the loss of water would have lead to the loss of only one crop, cantaloupes, the damage done to this crop would have cost the industry a million and a half dollars. Two weeks worth of water loss would have been catastrophic for this crop. Fortunately water was restored within four days.

Because the water table was high, numerous sand boils appeared all over the region—in fields, roads, and under houses—creating three-inch wide craters and sending water and sand several feet into the air. As a result of the earthquake, a 40,000 gallon water tank at Holtville collapsed as did a 100,000 gallon tank at Imperial. Miles of drainage ditches were obstructed by elevation of the ground with, in several locations, water escaping on to adjacent land. Bridges and flumes buckled as a result of repeated up and down earth movements. Reconstruction of banks became necessary as ground subsided. The initial estimate of the strength of the earthquake was 6.4 but, as surface destruction was examined in greater detail, it became clear that the present figure of 7.1 is more appropriate; putting the Imperial Valley earthquake comparable to the San Francisco 1906 quake as far as magnitude is concerned. This reassessment is also related to the unusual character of the earthquake. It consisted of numerous quakes, all of them occurring in the first fifteen seconds of the event, followed by several shakings within the next five minutes. Normally these would be called aftershocks but, because they were comparable in magnitude to the main event, they must all be regarded as part of a single earthquake.

The Imperial Valley is a large, flat, crop-growing area in the very south of California, between the Salton Sea which lies to its north and the Mexican border which lies to its south. The valley extends south into Mexico where it is called the Mexicali Valley. The Valley is a working agricultural area, one of the most productive agricultural areas of the world and the largest year-round irrigated agricultural area in North America. It is the seventh largest food producing area in the world with such crops as melons, citrus fruits, alfalfa, barley, lettuce, and other vegetables. The Valley was formed in 1907 from the eastern half of San Diego County. The county took its name from Imperial Valley. The Valley was named for the Imperial Land Company—a subsidiary of the California Development Company—which at the beginning of the twentieth century had reclaimed the southern portion of the Colorado Desert for agriculture. Irrigation water is supplied from the Colorado River via the All-American Canal. The population of the region grew from 13,000 in 1910, to 63,000 in 1950, and to 142,000 by the year 2000.

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Paricutin, Mexico, volcanic eruption

February 19, 1943
A brand-new volcano began to erupt in the middle of a Mexican farmer's cornfield

The eruption continued in the village of Paricutin, about two hundred miles west of Mexico City, and its cone reached a height of more than a thousand feet in its first year of life

On February 19, 1943, Dionisio Pulido, a farmer who lived in the village of Paricutin, was about to set fire to a pile of branches he had collected when he noticed for the first time a hole in the ground about eighteen inches deep. A few moments later he heard a noise like thunder and, at the same time, saw that the hole in the ground was pouring out smoke and ashes. Within a very short period of time he noticed that the ground had risen several feet and there was a continuous hissing sound and a smell of sulfur. He ran to the village priest and together they returned to the hole in the ground. By that time the hole was thirty feet deep and smoke was pouring out of it in large quantities. Fourteen months later the hole had grown and was now a mound that stood twelve hundred feet high and showed no sign of slowing down. At times, as in February 1952, nine years later, windows of buildings fifteen miles away were being shattered by explosions and earthquakes from the volcano and there were fresh outbursts of lava two hundred yards wide and up to five feet deep. Long before this date, Pulido had left Paricutin and found a job in California, still wondering if he could make some money from his unique status of being the only person in the world who owned a volcano.

Figure 58 The new cone viewed from the northeast. Paricutin Volcano, Michoacan, Mexico. February 22, 1943.

Paricutin, located two hundred miles west of Mexico City on the high plains of Mexico, is of much more than local interest. It is the first volcano to come under close scrutiny by scientists from its beginning, a rare event in the history of volcanoes. This only happens, on average, once in 10,000 years. All other volcanic eruptions are built on former volcanoes and their activities are our single direct contact with the inside of the earth. They come up from below through the thirty-mile-thick outer crust of the earth that insulates life from the high temperatures of the molten mass beneath. When the volcano first appeared, on that day in 1943, local people blamed it on a dispute that had erupted between two communities in the course

Figure 59 Paricutin Volcano, Mexico, eruption, viewed from the west. Note the heavy ash cover on year-old lava. November 7, 1947.

of which a holy cross had been destroyed. Others attributed it to an earlier plague of locusts. Statements like these have always been a feature of unexpected and poorly understood natural events.

For nine years scientists carefully monitored the evolution of Paricutin, seeing quantities of pyroclastics and lava diminish from an initial output of four thousand tons daily to less than three hundred in 1951. Occasionally, throughout that time, there were violent explosions and bursts of rock and lava. At the end of that time, six thousand acres of land had been buried in lava. All of that lava plus, an additional 70,000 acres were covered with a foot of ash. The village of Paricutin, four miles from the volcano, was completely destroyed and its more than seven hundred residents had to move away from the area. Federal authorities provided new land for them twenty miles away toward the southwest. All of the land that had been covered with lava or ash became useless for any form of agriculture. The human, animal, and botanical life was profoundly impacted in different ways. The records of these differential impacts on all forms of life and on human activities provide the only documentation ever obtained on the immediate effects of volcanic eruptions.

Four and a half thousand cattle and over five hundred horses died as a result of breathing volcanic ash. These animals were the basic resources for survival among the farmers. Humans too experienced some discomfort from the ash as all vegetation and food crops were destroyed. Mice and other small animals died off and so did some insect populations. The predator of one cane-boring insect did not survive and so the sugar cane crop was lost. In addition to the general destruction of the one farming community there were unexpected consequences in neighboring communities. Paricutin's volcano is on the higher ground of the plateau so, as summer rains arrived, ash-laded mud flows were carried to lower levels where they ruined dams and silted agricultural areas. As the years passed and the volcano ceased activity, plant and animal life began to reappear in and around the village of Paricutin. The lava fields remained useless for agriculture but the lands that had only ash began, in places, to be productive.

Some entrepreneurs discovered an economic value for volcanic rocks and these were mined for the construction industry. Gradually, as more and more of the former tenants or owners came back, tensions built up over ownership of particular areas as the old boundary marks had gone. By the 1970s there were social pressures for change. The old pattern of settlement could not be reinstated because new people had come to take the place of those who had gone elsewhere permanently. The general trend of change was toward greater interaction with the larger Mexican society and the loss of old Indian traditions. In Paracutin, nevertheless, it was possible to retain the old traditions, even the old language, because it was now a famous tourist center where people could come and see things as they were when the volcano Paricutin was born.

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San Juan, Argentina, earthquake

January 15, 1944

San Juan is situated in western Argentina, South America

This magnitude 7.8 quake was the largest natural disaster in the history of Argentina, which caused the death of 10 percent of San Juan's population

In the evening of January 15, 1944, the city of San Juan, Argentina, was hit with a magnitude 7.8 earthquake. It destroyed a large part of the city and killed 10,000 people, approximately 10 percent of the total population at that time. The event is generally considered to be the largest natural disaster in the history of Argentina. San Juan is located in the mountainous area in the west of Argentina, one of the most earthquake-prone regions in all of South America. The earthquake's epicenter was twenty miles north of the city. About 90 percent of all buildings were destroyed, probably a consequence of poor construction standards. There was considerable discussion as to whether the city should be moved to a safer location but, in the end, it was decided to undertake extensive reconstruction on the existing site.

Prior to the earthquake, many of San Juan's houses were made of adobe. The reconstruction that was necessary following the quake prompted the creation of a building code that respected modern knowledge of earthquakes. This code included use of brick and concrete one-story houses and wider sidewalks and streets. At the start of the reconstruction, emergency homes were built for the population with funds of the national state. This was the first state-directed massive construction plan in Argentina and it continued under different presidents. The earthquake had caused many families to scatter in the confusion, leaving many orphaned children, and created a new social challenge for the city's administrators. There was also the challenge of matching the physical reconstruction with the development of emergency plans for future earthquakes. Unlike other natural events, an early warning system does not make sense for earthquakes, because they are not predictable. Prevention strategies are the only tools available to keep hazards from becoming catastrophes.

The city of San Juan is located in the area of highest seismic risk in the country. This region experiences a strong earthquake approximately every fifty years. Today, as a result of the reconstruction process following the 1944 earthquake, a high percentage of the city's buildings meet the standards set in the new safety regulations. As of 2006, San Juan had a population of 400,000. Two-thirds of its homes and all of it public institutions were built under these regulations. This, however, leaves more than a third of non-seismic-resistant houses. A study on seismic vulnerability, conducted by the National University of San Juan in 2005, showed that 28 percent of the surrounding neighborhoods present medium risk, and 20 percent of the city can be classified as high or very high vulnerability.

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Shinnston, West Virginia, tornado

June 23, 1944
Shinnston, West Virginia, was hit with one of its worst ever tornadoes

This tornado had a width of a thousand feet as it touched down. It killed 153, seriously injured eight hundred others, and destroyed four hundred homes

In Harrison County of western West Virginia, on June 23, 1944, the community of Shinnston was hit with one of the most destructive tornadoes in the state's history. Its main path had a width of a thousand feet and in its two-minute transit it took the lives of 153 persons and seriously injured more than eight hundred. Over 1,600 families were affected and over four hundred homes destroyed. The devastation was all the more tragic because it occurred within nine miles of West Virginia's worst mining disaster, that of Monongah, in 1907.

This tornado arrived shortly after 8 P.M. and the first impression that people had was of a fire. Then, as it came closer, people could see a heavy mass of debris, timbers, and trees traveling before the cloud; then they knew the worst. The place hardest hit was Pleasant Hill, a suburban section of Shinnston with about fifty homes. This group of houses simply disappeared. Persons who witnessed the event said that at one moment it was there and the next it had gone. Dozens were killed at that spot. Bonds, checks, and papers from Shinnston were found two hundred miles away in different parts of the state. The steel radio tower of the State Police Headquarters was broken in two. A barn was blown away, leaving the horse in the stall uninjured. A pigpen disappeared leaving the pigs. Hail-stones were described as being as big as baseballs. Streetcar tracks were twisted as though made of macaroni, and a cook stove was found three miles away from its former home. The tornado faded out in the Allegheny Mountains.

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Northeast United States hurricane

September 15, 1944
The Great Atlantic hurricane devastated the east coast from North Carolina to Cape Cod

This Northeast hurricane received the name the Great Atlantic because of its devastating work on coast and sea all the way northward from Cape Hatteras, leading to the deaths of 390 and causing more than $100 million in damages

The outstanding U.S. hurricane of 1944 was the Great Atlantic hurricane, sometimes referred to as the Great American hurricane, an intense storm that traveled up the east coast, sweeping the beaches, sinking ships, and throwing wave watchers into the sea. The entire coastline, from North Carolina to Cape Cod was raked with hurricane-force winds. Damages from the storm amounted to $100 million plus the losses of ships. The death toll was 390, of which 350 represented those lost on ships at sea. This was wartime and many navy vessels plied the coastal waters.

On September 14, this hurricane reached Cape Hatteras, North Carolina, as a category 3 storm that extended over an area of six hundred miles. It made an initial landfall at Cape Hatteras but quickly moved offshore toward the northeast. At that stage it was moving at 16 mph but as it moved northwards it accelerated to 40 mph. This is not a common pattern. Storms that move into higher latitudes and, therefore, colder waters, tend to slow down both in internal wind speed and in rate of movement. However, this storm had many of the features of the very destructive 1938 storm that caused so much damage in the New England area. Two warm air masses, one from the Gulf and one from the Bahamas were moving north as the Great Atlantic hurricane left Cape Hatteras. At the same time, the Bermuda High had greatly strengthened and another high over the Appalachians began to weaken. The warm waters raised the intensity and forward speed of the hurricane and the Bermuda High made sure that it stayed close to the coastal areas.

This storm was different from the hurricane of 1938 in that there was plenty of advance warning. This was due to the better understanding in 1944 compared with 1938 of air masses and their role in transforming and guiding hurricanes. Thus, weather stations were able to predict their paths once they knew the conditions in the prevailing lows and highs. Hurricanes, because they are centers of low pressure, are attracted to lows and they move away from highs. The media were kept informed and the civil defense officials always knew of the storm's current position. As the hurricane moved northwards, its intensity and destructive power were reported along the way. Cape Henry, Virginia, noted sustained winds of 134 mph with frequent gusts of 154 mph. Hartford, Connecticut, reported gusts of 109 mph. In numerous locations rainfall of 6–11 inches occurred within two-hour time periods.

Tremendous damage occurred all along the coast from North Carolina to New England, including major damage to 41,000 buildings. In Maine, 40 percent of the total apple crop on one county was destroyed. Elsewhere in the same state trees were uprooted, limbs torn down, and electric and telephone service cut off. The hurricane went across eastern New England and into Canada by September 15 and, from there, it finally merged with a larger low near Greenland on December 16.

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Cleveland, Ohio, gas explosion

October 21, 1944

A massive natural gas explosion devastated Cleveland

In the dying days of World War II inferior materials, because of war shortages, were used to repair a gas tank. It exploded, killing 135 and injuring one hundred others

In the dying days of World War II when all the media were concentrated on the final outcomes in Germany and Japan, a massive gas explosion in Cleveland was almost totally overlooked. It was a devastating blast, killing 135 and injuring one hundred others. Liquefied natural gas was a fairly new thing at that time, Cleveland being only the second commercial installation in the nation.

Liquid natural gas (LNG), which is mainly methane gas, is a popular fuel for homes because it is odorless, colorless, noncorrosive, and nontoxic. It is used as a gas but stored in liquid form for compactness. LNG was formed from the buried remains of tiny plants and sea animals that died more than two hundred million years ago. These energy-rich materials slowly decayed and then changed form until all that was left were concentrations of natural gas in layers of rock. Natural gas is removed from the earth by drilling wells into the rock, then using pipes to bring the gas to the surface. Liquid propane gas (LPG) is also, like LNG, composed of the remains of plants and animals that inhabited the earth millions of years ago. Propane is gaseous at normal temperatures and under moderate pressure it becomes a liquid that vaporizes into a clean-burning gas when released from its storage container. Propane is sometimes referred to as the kissing cousin of natural gas and petroleum because it is usually found mixed with natural gas and petroleum deposits. Cleveland's commercial LNG installation in 1941 was the second in the country and it served the community well for the following three years despite the fact that little was known at that time about the dangers associated with its use.

In 1944, a larger tank was added to meet the demands of Cleveland's consumers but, because it was wartime, steel could not be obtained for the LNG container and an alloy was selected in its place. This alternative material was unsuitable for storage at very low temperatures and before long it began to leak, releasing supercold gas into the atmosphere. A fog began to form over the east side of Cleveland but authorities and residents were unaware of the extreme danger it posed. When mixed with air, LNG becomes a time bomb ready to explode on first contact with a spark. A spark did come and everyone on the east side of Cleveland knew what happened next. A massive explosion was triggered, America's worst from LNG in all of the twentieth century.

Emergency repair workers were called in but there was no spare tank into which they could transfer the gas. All were filled to capacity because winter was approaching. The only alternative was to repair the leak. No one knows what happened next since all the men and all the equipment vanished after the blast. There was a spark either in the course of the repair or elsewhere, and the conflagration followed. A home one block away from the gas tanks exploded into flames and the occupants managed to run away before they were incinerated. Others joined them and as they looked back they could see that flames were raising high into the air.

A series of explosions followed the first one as tank after tank succumbed to the heat and exploded like powerful bombs. Every building for several blocks was flattened and beneath the ground the main gas pipes were ripped out. Manhole covers were flung into the air like toys and must have added to the damage before reaching the ground again. The firestorm from all the explosions destroyed more than 150 homes and left ten times that number without a place to stay, all the more tragic because they were the poorest residents of the city.

Cleveland's tragedy was little known at the time because of the war. Even the news of 135 dead and almost as many additional ones injured did not seem important. It was a time when large numbers of deaths were being reported from the war fronts. The biggest entry in one newspaper was a short statement on the loss of hundreds of cars in one parking lot. For about twenty years there were no additional commercial installations but extensive research was undertaken to ensure that a major explosion would not occur again. New regulations were introduced governing choice of materials for storage tanks, procedures for transportation of LNG, and locations of storage tanks at a distance from residential sites. Other rules prescribed ways of testing tanks and installing safety valves on main pipelines.

Today there is widespread confidence in the safety of LNG plants and it is of interest that Cleveland has featured, once again, in pioneer usage of this fuel. In 1995, the Greater Cleveland Regional Transit Authority was the first to adopt natural gas as its alternative fuel of choice for buses.

Figure 60 Employees of County Engineer search for bodies in the meter house. The East Ohio Gas Company explosion, one of worst disasters in Cleveland history, occurred on Friday, October 20, 1944 when a tank of natural gas exploded on Cleveland's east side, destroying homes and businesses and killing 130 people.

It had the biggest natural gas fueling station in the country and served as a model for the rest of the country. Gas-powered buses were being added to Cleveland's streets year by year and air pollution was being reduced a little as each new bus joined the fleet. Worldwide, today, LNG provides a quarter of the world's energy needs. There was a similar story of inexperience in dealing with LNG seven years before the Cleveland tragedy. Had it been better known in Cleveland, perhaps the 1944 accident might never have occurred. The 1937 accident happened at a New London, Texas, school, known as the world's richest school because seven oil wells stood on its grounds. A gas explosion on March 18, 1937, demolished the whole building and killed 280 children, fourteen teachers, and two mothers. The tragedy was caused by the accidental ignition of large quantities of LNG that had leaked into the building.

The school was set in the middle of the oil fields of eastern Texas and it shared in the wealth-producing output of these oilfields that were at their peak of production at that time. The students at the school came from the homes of workers in the oil fields, some of the students arriving daily from as far away as fifteen miles. A natural gas line in the basement was the source of heat for the school but on the day before March 18, 1937, this line sprang a leak. Natural gas was a new thing at this time and the dangers associated with its use were little known. Even as recent as 1944, it was still only partially understood. In New London, Texas, natural gas was used in the form in which it came out of the ground; that is, it was odorless. Gas leaks were, therefore, not detectable by humans. In later years, some odor was always added for safety.

On Thursday afternoon, March 18, 1937, some classes had been dismissed for the day but about six hundred students remained. A group of mothers were at a meeting nearby. The gas leak that developed on the previous day was still there and natural gas had already filled every room of the school but no one was aware of this because it did not give off any detectable odor. As is now so well known, all that was needed in such a situation was a tiny spark and a huge conflagration would follow. A teacher in the manual skills section switched on a main power switch in order to start a power lathe and on contact there was a small spark.

The whole building became a bomb. Walls buckled, the floor lifted and the roof broke up and then collapsed. There was no time for anyone to escape. It was all over in a very short time and the damage was evident. Everywhere around there was dense smoke and rubble. Parents rushed to the school and some tried to tear away at the mountain of debris in search of their children. Others were just paralyzed. An army of workers from the oil fields arrived and began to dig for survivors. They brought in heavy lifting equipment and moved away the larger pieces of concrete. Some bodies were so badly broken that identification was impossible. Every available building in the New London area became a temporary morgue. Some bodies had to be taken to Dallas, almost a hundred miles away.

The search for bodies went on into the night of March 18. Giant floodlights were mounted for the workers. A line of helpers passed buckets from one to the other. In the middle of their night work a storm that broke over the area slowed them down but by morning the site was cleared. Eighty-five were found still alive and 294 dead. Two more died later from their injuries. A new school was built in due course and a memorial was erected nearby, a reminder of the terrible events of 1937. Investigators concluded that no one person was responsible for the tragedy. They decided it was the collective faults of individuals who were ignorant of or indifferent to the precautionary measures needed. Years after both the New London and Cleveland tragedies, another explosion from gas occurred, this time from an LPG installation in Mexico. On November 19, 1984, a store of LPG exploded, sending a cloud of gas into the air followed by a series of explosions and fires. One of the explosions was so powerful that it registered 0.5 on the Richter Scale at the seismograph station on the University of Mexico Campus. Five hundred people were killed and 7,000 injured as a result of this event.

In the 1940s, the Mexican government, through its state oil company Pemex, decided to store LPG in selected centers and distribute it to consumers by truck rather than build a gas pipeline from the gas fields to specific markets. San Juan Ixhuatepec was one of these storage centers in Mexico City and from it twenty-four-gallon drums were loaded daily and trucked to the surrounding communities. It was a good arrangement from the consumers' point of view. Gas reached most people in most places quickly and most Mexicans cook on propane stoves. The explosion early on November 19, 1984, was triggered by a gas leak in one of the storage tanks. Pressure had built up in that tank and a relief valve was forced open. Mexico City is in a warm climatic zone and temperatures can rise very high at times. To allow for the impact of temperature on the storage tanks they are designed to cope with pressures much higher than they normally encounter. A rise in internal temperature means an increase in internal pressure because some liquid gas always vaporizes under these circumstances. This can easily happen if the insulation is weak. Whether the quality of insulation was inadequate, or because of some other weakness in the storage tanks, pressure did rise high enough to force open a relief valve and allow a cloud of gas to escape.

This was not a surprise to the workers. They encountered danger signals and tragedies before, all of them related to Pemex. A few months earlier eighty-nine Mexicans died and hundreds were injured in four separate accidents at Pemex installations in other parts of the country. The residents at Ixhuatepec knew about these and lived in constant fear of an explosion. Smell of leaking gas was a constant complaint but management staff took little notice of it. A worker, on the night of the accident, reported that the pilot flame at the plant had gone out, something that should never happen, and in its place was a loud hissing noise. Several other workers noted that a strong smell of gas had been detected over the whole area on the previous night. Evidently a substantial amount of gas had escaped and a spark from somewhere set off the first explosion.

A series of fires followed; then a much more powerful explosion as two very large cylinders were heated by the fires and blew up. More explosions and fires followed as other tanks were caught in the conflagration. Fireballs erupted all around the plant whenever another cylinder or pipe blew up. Masses of fragments of metal rained down. One six-foot section of piping was flung two miles away. Another section landed on a house half a mile from the plant, killing twenty-one people. In one nearby area two hundred houses were totally demolished by a fireball. Most of the occupants died in their sleep. For several hours there was no organized evacuation. People just fled to the hills to get away from the fires. Some badly hurt people were left to die on the street.

Nine months after the explosion and all that followed, there was still no report from Pemex on the tragedy. The Netherlands Organization for Applied Scientific Research which tracks accidents of this kind from all over the world did report however in a detailed analysis of the event. The claim from Pemex that the disaster started at a neighboring plant was rejected. The Netherlands confirmed that a leak from a pipe in the installation at Ixhuatepec was the cause. The term used for the type of explosion that occurred is BLEVE, meaning boiling liquid expanding vapor explosion. Four of the explosions were big enough to be recorded on the local university's seismograph as the equivalent of a 0.5 on the Richter Scale.

The true count of dead will never be known. The official figure stands at five hundred but some were sure that the number was higher. Almost no attempts were made to identify those who were killed. A day after the tragedy, coffins containing the remains of the first three hundred victims were placed in two huge holes, each five hundred feet wide, in the hillside of a cemetery close to Ixhuatepec. Investigators from Holland who had been brought in to assess all aspects of the accident confirmed that only 25 of the three hundred had been identified before burial. For most of them, therefore, their families have no official record of their deaths.

About 150,000 people had lived close to the plant, against all the rules governing industrial safety. In a large LPG plant like this one at San Juan Ixhuatepec there should have been no homes near the plant. However, in Mexico, land costs within the city are prohibitive for those who work for Pemex. They take the risk of living next door to the huge LPG cylinders and company officials do not interfere. They were the ones who were killed or injured. Even in the aftermath of this terrible tragedy, when what remained of the neighboring homes had been cleared away, new homes began to appear where they had previously been illegally located.

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Hiroshima, Japan, nuclear bomb

August 6, 1945

The first atom bomb used in warfare was dropped on Japan

Hiroshima, a city in the south of the main Island of Honshu, was the target in this first use. Most of the buildings were destroyed and 80,000 people were killed instantly

The first atomic bomb to be used in warfare was dropped on Hiroshima on August 6, 1945. Few knew what the effects would be. There had been only one other bomb of this kind previously detonated. The destruction unleashed on the city was total. About 70 percent of all buildings and 80,000 people were obliterated in an instant. In the introduction to these books about disasters it was pointed out that there would be no events related to warfare. This one on Hiroshima is the exception to that rule. It is included because it affected so many events all over the world since 1945. Much of what was learned about the nuclear power accidents described in these two volumes came from the experiences of people in Hiroshima.

Why was the bomb dropped on Hiroshima? There are many answers to this question because there were many people involved in the decision. The best estimate of why the decision was taken at that time related to strategic plans. The United States wanted to force Japan's surrender as quickly as possible in order to reduce American casualties. Alongside that concern was the desire to prevent the Soviet Union becoming involved in the conquest of Japan. Up to that time, the Soviet Union had only attacked and occupied some islands north of Japan. Although an ally of the United States at the time, the dictatorship of the Soviet Union was not trusted by the United States. Several voices, including that of Dr. Albert Einstein, were raised in opposition on ethical grounds, but they did not prevail. One

Figure 61 Official U.S. Army photo that offers a general panoramic view of Hiroshima after the bomb, which shows the devastation from a distance of about four-tenths of a mile.

of these came from Dr. Edward Teller, one of the designers of the bomb. He urged President Truman to drop the bomb high above Tokyo where it would be less destructive but where its destructive power could be felt by the Japanese but without loss of life. That may have seemed like a good idea at the time, but even atomic scientists could not have foreseen then that such an event could have been worse than a direct hit because radiation would have been distributed all over the city of Tokyo and its surroundings.

The history of the bomb tells quite a lot about the harmful influences of dictatorships on scientific research. In the years before World War II, several of the world's leading physicists, scholars who knew most about how to make an atom bomb, lived and worked in Germany and Italy. As these nations became dictatorships and began to single out Jews for persecution, many of these scholars, fearing they might be targets for attacks by state officials, left their home countries and went to Britain and the United States. One of them, Leo Szilard, who went to the United States along with Einstein in 1940, persuaded Einstein, at that time the most eminent scientist in the country, to write to President Roosevelt proposing a research project to develop an atom bomb. Roosevelt was not interested at that time. He saw no need for such a weapon, but changed his mind quickly a year later after Pearl Harbor and America's sudden involvement in World War II. There was good reason for Szilard and Einstein to suspect that Adolf Hitler would attempt to develop an atom bomb. Later, during World War II, Britain discovered that Hitler was busy trying to do that. If he had not changed his country into a dictatorship with terrible murderous policies toward Jews he might have retained the services of the necessary experts and succeeded.

The United States went ahead with a research project for an atomic bomb within a month or two after Pearl Harbor and produced the first successful explosion in July of 1945. It was the costliest military project ever undertaken to produce one bomb. The bomb cost two billion dollars, weighed 4,000 tons, and had the power of 20,000 tons of TNT. The four-year project was located at a new specially constructed lab complex in New Mexico and code-named for secrecy "Manhattan Project." Both British and U.S. scientists became involved in it. Once there was a successful explosion in the United States, action followed quickly to plan for the dropping of a second bomb over Hiroshima. Individual parts of the second bomb, each encased in a lead container, were shipped one at a time to Tinian Island in the Mariana group of islands. From there the final flight would be made, a distance of about a thousand miles. In preparation for the flight with the bomb, the bomber crews involved had been doing extensive training and flying both at base in Tinian and in flights over Japan. It was during this period that some uncertainty developed over how best to load the triggering device into the bomb. The pilot of the plane that was to carry the bomb, after consulting with his crew, decided to do the loading while in flight. He reasoned that, if something went wrong, the loss of everything in flight would be better than totally destroying the Island of Tinian. It was a bold decision. Fortunately for him and his crew, the loading of the bomb in flight was successful and they arrived over Hiroshima early on August 6.

There were additional reasons for selecting Hiroshima as the target. The size and the nature of the surrounding terrain made this city suitable for discovering the destructive capabilities of the bomb, critical information that was not known at that time. A second reason was its concentration of military installations, munitions factories, and troop concentrations. There was also the advantage of surprise, an important consideration in a critical bombing mission, since no bombing had previously been carried out there. Hiroshima in August of 1945 was a city of 245,000 people, about 100,000 less than its population at the beginning of the war because many children and others had been evacuated to countryside locations for safety. Almost all the dwellings were of wood construction, half of them single story and half one and a half stories. Fire-fighting equipment was antiquated but that, like all other public services, mattered little after August 6, 1945. The bomb was dropped around 8:00 A.M. and timed to explode close to the ground. The plane, *Enola Gay*, was nine miles away when the bomb went off. As the crew looked back at it from 30,000 feet up, and with special protective goggles, one man observed, "We're looking into hell."

The day after the bomb, President Truman broadcast news of the event to the United States in words like these: We have captured the energy of the sun in a new and terrible bomb and one of these has already been dropped on Japan. If they do not now accept our demand for unconditional surrender, they may expect a rain of ruin from the air, the like of which has never before been seen on this earth. There was no response from Japan for two days and President Truman decided that the emperor was stalling for time in order to try to arrange something less than total surrender. The reality was quite different. Protocol in Japan, unfortunately unknown in the United States, because the emperor was seen as God, required a few days for action. The emperor had already decided to surrender but he waited for the military leaders to agree. He knew that they would but not immediately. President Truman decided to launch a second strike. On August 9, Nagasaki was hit with an atom bomb, again from a plane that came from the Island of Tinian. U.S. estimates put the death toll at 35,000 but Japanese authorities later gave it as 87,000.

Everything within the city had been devastated by the bomb and people had to wait for help from elsewhere. For an area of four and a half square miles around ground zero, that is the point on the ground immediately below the bomb explosion, every living person or animal was destroyed. With an atom bomb explosion extremely high pressures and equally high temperatures are present, far greater than are ever experienced in industrial enterprises. The bomb was dropped from a high elevation and timed to go off as it neared the ground. Directly below the bomb everything was vaporized. The metal framework of one building was all that was left and this became part of a museum that was built later in the center of the city. Beyond the vaporized zone, the supersonic blast of air and heat, releasing millions of degrees of heat, destroyed everything. People standing ten or more miles away were burned right through their skins. They died either immediately or soon afterward. Iron, stone, and roof tiles were twisted out of shape. Clothing, railway ties, and trees instantly ignited. At eight hundred miles an hour of speed and 9,000 degrees of temperature, the hot air created huge swirls of wind that circled back into the city to fill the vacuum initially created. Whatever remained was then destroyed.

The harm done to humans is quite a different story. In 1945, no one knew much about nuclear radiation or the cancerous and other diseases it would generate. Many of the people who were still alive after the bomb had done its work received heavy doses of radiation. Prior to August 6, 1945, there had been more damage and more casualties inflicted on Tokyo by all the bombing raids than was done on Hiroshima by the one bomb. However, the nature of the damage done to humans in Hiroshima was far worse, much longer lasting, and more psychologically harmful. Furthermore, the final death toll directly attributable to the atom bomb was far beyond the 80,000 who died on August 6. Twenty years after that date the

Japanese Broadcasting Corporation announced that the total number of deaths from the atom bomb that was dropped on Hiroshima was 240,000. People standing beside concrete walls when the bomb exploded left a silhouette on the wall. Everything else about them had vanished. Others were burned or cut by flying pieces of metal, wood, or glass. In the months that followed, large numbers of these people died from different illnesses and over a few years many more succumbed. Within two weeks after the bombing, those who had been within five hundred yards of the explosion, even if they were sheltered behind buildings, showed symptoms of deadly radiation sickness, vomiting blood and loss of appetite. Most of them died a week or two later.

By December of 1945 the death toll had risen to 140,000. Over the years since then casualty numbers have continued to mount but statistics are difficult to collect because of health complications additional to those caused by radiation. The special atomic bomb museum that now stands in the center of the old city of Hiroshima carries a detailed, visual documentation of the horror that citizens endured on and after 1945. Many thousands from all over the world visit this memorial annually. At the present time, the people who were put through the terrible events of August 1945, and their offspring, are more closely monitored than almost anyone else in the world. This is the only place where the effects of radiation on the human body are evident. The relations between levels of exposure and epidemiological conditions are examples of the kinds of things that are measured. From such guidelines for safe exposure to radiation are deduced and employed around the world in the nuclear industry. One scientist believes that almost half a million workers in the radiation industry in the United States and at least that many in Europe have benefited from these guidelines.

There is a major concern about the survivors from the A-bomb as they get older. When they were exposed to the radiation, they suffered damage to their genes, with those closest to the center of the explosion the worst affected. In many cases their genes repaired themselves. It is possible that those repairs were imperfect, making it more likely that they will develop cancer in later life. The highest risk for A-bomb victims developing cancer is among the youngest victims. These people are now approaching an age where they would be more likely to develop a cancer naturally. New genome technology coupled with new methods of diagnosis and treatment offers the possibility of repairing cell damage. It is expected that the number of victims who were young in 1945 will peak in the year 2020 so there is time to develop this approach of cell repair.

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Bikini Atoll, Marshall Islands, nuclear tests

February 1, 1946
Tests of atomic bombs in Bikini Atoll started soon after the first strike on Hiroshima

Extensive tests, involving the removal of the native residents, were carried out in the Atoll from 1946 to 1954

Shortly after the end of World War II, the U.S. Navy decided to carry out a series of atomic bomb tests on different kinds of ships. Bikini Atoll in the Central Pacific was chosen for these tests and the islanders were persuaded to move temporarily to another island group. They were assured of a safe return to their homes in due course. That return never happened. Short visits soon made it clear that the soils of their atoll carried extremely high levels of radiation. Bikini had become a wasteland, an environmental disaster.

Bikini Atoll is one of a group of atolls that compose the Marshall Islands, a U.S. protectorate under the United Nations in the years following World War II. These islands are located about halfway between Hawaii and Australia and stretch over the Pacific Ocean for hundreds of thousands of square miles. Average temperature is over eighty degrees Fahrenheit and rainfall amounts to sixty inches annually. The first Europeans to reach the area were Spanish. That was more than three hundred years ago. For most of the succeeding 250 years there was little continuing contact with western nations. Trade in copra oil from coconuts was carried on but the islanders remained isolated, free to live in their closely integrated society, strengthened by extended family ties and local traditions.

All this changed dramatically after World War I when Japan was mandated by the victorious nations to govern the islands. A military buildup

Figure 62 Mushroom cloud rising above Bikini Atoll after 1946 atom bomb test.

began on Kwajalein Atoll, two hundred miles to the south of Bikini as this place became headquarters for Japan's armed forces in the Marshall Islands. A watchtower was built to guard against possible invasions. This Atoll was still a fortified military position throughout World War II and was finally captured by U.S. forces in 1944 after a terrifying and costly conflict.

After the war President Truman directed the U.S. Navy to investigate the effects of atomic bombs on U.S. warships. Bikini Atoll was chosen for this project for several reasons. It was located away from regular air and sea routes, had a good-sized lagoon, and close by there were a few large islands that could serve as observing stations. There was good access to the lagoon through wide channels and a shallow area a few miles away was a suitable site for anchoring the target ships. Kwajalein and Enewetak were close enough to serve as bases for aircraft.

In February of 1946 the Bikinians, all 167 of them, were asked if they would be willing to leave temporarily so that the United States could begin testing atomic bombs. The U.S. governor assured them that this move would be for the good of mankind and to end all world wars. After much sorrowful deliberation King Juda, the Bikinian leader announced "We will go, believing that everything is in the hands of God." The Bikinians were sent to Rongerik Atoll, 125 miles to the east, a place about one-sixth the size of Bikini and a location that was traditionally regarded by the Bikinians as unlivable because of inadequate resources of water and food. There was also a deeply-felt conviction that Rongerik was inhabited by evil spirits.

The Bikinians were given food supplies for several weeks and then left to fend for themselves. Soon after these provisions ran out, the islander's worst fears began to surface as they were unable to find adequate local food supplies of the kind they were accustomed to, coconuts and fish. A rash of serious illnesses late in 1946, perhaps due to lack of food, and a fire damaging a large number of coconut trees, reduced them to near starvation. They begged the Navy to let them return to Bikini. Instead they were moved to Ujelang Atoll early in 1947, but something went wrong with that plan and their odyssey took them to yet another group of islands, Kwajalein, where they were housed in tents on a strip of grass beside the airport.

The reason for these migrations was always the same, the operational needs of the atomic bomb tests. The health and welfare of the islanders seemed to matter little. In 1948 there was another move and they left Kwajalein for the Island of Kili, far to the south of the Marshall Islands. While the islanders struggled to set up their new community on Kili, Bikini continued to be irradiated with a steady succession of bombs. The first two, each of the same power that had devastated the cities of Hiroshima and Nagasaki in 1945 just before the end of World War II, were detonated in the air. They were followed by more than twenty other blasts between the years 1946 and 1958, some on the ground, some above.

In 1954, the new and vastly more dangerous hydrogen bomb, a thousand times more powerful than the one that destroyed Hiroshima (see Hiroshima, Japan, nuclear bomb), was detonated on the ground. Weather forecasting was very different in 1954 from what it is today. There were no satellites and no computers. Furthermore, little historical data was available for Bikini so it was very difficult to predict how winds might change in the short term. The enormous amount of planning and arranging that went into a bomb test, especially this new type, necessitated a decision some time ahead of the blast. Winds were favorable all day right up to eight hours before blast time, but then they changed. The test went forward in spite of the fact that radiation would inevitably blow in the direction of some inhabited islands.

The site was the surface of the reef in the northwestern corner of Bikini Island. The area was illuminated by an expanding flash of blinding light. A raging fireball of intense heat measuring into the millions of degrees shot skyward at a rate of three hundred miles an hour. Within minutes the monstrous cloud, filled with nuclear debris, shot up more than twenty miles and generated winds at hundreds of miles per hour. These fiery gusts blasted the surrounding islands and stripped the branches and coconuts from the trees. On Bikini Island, millions of tons of sand, coral, plant, and sea life from Bikini's reef and the surrounding lagoon waters were sent high into the air. The force of the explosion was far beyond the expectations of observing scientists. It was the most powerful bomb ever exploded by the United States. Fifty thousand square miles were contaminated.

Ships which were stationed about forty miles east and south of Bikini, in positions enabling them to monitor the test, detected the eastward movement of the radioactive cloud from the fifteen megaton blast. They recorded a steady increase in radiation levels that became so high that all men were below decks and all hatches and watertight doors were sealed. One-and-a-half hours after the explosion, twenty-three fishermen aboard a Japanese fishing vessel, the *Lucky Dragon*, watched in awe as a "gritty white ash" began to fall on them. The men aboard the ship were oblivious to the fact that the ash was the fallout from a hydrogen bomb test. Shortly after being exposed to the fallout their skin began to itch and they experienced nausea and vomiting. One man died.

On Rongelap Atoll—located about 125 miles east of Bikini—three to four hours after the blast, the same white, snow-like ash began to fall from the sky onto the sixty-four people living there. Not understanding what had happened they watched as two suns rose that morning, observed with amazement as the radioactive dust soon formed a layer on their island two inches deep turning the drinking water a brackish yellow. Children played in the fallout. Their mothers watched in horror as night came and they began to show the physical signs of exposure. There was severe vomiting along with diarrhea and hair falling out. The islanders fell into a state of terrified panic. Two days later they were finally taken to Kwajalein for medical treatment.

About twelve years after the series of bomb tests was completed, U.S. government agencies began to consider returning the Bikinians to their homelands in compliance with the original promise in 1946. Specialists measured radiation levels on Bikini Atoll and it was considered safe. One report from the Atomic Energy Commission (AEC) went so far as to say, "Well water could be used safely by the natives upon their return to Bikini. It appears that radioactivity in the drinking water may be ignored from a radiological safety standpoint. The exposures of radiation that would result from the repatriation of the Bikini people do not offer a significant threat to their health and safety." Accordingly, in June of 1968, the 540 Bikinians living on Kili and other islands returned to their homeland.

For seven years there was little indication of any problem. The population of Bikini slowly increased. Then in 1975, during regular monitoring, radiological tests discovered higher levels of radioactivity than was originally thought. The U.S. Department of Interior officials stated that "Bikini appears to be questionable as to safety" and an additional report pointed out that some water wells on Bikini Island were also too contaminated with radioactivity for drinking. A couple of months later the AEC, on review of the scientists' data, decided that the local foods grown on Bikini Island, i.e., pandanus, breadfruit, and coconut crabs, were also too radioactive for human consumption.

Within a few months, after contemplating these new, terrifying, and confusing reports on the radiological condition of their atoll, the Bikinians filed a lawsuit in U.S. federal court demanding that a complete scientific survey of Bikini and the northern Marshalls be conducted. The lawsuit stated that the United States had used highly sophisticated and technical radiation detection equipment at Enewetak Atoll, but had refused to employ it at Bikini. More than three years of bureaucratic squabbles between the U.S. Departments of State, Interior and Energy over costs and responsibility for the survey, delayed any action on its implementation. The Bikinians, unaware of the severity of the radiological danger, remained on their contaminated island.

In April of 1978 medical examinations performed by U.S. physicians revealed radiation levels in many of the 139 people on Bikini to be well above the U.S. maximum permissible level. The very next month, U.S. Interior Department officials described the 75 percent increase in radioactive cesium 137 as incredible. The Interior Department immediately announced plans to move the people from Bikini "within 75 to 90 days," and so in September of that same year people were once again evacuated. The Bikinians saw their homeland again only once in 1988. They were brought back to witness the beginnings of a long-term project, the decontamination of the soils all around the lagoon. Some day, as yet unknown because of the enormity of the damage, that project might be completed so that a future generation of Bikinians can live there.

After the people of Bikini were removed from their atoll for a second time, the U.S. government established a $6 million trust, The Hawaiian Trust Fund for the People of Bikini. A second grant of money, $20 million, was given to the Bikinians in 1982 to help them when they could return to their homeland. In 1997 there was a third grant, $90 million, this time for the cleanup of Bikini and Eneu, two of the group of islands known as Bikini Atoll. The total value of the fund by the year 2000 was $130 million. Ninety of the original 167 Bikinians, who left in 1946, were still alive at that time.

In March of 1998 the International Atomic Energy Agency (IAEA) presented its final report on radiological conditions at Bikini Atoll. It concluded that, on the basis of the amount and quality of the information now available, no further testing is necessary. The Bikinians should not be allowed to return to their homeland of Bikini Island permanently, and eat locally grown food, until remedial measures are carried out. However, if the food consumed is imported, as is presently the case in a number of sites on the Atoll where fishing in the lagoon and diving-tourist enterprises on the big sunken ships are in operation, there are no dangers associated with temporary occupancy.

The IAEA is quite sure that it is safe to walk on all of the Bikini islands. While the residual radioactivity is still too high for growing crops, it is not hazardous to health. The air, land surface, lagoon water, and the drinking water are all safe. There is no radiological risk in visiting the lagoon or the islands. The nuclear weapon tests have left practically no cesium in marine life. The cesium deposited in the lagoon was dispersed in the ocean long ago. The main radiation risk would be from the food. Eating locally grown produce, such as fruit, coconuts, and breadfruit would not be safe.

One measure under consideration by the IAEA for ensuring the return of the islanders with freedom for them to eat locally grown food uses a potassium-based fertilizer. This would be spread on all areas of Bikini Island, not other islands of the Atoll, together with removal of soil beneath and around homes and replacing it with crushed coral. Because Bikini Island is extremely deficient in potassium, it has been found that plants will choose this when it is available rather than radiated minerals. The problem with this approach is its short life. It will work for four or five years only before repeated applications of the fertilizer are needed.

The Bikinians are wary of any short-term measures. They have been badly hurt already by temporary arrangements, bringing them close to starvation. They favor the IAEA's soil-scraping approach whereby the top fifteen inches of soil is removed. This would eliminate the danger of radiation but it would be environmentally costly. The fertile topsoil supports the tree crops which are a major local food resource. Nevertheless, the Bikinians continue to campaign for a soil-scraping approach for all twenty-three islands of the Bikini Atoll. They would like to see it happen first on Bikini Island with the soil used to build a causeway to a neighboring island presently accessible only at low tide.

The enormous ignorance that prevailed in 1946 about the dangers of radiation from atomic bombs created a lethal atmosphere around the Bikini test area. Some of the tragic effects of this were immediately evident but others came to light gradually over succeeding years. Hundreds of military personnel who were involved in the tests suffered from radiation diseases of various kinds. Today the dangers from radiation are well known and protective measures are in place. Of the more than two hundred ships that were brought to Bikini for the tests, ten of the biggest, including the former aircraft carrier *USS Saratoga*, still lie in the Bikini lagoon. They are uncontaminated now and serve as popular sites for diving tourism.

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Unimak, Alaska, tsunami

April 1, 1946

One of Alaska's greatest tsunami occurred at Unimak Island

This tsunami, with a wave height of one hundred feet, was triggered by an underwater earthquake of magnitude 8.1

On the first of April 1946 Alaska experienced one of its greatest tsunamis, triggered by an earthquake of magnitude 8.1 near Unimak Island in the Aleutian Island Chain. This tsunami carried a wave height exceeding one hundred feet. It completely destroyed the U.S. Coast Guard's Scotch Cap lighthouse on Unimak and killed all five of its occupants. The lighthouse was a steel-reinforced concrete structure standing about ninety-five feet above sea level. The tsunami reached the Hawaiian Islands five hours later, causing considerable damage and loss of life. Hilo's waterfront on the island of Hawaii was completely obliterated and 159 people lost the lives there. Another six were killed in other parts of Hawaii. Total damage was estimated at $26 million and, two years later, the United States established a Pacific Tsunami Warning Center in Hawaii

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During the quake, a large section of seafloor was uplifted along the fault where the quake occurred, producing a large, Pacific-wide tsunami. The most detailed and documented accounts of the tsunami come from Scotch Cap, located on Unimak Island, and the Hawaiian Islands. The tsunami had little effect on the Alaskan mainland, due to the presence of the Aleutian Islands, which absorbed the brunt of the tsunami's power. The effects of the tsunami were felt along the west coast of the United States, in Washington, Oregon, and California. Oregon reported a ten-foot wave. In California, Fort Bragg reported five- to nine-foot waves. One person drowned as a result of the ten-foot waves that struck Santa Cruz. The tsunami was also noticed in Santa Barbara and the greater Los Angeles area. The tsu-

Figures 63 (top) and 64 (bottom) Tsunami generated by earthquake of April 1, 1946, Aleutian Islands, Alaska. Before and after pictures of the Scotch Cap Lighthouse on Unimak Island, Alaska. A magnitude 8.0 (Mw) earthquake with the source to the south of Unimak Island generated a tsunami that destroyed the five-story lighthouse, located 9.8 m above sea level. Only the foundation and part of the concrete sea wall remained. All five occupants were killed. The waves deposited debris as high as 14 feet above the sea. Although little damage occurred in Alaska, except at Scotch Cap, the tsunami was one of the most destructive ever to occur in the Hawaiian Islands.

nami crossed the Pacific, producing waves up to thirty feet high in French Polynesia. It also damaged fishing boats in Chile.

A mystery surrounded this earthquake for a time. It got more and more puzzling as a seafloor search failed to reveal what scientists expected to find. The earthquake seemed too small to spawn the huge local wave and scientists struggled for decades to figure out what happened. The leading theory was that the earthquake triggered an underwater landslide and the landslide gave rise to the big tsunami but a seafloor-mapping project by Scripps Institution of Oceanography, designed specifically to look for the cause of the tsunami, didn't find evidence to support that theory. Researchers did see colorful corals and an unusual methane seep teaming with marine life, but the sea floor looked as if it had been undisturbed for millennia. A long-simmering scientific debate continues over just what caused the 1946 tsunami. Generation by one or more major earthquake-triggered submarine landslides near the shelf edge south of Unimak Island seems to be the only viable mechanism to account for the data on wave arrival time, run-up heights, and the distribution of tsunamis across the Pacific.

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Vancouver Island, Canada, earthquake

June 23, 1946

Vancouver Island's largest earthquake and Canada's largest intra-plate occurred on Vancouver Island

This earthquake was not one of the subduction ones that are likely to hit this area in the future. Instead it occurred within the island, about ten miles west of Campbell River

Vancouver Island's largest historic earthquake, and Canada's largest intra-plate quake, was a magnitude 7.3 event that occurred on Sunday, June 23, 1946, in the north central part of Vancouver Island. It caused a great deal of damage on Vancouver Island and was felt as far away as Portland, Oregon, and Prince Rupert, north of Vancouver Island, both places at a distance of three hundred miles. The earthquake knocked down most of the chimneys in the closest communities, Cumberland, Union Bay, and Courtenay and did considerable damage in Comox, Port Alberni, and Powell River. Fortunately, because of the few people living in the area, casualties were very small, one due to drowning when a small boat capsized and the other from a heart attack in Seattle.

The epicenter was ten miles west of the town of Campbell River and tremors were felt all over Vancouver Island as well as on adjacent islands and the coastal areas of the mainland. It is always interesting to read accounts of earthquakes that were made before the 1960s, before there was any knowledge of the global tectonic plates that cause most of the big earthquakes. Such reports help us understand the perplexity that must have accompanied earthquakes from the dawn of history. In this case, experts visited Vancouver Island in 1946 after the earthquake, interviewing people in all the affected communities and thereby arriving at probably causes. Their reports describe an epicentral region, rather than an epicenter, dominated by two fault lines extending north and south in the Strait of Georgia and east and west through Alberni. In both of these faults evidence for their existence is drawn substantially from surface features such as lakes and sea inlets. We know today that the tectonic boundaries that generate earthquakes in and around Vancouver Island lie far below the surface.

A damaging earthquake occurs somewhere in the Vancouver Island Region about once every twenty years. This one in 1946 was the largest of the twentieth century. Most of these earthquakes occur on the fault separating the subducting Juan de Fuca and North America plates. The greatest earthquake of the past several hundred years occurred on this fault in 1700 and it affected the entire coast from northern California to northern Vancouver Island. It had a magnitude of 9 or more. The lesser and more frequent earthquakes like this one in 1946 and a magnitude 7 quake in 1918 are intra-plate events, caused by stress within the crust of the North American Plate as it interacts with both the Juan de Fuca and Explorer plates lying off the west coast of Vancouver Island. The data that is available on the 1946 earthquake is necessarily of the anecdotal kind since it was collected in 1946. There is a general and brief reference to serious damage in the areas described as the center of the earthquake. They consist of extracts from local newspapers. A much larger series of reports is taken from places at a distance from the epicenter, suggesting that the damage was greatest in these places. For example, tremors were experienced all over Vancouver Island. This is what we would expect if the causal factor had been general stress within the North American Plate.

Landslides were common all over the island according to the 1946 report. There were also widespread incidents of subsidence, almost all of them along coastal areas in the Strait of Georgia. Uplift of Vancouver Island in some areas along with subsidence elsewhere has always been a feature of the region, due to the ongoing subduction of the Juan de Fuca Plate under the North American Plate. Ships experienced the shaking that was happening in so many places, mostly in the Strait of Georgia but in one or two cases on the west coast. Their experiences were described as either having run over a sand bar or striking a rock. Underwater cables were damaged in Alberni Inlet and in approaches to Powell River. All lighthouse keepers in the surrounding area reported shaking along with some damage, windows cracked and dishes broken. There was one report of a tsunami on the west side of Texada Island; two waves arrived, the first was seven feet high and the second four feet. One fortunate occurrence enabled researchers at a later time to reexamine the impact of the earthquake: an aerial photographic survey had been made of Vancouver Island in 1946, after the earthquake, and these were examined by a geologist in the late 1970s.

With the advances made in the intervening thirty years the epicenter was located more accurately than the estimated location of 1946, putting it significantly farther north and farther west. The two faults that had been identified in the earlier report were confirmed, but again they were located closer to the new epicenter. The evidence available from the aerial photography was entirely related to landslides. Large numbers of earth movements beyond what would have happened in the ordinary course of nature were clearly visible in these photographs but in the opposite set of locations compared to the area mentioned in 1946. Because the reports from the people affected had come from areas of low elevation, the places where the main population centers are found, the author of the 1946 report concluded that most of the landslides had occurred there. He had also emphasized the amount of damage that had occurred on the east coast, within the Strait of Georgia, and on the coast of the mainland. The 1970s perspective is quite different. The vast majority of the landslides from 1946 were found on the west coast of the island from Barclay Sound northwards.

The reasoning that explains the sharp differences of interpretation between the two time periods relates to topography. The earlier report linked reports of damage to the earthquake, so it seemed that most of the landslides occurred in those areas. The places, however, where landslides would occur are those that have the greatest differences in elevation. That is, the vertical displacement of surface soil and rocks will always be at a maximum where the differences in elevation are greatest. In the case of Vancouver Island, the chain of mountains that defines its highest terrain lies on its west coast so it was there that the aerial photographs revealed the majority of the landslides. Most of these landslides were directed toward the southwest. When the constant interaction at considerable depth between the offshore smaller plates and the North American Plate is taken into account, it is feasible to expect that the visible signs of the earthquake would be close to that interface rather than at one of the many interior fault lines.

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111

Nankaido, Japan, earthquake

December 20, 1946
The Nankaido 8.1 earthquake struck south of Kyushu Island along the length of the Nankai Trough

The Nankai Trough was frequently hit in the past by powerful earthquakes

Along a three hundred-mile long fault line known as the Nankai Trough, stretching from south of the Island of Kyushu to Kii-Hanto in the Island of Honshu, there is a long history of major earthquakes. On December 20, 1946, while Japan was recovering from all the devastation of World War II, it was hit once again with the Nankaido earthquake, a very powerful one of magnitude 8.1, along this line. From its epicenter offshore south of Kii-Hanto it triggered a twenty-foot high tsunami that reached the eastern shores of Kyushu where 1,400 people were killed, another 3,800 injured, and 12,000 houses completely destroyed.

The Philippine Sea Tectonic Plate is constantly moving at a rate of two inches a year toward the Nankai Trough as it subducts beneath Japan, part of the Eurasian Plate in this area. In this instance, since it was an earthquake of magnitude 8.1, it represented a massive disruption of the seafloor and, in contrast to past events it affected a bigger part of the trough. Japan is better acquainted with earthquakes, even ones of magnitude 8 or more, than almost any other nation on earth. As recently as two years before this Nankaido earthquake this same fault line was struck by the Tonankai earthquake, which was of magnitude 8.1. It is rare for a specific location to experience two earthquakes of this magnitude within a two-year period. Both of these earthquakes were of the interplate kind. They occurred in the same area off Japan and their epicenters were located in the same general area.

Earthquakes have recurred in this area in the past. Historical data indicates that most of them were of magnitude 8 or greater and their recurrence rates have been one hundred to 150 years. Data for this in Japanese records goes back for more than 1,500 years so, like one or two other locations in Japan, there is something approaching predictability regarding future earthquakes. There are four tectonic plates actively moving or resisting movement in and around Japan: the North American Plate (NAP) that includes part of northern Honshu and places north of Honshu, the Pacific Seas Plate (PSP) that dominates ocean areas south and east of central Honshu, and the two very large plates, the Pacific and the Eurasian, that lie east and west respectively of the NAP and PSP plates. Aftershocks are common and, in the case of the Nankaido earthquake, they continued for more than a month after the main shock with magnitudes of 6 or more. Conditions about a month after the initial shaking revealed a twenty-inch uplifting of the Kii-Hanto peninsula at Kushimoto.

The 1944 Tonankai earthquake also triggered a tsunami that affected the neighboring coasts. Wave heights reached thirty feet causing, like the Nankaido, numerous deaths and destruction of houses. Overall there were 1,250 fatalities, 2,970 injured, and 16,455 houses totally collapsed. There will be more earthquakes in the future in this very active multi-faulted part of Japan. A newspaper report dated September 7, 2004, noted that two strong earthquakes hit the Kii-Hanto region. Their magnitudes were not given.

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Woodward, Oklahoma, tornado

April 9, 1947

Oklahoma's worst ever tornado struck Woodward in 1947

This was a violent category 5 tornado, more than a mile wide. It destroyed one hundred city blocks and killed 181 people

The most deadly tornado to ever strike within the borders of the state of Oklahoma occurred on Wednesday, April 9, 1947, in the city of Woodward. It began near Canadian, Texas, and after traveling for about one hundred miles reached Woodward. The tornado was a violent F5 storm, more than a mile wide, and it unleashed its worst destruction on Woodward, striking the city without warning at 8 P.M. Over one hundred city blocks on the west and north sides of the city were destroyed. There was lesser damage in the southeast portion of the town. Confusion and fires reigned in the aftermath with over 1,000 homes and businesses destroyed. The total death toll from this storm was 181. There were an additional 1,000 people injured in Woodward. Normal communications between Woodward and the outside world were not restored for some time.

This tornado began as one of a series in Texas. The first tornado formed five miles northwest of Pampa, Texas. Others followed as the path of destruction passed through three states before one did its greatest damage in Woodward, Oklahoma. As the storm moved beyond Woodward into Kansas, it weakened, although serious damage was reported in Barber County before it finally dissipated north of Kingman County. Because of the Woodward tornado and other devastating storms in the late 1940s and early 1950s, and because of new technologies available after World War II, the National Weather Service began a tornado watch and warning program in 1953. Since that date the warning system composed of the National Weather Service, local civil preparedness agencies, and the media, have continued to mature and provide better and better information to citizens to protect against tornadoes. Because of the strengths of the warning system, tornado death tolls in Oklahoma and nationwide have dropped considerably with each passing decade.

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Texas City, Texas, explosion

April 16, 1947

Two explosions of ammonium nitrate shattered Texas City

Lack of awareness of the dangers from ammonium nitrate despite published guidelines and earlier similar historical tragedies caused the tragedies at the port of Texas City on Galveston Bay

Two explosions of ammonium nitrate fertilizer shattered Texas City and its surrounding area beginning on the morning of April 16, 1947. In the first explosion the freighter Grandcamp's explosion was heard 150 miles away. The second one, High Flier, was no less fierce when it blew up sixteen hours later. Several thousands were injured and 568 killed. It caused the greatest number of casualties of any U.S. industrial accident.

Texas City on Galveston Bay, about thirty miles southeast of Houston, Texas, was a thriving oil port in the 1930s with a population of six thousand. Several oil refineries stood near the docks and the shipping traffic was mainly occupied with crude oil and petrochemical products. With the onset of war in the first half of the 1940s and a rising demand for aviation fuel and a range of synthetic chemicals both the population of the city and the growth of industrial capacity expanded dramatically. Production of oil-based products jumped fivefold in five years and the population more than doubled. By 1947 there was an aura of success and confidence as business continued to grow in the aftermath of the war.

A zoning law was passed in 1946 to establish which areas were to be devoted to industrial, residential, and institutional activities and in each of these places safety precautions were given high priority. Gas and oil storage tanks were both equipped with fire control systems and surrounded by dikes that would prevent spills reaching other buildings if accidents occurred. There were good reasons for these precautions. Within a one square mile area next to the docks there were six oil-company complexes, eleven warehouses, plus several other installations and residential blocks. Experts in fire prevention assured the port authorities that only one-fifth of this area was in danger of a serious fire and existing precautions would be adequate to cope with such an eventuality.

All of this thinking should have changed when large quantities of ammonium nitrate fertilizer began to be shipped from Texas City in 1946. Now, in the event of an accident, there was the possibility of a conflagration that would affect the whole dock area, not just one-fifth of it. Two conditions prevented the kind of new thinking that was required. The port authorities responsible for handling the nitrate—the railways and the masters of ships—operated independently of the other agencies and they saw no reason for coordinating their safety systems with those already in place. In their minds these shipments were no different from the cotton and the other bulk commodities they handled. The second dangerous condition was general ignorance of the lethal potential of ammonium nitrate.

The fact that the nitrate had come from an army ordnance factory should have raised questions about safety, especially since a 1941 army manual listed ammonium nitrate as high explosive. It had in fact half the explosive power of TNT. In addition, a 1945 U.S. Department of Agriculture publication on the same subject said that it would explode if given a strong impulse or is held in a restricted space under conditions of rising heat and pressure. There were other conditions listed in different publications—such as the effect of fire—that added to the lethal potential of ammonium nitrate, some of them directly related to the tragedy that occurred at Texas City. In Germany, twenty-six years earlier, as will be described later to illustrate the seriousness of neglecting the lessons of past disasters, a gigantic explosion occurred in a storage unit containing this same substance, ammonium nitrate, yet ignorance of it was as common as the unfamiliarity with the U.S. Army publication.

Prior to April 16, 1947 almost a hundred thousand tons of ammonium nitrate had passed through the port at Texas City for onward shipment to other countries. There had been no incidents in this time and so the assumption that it was not an explosive substance was reinforced. The nitrate was manufactured in ordnance plants where formerly it formed part of the ingredients for bombs. Small quantities of clay were added to each shipment to prevent caking, a problem that led to the disaster in Germany. Ammonium nitrate had the double advantage of being relatively inexpensive as ell as being richer in nitrogen than some other fertilizers. Following the end of World War II principal destinations for the fertilizer lay in Europe where the United States sought to expand food production and speed up recovery from the war. The freighter *Grandcamp* was to take its cargo to France.

More than 2,000 tons of ammonium nitrate had already been loaded on to the *Grandcamp* when a small fire was found in the hold, possibly due to a smoking cigarette stub. Smoking, while officially prohibited on the docks, was generally permitted at that time. Longshoremen who were working in the hold tried to put the fire out with fire extinguishers but failed. At that point the captain intervened. He felt that the use of water would damage other things in his cargo so, instead of dealing with the problem, he closed the hatches and ventilators and turned on the steam system in an attempt to smother the fire. It was the kind of move that almost certainly guaranteed an explosion. In addition, as a precautionary measure, he had cases of ammunition removed from a nearby hold. As the fire grew, the heat forced both longshoremen and crew to leave the ship. The ship's alarm was then switched on and contact established with the fire department onshore. Before any help could arrive, hatch covers were blown off by the pressure buildup, smoke and flames shot upward, and moments later the entire ship blew up in one gigantic explosion.

The shock wave alone, quite apart from the cluster of steel that accompanied it, did enormous damage. Two planes flying overhead were brought down. The intensity of the fire at this stage ensured that everyone still on board the ship or near it was vaporized. Flying objects killed hundreds in the immediate vicinity of the pier and lighter debris damaged buildings in the business district, a mile away. Some of the flying pieces from the *Grandcamp* weighted several tons. A fifteen-foot wave, a sort of tsunami swept up from the harbor by the explosion, picked up a large steel barge and carried it onshore. There were quantities of cotton and other textiles in the ship's cargo and these now became fireballs raining down on shore, triggering fires everywhere.

At Galveston, ten miles south of Texas City, people were thrown to the pavement by the force of the blast, and at some locations twice as far away buildings swayed. People rushed to the docks at Texas City to search for relatives and friends. Wounded ones were everywhere, covered in black oil, stunned into passivity by their ordeal. The city auditorium was transformed into a first-aid center to cope with the thousands of casualties. Doctors, nurses, and ambulances were brought in from neighboring communities. Law enforcement officers also had to be called into service from other places to help establish some sort of order. But just as things began to come together there was a second cataclysm.

Because of the general indifference to the dangers of ammonium nitrate, no one took much notice of the second freighter that also was being loaded with the same dangerous cargo and was now carrying a thousand tons of it. The *High Flier* had been torn away from its moorings by the force of *Grandcamp'* sexplosion and was stuck alongside other vessels. It had been severely damaged and before long the thick black fumes from the first explosion forced everyone to leave it and head for shore. Rescuers looking for survivors checked the *High Flier* in the course of their search and noticed a fire in one of the holds but there was so much anxiety over the first explosion that little thought was given to this.

Not until late on the evening of the sixteenth was any action taken to deal with the *High Flier*. At that time flames were shooting high into the

Figure 65 Rescue workers search for survivors at the Texas City Terminal building after the 1947 Texas City disaster.

air. Before anything could be done, either to move the ship out to sea or douse the fire, it blew up in a second blast just like the first one. Casualties were much lighter this time, not because the explosion was less powerful but rather because there had been a general evacuation from the port area. Additional damage was now done to buildings that were already partly destroyed with the first blast, additional oil tanks caught fire, and a shower of large pieces of steel, just as had happened in the earlier blast, caught everyone who still happened to be near the piers.

It took a lot of time to get federal and local authorities into action to ensure that a tragedy of this kind would never recur. Culpability was not acknowledged by anyone yet errors due to neglect were everywhere. The whole infrastructure of the port area was wrong. Large oil tanks and other highly inflammable products were stored close to the piers without regard to the conflagration that would erupt in the event that a ship caught fire. No procedures were in place to deal with emergencies. The disaster brought changes in some of the processes involved in chemical manufacturing and there were new regulations for the bagging, handling, and shipping of chemicals. Thousands of lawsuits were finally settled in 1956 with a total cost of more than sixteen million dollars. The bodies of the sixty-three unidentified dead were buried together in a memorial cemetery. A park beside this cemetery was dedicated to them forty years later.

Had there not been neglect of previous accidents with ammonium nitrate, together with indifference among the authorities at the Galveston Bay to warnings regarding the handling of this product, the whole tragedy of April 16, 1947, could have been prevented. Twenty-six years earlier, in the morning of September 21, 1921, in Oppau, Germany, a massive ammonium nitrate explosion occurred at a chemical plant. The factory that processed the chemical and the village of Oppau were totally destroyed. Casualties were many. The cause of the accident was ignorance about the explosive potential of ammonium nitrate. The Badische Anilin Company built a factory in Oppau in 1911 to produce, among other chemical products, agricultural fertilizers. Oppau was a small community of about 6,500 people not far from Mannheim. A new process had just been developed by German chemical engineers to produce these fertilizers from ammonium sulfate. The traditional natural supply from organic waste was in short supply so this was a timely substitute for Germany's agricultural industry. The country was prosperous with an expanding economy and needed a stronger agricultural base.

Since farmers use fertilizers almost entirely in spring the factory had to stockpile large quantities through the year in preparation for sales at the beginning of the following year. A large number of sixty-foot silos were built to store the ammonium sulfate. These were still in place ten years later as Germany tried to cope with the four-year devastation of World War I from 1914 to 1918. The country was impoverished with its currency so low in value that little could be purchased beyond its own borders. Raw sulfur could not be purchased from abroad so the factory shifted its fertilizer production to ammonium nitrate, an acceptable substitute.

The new chemical was stored in the same sixty-foot silos that had been in use previously. Because there was no great outcry regarding the dangers associated with the new chemical, the same procedures that were in place for handling ammonium sulfate remained unchanged. There was, in fact, a widespread assumption that ammonium nitrate was non-explosive. To some extent this was true. Ammonium nitrate requires high pressure or very high temperatures before this chemical will cause an explosion. In the Oklahoma City bombing of 1995, Timothy McVeigh needed starter explosions in order to make the ammonium nitrate explode.

Ammonium nitrate has a particular quality that workers in Oppau did not have to contend with before, namely its tendency to attract moisture from the atmosphere and become sticky. In the course of a year this can compress into a solid mass almost like concrete. In the context of sixty-foot-high silos additional pressure was applied to the nitrate. After many failed attempts to loosen the ammonium nitrate with picks and shovels the Oppau workers decided to use low-grade dynamite. They bored holes, set the dynamite, and blasted some of the very hard material into smaller pieces. This level of explosives was quite permissible for breaking up solid substances. It was a risky business and it would never have been employed if workers knew the properties of the new substance they were now handling. For a short time it worked and nothing went wrong.

On the morning of September 21, the method failed. Instead of the previous effects there was one large blast, followed a short time later, as other containers were heated and ignited, by a gigantic explosion. A column of fire shot upward into the air for a thousand feet and everywhere around there was total destruction. An eight-foot-deep hole, a third of a mile in diameter, was carved out beneath the factory. Much of the depression formed at that time can still be seen today. The entire town of Oppau disappeared. The blast was so strong that it shattered windows forty miles away. More than five hundred people were killed and 1,500 additional people injured.

Workers lived in three and four story apartments within walking distance of the factory so they and their families had no chance of avoiding the blast. Like many industrial communities of that time, a hard lesson was learned, namely that residential buildings must never be built close to factories. In many developing countries today this rule is ignored because it is cheaper to live close to work. In the Bhopal tragedy in India in 1984, thousands might have been saved had thus rule been followed. In spite of a local law that forbade it, workers persisted in living close to the factory.

In Oppau, the explosion was made worse by an absence of any medical facilities. The community had neither a hospital nor doctors so all the injured had to be taken to Mannheim. Because of the widespread damage and large numbers of casualties there were numerous delays. The roofs of buildings in Oppau were made of heavy clay tiles that lay on support beams that were not fixed to anything. As a result, these tiles became flying missiles, adding to the horrors of the time.

A great deal of suspicion accompanied the explosion and it took a long time for newspapers to get accurate information. For one thing, it was well known that the factory had been a producer of munitions and people thought that the explosion was the result of experiments with new explosives. It was also known that just before World War I this place had been manufacturing the poison gas that was used in the course of the war. This unsavory reputation may have isolated the community and hindered them from knowing more about the dangers of ammonium nitrate.

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Puget Sound, Washington, earthquake

April 13, 1949

Puget experienced its largest earthquake since 1700

An eighty-mile coastal strip from Seattle to Chehalis was severely damaged

On April 13, 1949, a 7.1 magnitude earthquake occurred in western Washington. Its epicenter was close to the coast between Olympia and Tacoma and it was felt strongly in Washington, Oregon, Idaho, and British Columbia. It was the largest earthquake in Puget Sound since 1700. Eight people were killed and dozens received serious injuries. Greatest damage was experienced along an eighty-mile coastal area from Seattle to Chehalis. Approximately 40 percent of Chehalis' business buildings and houses were damaged and more than 10,000 chimneys in Washington required repair. The value of the damage caused was $25 million.

Eight buildings at the state capital in Olympia were damaged. A large sandy spit jutting into Puget Sound north of Olympia disappeared. In Portland, the earthquake caused rockslides and cracks to buildings. Earthquake damage in Seattle included the quake's strongest ground shaking. Damage was considerable to well-built structures and extensive to poorly built ones. Some buildings collapsed. Chimneys, factory stacks, columns, and monuments fell. Heavy furniture overturned and people had difficulty driving. Three schools received major damage and were ultimately condemned. At Lafayette Elementary School in West Seattle, the large brick gable over the main entrance collapsed. Three bridges crossing the Duwamish River were jammed shut due to shifting earth. Cracks opened in the earth near Green Lake. Numerous brick walls throughout the city collapsed, fractured, or bulged. They were all condemned.

Many houses in Seattle that were built on filled areas were demolished and, in some places, the ground turned to quicksand causing floors to crack and basements to fill with silt. Cracks opened in the ground, some spouting water six feet high. Seattle gas lines broke in one hundred places but fortunately no fires occurred. This has been a common problem in coastal cities on U.S. coasts. The experience of San Francisco both in 1906 and in subsequent earthquakes is a classic illustration of the problem. Cities extend their footprint by reclaiming land from the sea. Rarely are the new foundations designed for the support of new buildings. Thus, when an earthquake strikes, liquefaction takes place as a result of the shaking and the former surface beneath buildings becomes a muddy mass unable to sustain any weight. Farther south of Seattle, near Tacoma, a two hundred-foot-high cliff collapsed into Puget Sound. In the same area several railway bridges were thrown out of alignment.

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Queen Charlotte Islands, Canada, earthquake

August 22, 1949

Canada's largest earthquake in three hundred years struck the coast of British Columbia

This earthquake occurred on the boundary between the Pacific and North American tectonic plates at the Queen Charlotte Fault. Its magnitude was 8.1

Canada's largest earthquake of the past three hundred years, magnitude 8.1, occurred on August 22, 1949 off the coast of British Columbia on the Queen Charlotte Fault, the boundary between the Pacific and North American plates that runs underwater along the west coast of the Queen Charlotte Islands. The shaking was so severe that cows on the Queen Charlotte Islands were knocked off their feet. A geologist working on the north end of Graham Island, the biggest island of the Queen Charlottes, could not stand up. Chimneys toppled, and an oil tank at an inlet collapsed. In Terrace, on the adjacent mainland, cars were bounced around. In Prince Rupert windows were shattered and buildings swayed. The earthquake was felt at Jasper, over six hundred miles away.

The fault rupture began in the ocean bottom offshore from Graham Island and spread for more than three hundred miles along the Queen Charlotte Fault. This fault extends from Vancouver Island to the Gulf of Alaska. It is a strike slip fault, similar to the San Andreas of California, and capable of generating equally large earthquakes. However, the Queen Charlotte Fault is offshore, whereas the San Andreas bisects major cities. The Queen Charlottes are sparsely populated. There were no deaths from this earthquake but there were landslides and other damage. The offshore region of

British Columbia is one of the highly active seismic regions of the world. In addition to the 1949 giant earthquake, there have been ten large earthquakes since 1872 with magnitudes between 6.7 and 7.9, all potentially very destructive. Fortunately, most of them occurred offshore or in remote regions so there were few deaths and only moderate damage.

The Juan de Fuca Plate is a completely different geological structure that separates the Queen Charlotte Fault from the San Andreas Fault. This plate extends from central Vancouver Island to southern Oregon. The Juan de Fuca Plate is a large part of the Pacific Ocean seabed which is slowly moving, driven by tectonic forces deep within the earth, and pushing under the coast of Oregon, Washington, and British Columbia. Movement of the Juan de Fuca Plate is thought to have caused a super giant earthquake on January 26 in the year 1700. Canadian, Japanese, and American scientists have found evidence in Indian legends, sea bottom sediment, and accounts of Japanese tsunamis that an earthquake occurred off western Vancouver Island with magnitude 9 or greater. Large sections of coast were drowned, Indian villages were lost, and a great sea wave or tsunami was observed hours later in Japan. Geological evidence shows that large earthquakes have in fact occurred repeatedly on the west coast in the past. Current observations of seismic activity and uplift of the coastal regions suggests that another super giant earthquake may be in the making.

The Queen Charlotte Fault, off western Canada and southeast Alaska, is a boundary between the Pacific and North American plates. Prior to the mid 1980s, very little was known about the detailed distribution of earthquakes in this area as there was no local seismograph network to detect and locate small earthquakes. Between 1982 and 1987, a network of twelve short period analogue seismographs was established on the Queen Charlotte Islands and the adjacent mainland; this network continued to operate until early 1996. Analysis of earthquakes observed on these seismographs has revealed a more extensive earthquake pattern than that associated directly with the Queen Charlotte Fault. In particular, considerable seismicity occurs east of the fault, on Graham Island and in Hecate Strait, the ocean region between Graham Island and the Mainland of British Columbia.

Tectonically, both the Queen Charlotte region and California are dominated by a transform plate boundary between the Pacific and North American plates. In California the plates are moving at a relative rate of twenty-five miles per million years, mainly related to the San Andreas Fault. Off British Columbia's coast the rate is thirty miles per million years, almost entirely carried by the Queen Charlotte Fault. Geometry of the plate boundary in California has changed dramatically as two triple junctions migrated along the coast; the main transform fault has progressively moved inland over the years. The geometry of the Queen Charlotte Fault seems to have been fairly stable over tens of millions of years; triple junction complications have mostly been accommodated in oceanic crust to the south.

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Assam, India, earthquake

August 15, 1950

Assam, India, experienced a gigantic quake of magnitude 8.6

The quake's epicenter was in China but almost all the damage and death toll occurred in the valley of the Brahmaputra River

The Assam earthquake of August 15, 1950, magnitude 8.6, was centered at Rima in China, but it was the Brahmaputra valley in Assam that the most extensive damage was experienced. Accordingly, it was named the Assam earthquake. Two thousand homes, temples and mosques were destroyed there and over 1,500 people killed. Many rock falls and destruction of forests were reported in the Mishmi hills north of Assam. As a result, many of the tributaries of the Brahmaputra were blocked. When some of these opened after a week they created a wall of water, thirty feet high, that destroyed several villages. This earthquake was even more powerful than the Assam earthquake of 1897 but, despite its significance for Assam, it was not an Indian earthquake.

The great Assam earthquake of June 12, 1897, magnitude 8.3, is the largest known Indian intraplate earthquake of the last two centuries. It raised the northern edge of the Shillong Plateau by more than thirty feet, resulting in the destruction of structures over much of the plateau and surrounding areas, and causing widespread liquefaction and flooding in the valley of the Brahmaputra River. Due to the powerful shaking that this 1950 earthquake caused, the rivers brought down sand, mud, trees, and all kinds of debris. Pilots flying over the area reported great changes in topography. Huge landslides had occurred and, as they were photographed and compared with existing images, it was seen that the overall topography had changed, to the extent that the view from the air was no longer the same as it had been before 1950.

The only available on-the-spot account of earth movements came from a botanical explorer who was at Rima. However, he had little opportunity for observing more than the violent shaking and the rise in level of the streams because his attention was devoted to how he could escape from the area and get back to India. Aftershocks from the 1950 earthquake were numerous. Many of them were more than magnitude 6 and well enough recorded at distant stations for locating the epicenter. From such data, the Indian seismological service established an enormous geographical spread for the impact of this earthquake, from about ninety degrees to ninety-seven degrees east longitude, with the epicenter near the eastern margin. One of the aftershocks, a few days later, was felt more extensively in Assam than the main shock, leading certain journalists to the conclusion that the aftershock was bigger than the main one and must therefore be the greatest earthquake of all time!

Assam, from the beginnings of British occupation of India, has always been a fertile agricultural area. It lies in the valley and flood plain of the huge Brahmaputra River and is thus an enormous relatively flat region, facilitating intensive settlement. It receives the highest amounts of rainfall of any part of India and this factor, combined with its warm climate, a function of latitude, has attracted more and more people as infrastructures of roads and railways made it accessible. Gauhati is a large city near the Brahmaputra River. Over the past few years it has had to face the challenge of invading elephants. There are about 5,000 of these huge animals in the Assam Region and the encroachment on their natural habitat by more and more farmers, involving removal of forest, coupled with the destruction caused by natural disasters, forced the elephants to raid human areas for food for the first time. In the year 2006 as many as fourteen people were killed by these elephants when they invaded Gauhati.

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Kern County, California, earthquake

July 21, 1952
The largest Californian earthquake since 1906 struck Kern County in 1952

The epicenter was located about twenty-three miles south of Bakersfield

An earthquake of magnitude 7.3 shook an area in Kern County, twenty-three miles south of Bakersfield, on July 21, 1952. It was the largest in the conterminous United States since the San Francisco event of 1906 and the largest in southern California since Fort Tejon in 1857 and Owens Valley in 1872. It claimed twelve lives and caused property damage worth $60 million. Near the epicenter, on the Southern Pacific Railroad, the earthquake cracked reinforced-concrete tunnels with walls that were eighteen inches thick and shortened the distance between portals of two tunnels by ten feet, bending the rails in the process into S-shaped curves. At Owens Lake, more than one hundred miles from the epicenter, a pipeline was broken and salt beds were shifted by the quake.

The earthquake occurred on the White Wolf Fault near the intersection of the Garlock and San Andreas faults. The area shaken was impressively large. It was felt in Reno, Nevada, and in Las Vegas it required the assistance of a construction crew to realign steel structures. Shaking was experienced in San Francisco in the upper floors of high rise buildings and, in Los Angeles, there were power outages. Many surface ruptures occurred along the slopes of Bear Mountain and, in the surrounding valley areas where the alluvium was poorly consolidated, there were numerous cracked and re-contoured surface breaks. To the southwest of Arvin, in the San Joaquin Valley, the concrete foundation of one house was split, causing partial collapse of the structure. To the east of the epicenter there were numerous evidences of the event: a surface rupture four feet wide and two feet deep, fill areas along Highway 466 lowered by as much as one foot in one location and raised by two feet vertically while moved sideways by eighteen inches in another location, and a large part of the same highway cracked and wrinkled.

Property damage was heavy in Tehachapi. Both brick and adobe buildings were damaged with the adobe structures suffering the most. Nine of the twelve casualties occurred here. Only a few wood-frame homes were destroyed, far fewer than was experienced in earlier earthquakes in similar locations. Bakersfield experienced relatively moderate damage. A few walls were knocked down and there were cracks in many brick buildings. High rise steel and concrete buildings had their ground floors damaged and Kern General Hospital was heavily damaged. The main shock was felt over most of California as well as in Phoenix. The California Institute of Technology at Pasadena recorded six aftershocks on July 21 and later of magnitude 4 and slightly higher, some of which sufficiently affected buildings in Kern County that they had to be taken down. Reports of long-period wave effects from the earthquake were widespread. Water splashed from swimming pools in Los Angeles, water damage to tall buildings there was nonstructural but extensive, and water that splashed from pressure tanks on tops of buildings in San Francisco did minor damage. At least one building was damaged in San Diego.

This earthquake on the White Wolf Fault in Kern County was a major surprise to geologists and seismologists. It had never been previously con-

Figure 66 Collapsed school in Kern County, California, earthquake, 1952. The Cummings Valley School completely collapsed. The school building was reportedly constructed in 1910 of concrete walls and a wood roof. The building was a total loss.

Figure 67 Earthquake damage along the Southern Pacific Railroad near Bealville. Sharp bend in the tracks south of Tunnel 3 strikingly demonstrates that the ground had been shortened in this area. A landslide blocks the east portion of the tunnel.

sidered as an earthquake risk and, when it did rupture, its size seemed disproportionate to its length. White Wolf is only thirty-four miles in length, much too short in the mind of geologists to produce a major earthquake. By comparison the San Andreas Fault is about 250 miles in length. The amount of displacement at the surface was also small in relation to the amount of energy released. The conclusions that geologists and seismologists arrived at all related to the underground characteristics of the fault. It may be that much of the fault is buried so that there is no surface trace. If it were a deep rupture on a nonvertical fault, that could explain the quake's large size. A shorter but deeper rupture on a fault with a significant dip would release as much energy as a lengthier, shallow rupture on a vertical fault, since it is the rupture area, not merely the length, that determines the energy released in an earthquake.

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Kamchatka, Russia, earthquake

November 4, 1952

Kamchatka experienced yet another very powerful earthquake

Kamchatka, Russia, frequently experiences subduction earthquakes of the most powerful kind. This one had a magnitude of 9.0 and it caused tsunamis that reached and damaged Hawaii and locations on the west coasts of North and South America

An earthquake of magnitude 9.0 hit the coast of Kamchatka along a 350-mile subduction zone fracture, on November 4, 1952. The epicenter was twenty-five miles beneath sea level. Within fifteen minutes of seismic recognition of the earthquake, the Tsunami Warning System (TWS) that had been set up four years earlier in Hawaii began to follow the path of the expected tsunami. Years of experience told authorities that an earthquake of magnitude 9 or even magnitude 7 in Kamchatka would give rise to destructive tsunamis. TWS had been set up after the devastation inflicted on Hawaii from the Alaska tsunamis that were triggered by the Unimak Earthquake of 1946. It was estimated that the first tsunami waves from Kamchatka's 1952 event would arrive about seven hours after the quake and they did arrive with very destructive force.

The warnings that were periodically issued served to alert people to the dangers. The waves beached boats, caused houses to collide, destroyed piers, scoured beaches, and broke up road pavements. A farmer on Oahu reported that six of his cows were killed. In Honolulu harbor, waves tore a cement barge from its moorings and hurled it against the freighter Hawaiian Packer. At Pearl Harbor, Oahu, the tsunami was evidenced by the periodic rise and fall of the water, but no damage was done. A boathouse worth $13,000 was demolished in Hilo where the highest wave levels were seen, twelve feet above normal sea level. Property damage from these waves amounted to one million dollars. Fortunately, no lives were lost but it seems that TWS failed to alert people to the nature of tsunami waves, especially their number. In Honolulu sightseers ran toward the beach at the second wave instead of running away from it, apparently unaware of the great potential danger from subsequent waves.

At the source of the 1952 earthquake severe damage was caused to Kamchatka Peninsula with waves reaching heights of from 50 to one hundred feet. A settlement on the Kuril Islands just south of the epicenter experienced tsunami waves sixty-five feet above sea level. The settlement was completely destroyed. The height of the waves and amount of destruction in Alaska were surprisingly, small. However, on Midway Island, as the tsunami moved toward the Hawaiian chain, six-foot and nine-foot waves flooded the island, lifted buildings, washed debris and barges ashore, and deposited quantities of sand on an airfield. Tidal gauges all along the west coast of the United States registered higher water levels, all of them five inches or less in height. The west coast of South America experienced much higher water levels than on the west coast of the United States and was damaged significantly. In Peru, several houses were

Figure 68 Tsunami generated by earthquake of November 4, 1952, Kamchatka Peninsula, (former) Soviet Union. Flooded street resulting from the tsunami on Midway Island. The tsunami was generated by a magnitude 9.0 (Mw) earthquake on Kamchatka where it caused severe damage. The tsunami then struck Midway (1,800 miles away), the Hawaiian Islands (3,120 miles away), and other areas in the Pacific. Midway reportedly was covered with one meter of water.

washed away and a four hundred-foot section of a pier destroyed. In Chile, at Coquimbo, five hundred feet of railway track and a customs house were flooded.

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London, England, suffocating smog

December 5, 1952

London's smog closed down the entire city for four days

London's nine million residents were almost totally immobilized for four days as a thick smog smothered the city and killed 4,000 people

From the fifth to the ninth of December 1952, a mass of dry, cold air settled over London, strong enough to prevent any upward movement of the air on the ground. Above this strong layer of very cold air there was a layer of warm air, the opposite of what one would expect. This is often referred to as a temperature inversion. In this situation pollutants get trapped at ground level and, since there was no wind on this occasion, pollutants stayed within the areas of highest population densities. The air became a blinding, suffocating cloud of gas, creating the worst fog in living memory. Breathing passages were clogged and eyes hurt. Within a few hours people were breathing foul and very dangerous gases. Before cleaner air returned a few days later, 4,000 people had died and many thousands more were seriously ill.

London's history of fogs is well known. Novelists often refer to it and many of them conjure up pictures of a dark, damp, foggy atmosphere to enrich their stories, especially if they are murder mystery ones. The tons of sulfur dioxide and other pollutants that come from coal-burning fires and furnaces are the causes of this unhealthy atmosphere. Smog might be a better word than fog to describe what actually occurs. Locally, the preferred word is pea soup. From the earliest days of the industrial revolution coal was the choice of almost everyone for heating and cooking so, over

Figure 69 Smog along the Strand, London, which almost completely obscures the midday sun.

the past two centuries, huge population centers like London had a growing problem that came from coal fumes. Long before 1952 there were complaints that the outsides of heritage buildings were decaying from coal smoke. By the middle of the nineteenth century the problem was acute. Novelists made reference to London's half million coal fires mingling with the surrounding air, being modified by inadequate drainage, and causing a black unhealthy atmosphere.

It is hard to imagine a metropolitan area of nine million people coming to a complete standstill, but that is exactly what happened. Every aspect of city life was crippled and, perhaps for the first time, most of its residents discovered how interconnected and interdependent all the parts really were. Fortunately, the paralysis lasted no more than four days yet in that time some 4,000 people lost their lives and as many more died later as a result of what they had breathed. Many thousands of others were seriously ill. Of those who died, 90 percent were over forty-five years of age. Try to imagine what life would be like in London during those days of December

1952 and compare your list with the reality that is recorded in the next few paragraphs.

All transportation except the underground railway system was stopped. Even the underground trains had trouble when they emerged above ground for part of the way. In streets everywhere visibility dropped to a point where nothing could be seen beyond a couple of feet. Drivers who tried to move were confronted with barricades of abandoned cars. One ambulance attendant walked twenty-five miles holding an open-flame torch to guide his driver. Heathrow airport was closed and planes told to use Bournemouth, a seaside town 150 miles southwest of London. Ships unloading food and other essentials had to stop their work because of fears that people as well as goods might fall into the water and no one would know.

Polluted air poured through windows and under doorways. The city became a place of lost and troubled people. Fleets of ambulances were called in from surrounding communities to help with the masses of people of all ages who just could not cope with the attacks on their lungs. They were of little use because visibility made it almost impossible for them to get to where they were needed. Doctors were unable to reach hospitals or individuals at home and resorted to telephone calling to diagnose as well as recommend treatment. Fires broke out but nothing could be done. In one location the fire station was only four hundred yards away from a building that caught fire yet could not get to it. The building was totally destroyed.

Pregnant women were unable to reach their hospitals and had to deliver babies in all kinds of places. Weddings had to be cancelled or else rushed through, if the parties managed to reach the church or registry office, in order to give place to the next latecomer. Electric power was cut off for large sections of the city when staff failed to turn up for duty at the control stations. The story was similar at the main studios of the British Broadcasting Corporation. Both radio and television programs were curtailed. At a cattle auction animals were dying as they inhaled the poisonous fumes. Some were saved by an enterprising worker who covered the animals' noses with cloths that were moistened with whisky.

For the fearless that decided to attend theaters the usual tactic was to form a crocodile that is a line of people with each holding on to the next ahead as they tried to find their destination. If they succeeded they had to sit near the front. The movie was barely visible from the back seats. On one of the four evenings of the disaster, the opera La Traviata was cancelled after the first act because of the intensity of the fog. Birds crashed into buildings or plummeted on to streets. Two of the very few positive outcomes were the increases in business by dry cleaners and beauty shops. If a person went outside for an hour, clothing and hair were soon covered with a black unpleasant coating. Saddest aspect of all, though predictable, was the crime rate. It rose very high because police were powerless to do anything about it.

Air pollution is a major global problem. An Indonesian smog cloud of

1997 was not as destructive as the London one but its effects were similar. Many of the causes of global warming stem from similar climatic conditions and human behaviors as appeared in London. In 1997 Indonesia recorded the destruction of more than seventeen thousand square miles of forest land on the islands of Borneo and Sumatra. Emissions from these fires caused air pollution problems through all the countries of Southeast Asia, especially Singapore, Indonesia, and Malaysia. A glance at a map will show why these countries were the worst affected. They are the closest to the sources of pollution. Tiny pieces of the carbon remnants from the fires proved to be the most damaging pollutants. They caused acute respiratory diseases such as bronchitis and asthma and often caused death. Secondary effects of this kind of solid matter in the air were poor visibility and disruption of transportation systems. Flights were delayed and transportation on land and sea was slowed down. Construction work was stopped for fear of damaging the health of workers. Tourists stayed away.

The fires were the result of bush clearances. These were carried out by companies that wanted to make way for the development of new palm oil plantations. The first of these practices, often known as slash and burn, is widely condemned by environmentalists all over the world. It is an ancient mode of agriculture, once acceptable in remote areas of jungle among small groups of people, but too destructive when conducted on a large scale. Plantation planning is on a much bigger scale and affects greater areas of land. About a tenth of the world's supply of tropical rainforests is in Indonesia and these are the forests that are exceptionally rich in biodiversity. For this reason alone, these forests of Indonesia are a valuable area that needs to be preserved for the sake of humanity as a whole. One problem in trying to take action is that our knowledge of the resources of this country is not accurate. It is not known for instance how much of forest is being cut down each year. Some estimates go as high as two million acres.

Satellite imagery from the National Aeronautics and Space Administration (NASA) identified a smoke haze extending over more than a million square miles from Indonesia to Thailand in 1997. NASA also noted that the level of pollution was far above normal air quality standards for that region and was, in fact, thirty times higher in places close to the fires. Visibility in the islands where burning was taking place dropped to half a mile and at times to less than three hundred feet. The urban centers of Southeast Asia are already overcrowded and their services are inadequate to cope with the steady influx from rural areas. Air quality is always poor so any sudden increase like the 1997 one raises pollution to dangerous levels. In Singapore, all though the latter part of 1997, there was a 30 percent increase in hospital attendance regarding illnesses related to the haze. Estimated damages for the smog cloud of 1997 were one billion dollars in Indonesia alone. For Malaysia and Singapore combined it was half a billion dollars and for the whole of the ASEAN Region about four and a half billion dollars.

Air pollution is the source of environmental damage to forests, soils, air, and acid-sensitive aquatic organisms. All these impacts add significant economic costs. As this becomes widely known, pollution abatement policies are given higher priority. Direct regulation, the one used in Britain in the wake of the 1952 disaster, is one way of responding. Taxation and private litigation are other approaches. Contamination of the atmosphere is a long-standing side effect of industrialization. The severity of the problem and the public awareness of it, however, are relatively new. As industry expanded rapidly throughout the world after World War II, pollution followed. London's deadly fog, while rare even in England, has served to highlight the global challenge. In the capitals of the two biggest countries of the world in terms of population, Delhi in India and Beijing in China, conditions approximating those of London are common. Sources of the problem in these cities are the same as London's, burning of fossil fuels.

From time to time across the United States, there are problems of air pollution that endanger health. In Donora, Pennsylvania, in 1948, a temperature inversion occurred, very similar to London's. Donora was the site of a steel mill and other industrial plants and normally the smoke and fumes from them posed little danger to health. This time, because of a mass of cold air, pollutants were concentrated in one area for three days. Twenty people died and thousands became ill. In the summer of 1955, Los Angeles experienced a week of temperatures that stayed above one hundred degrees and led to a smog emergency. A deadly dark haze filled the air as the sun's rays interacted with the exhaust fumes of cars. Large numbers of people complained of painful eyes and difficulty with breathing. Los Angeles has been aware for a long time of this kind of eventuality because of its climate and its extensive use of cars. Years ago it mandated low emissions for all cars and this has helped reduce the frequency of serious smog emergencies.

The end of London's tragedy arrived three days after it began. Stagnant air gave way to winds and the smog began to lift. An investigation was launched into the cause of the disaster. Within the millions of tons of sulphur were huge volumes of sulphuric acid and it is this that caused the greatest damage. It combined with metal, stones, and clothing to weaken and destroy them. As a result of this disaster, the Clean Air Act of 1956 was introduced. Stricter regulations were placed on coal-burning furnaces and anti-pollution laws were strongly enforced, but it took time for change to occur. Six years after the passing of the act a smog attack killed sixty people within three days. A newspaper reported that, on that day, smoke levels were 10 percent above normal and sulfur dioxide fourteen times higher. Gradually the switch to low-sulfur fuels like natural gas changed the city's air. London's pea soups now belong to history. Coal is no longer in widespread use. Where it is still used in electricity-generating stations there are scrubbers in place to minimize the amounts of pollutants released into the atmosphere.

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Netherlands (Holland) flood

January 31, 1953

A large part of the nation of Netherlands was overwhelmed by a North Sea flood

A combination of high tide and severe wind storm raised the level of the North Sea sixteen feet above normal, sufficient to overwhelm the nation's protective dikes and flood large areas

A combination of a high spring tide and a severe windstorm combined to create a major natural disaster along the coastlines of Netherlands and England on the night of January 31, 1953. Belgium, Denmark, and France were also affected by what happened. The water level on the coast of Netherlands rose sixteen feet above normal so that the dikes were overwhelmed and extensive flooding followed. The vast majority of all the damage that was inflicted on the countries bordering the North Sea occurred in one country, Netherlands. There, over 1,800 were drowned, 72,000 displaced, and 47,000 homes either destroyed or seriously damaged. About 800,000 acres of rich farmland were submerged for days in salt water and farmers lost 250,000 of their cattle, hogs, and poultry.

The people of Netherlands, or Holland as it is more generally known, had been warned of the poor condition of many of the dikes in reports dating back to 1928 and 1934 but little action was taken because the costs of improvements were considered prohibitive. It is easy today to make a comparison with New Orleans where the poor conditions of the foundations on which its protective levees were built caused the disaster of 2005. New Orleans is a city just like the whole country of Holland in the sense that almost all of it is close to sea level. Like the leaders of Holland, the authorities responsible for the protection of New Orleans decided it was too costly to rebuild the city's levees. After the disaster, just as the people of Holland found out, they discovered it would have been far less costly to rebuild the levees before Hurricane Katrina struck than face the enormous costs they incurred in late 2005 and in 2006.

Beginning in the nineteenth century, Dutch engineers launched a plan for constructing a series of polders, a name given to land reclaimed from fresh or salt water. Today there are three thousand polders. Dikes were built around the areas reclaimed from the sea and, because some water always seeps into the protected areas behind the dikes, there is a constant need to pump out excess water. In earlier times, this was accomplished by using windmills and later on by employing steam and electric pumps. Traditionally, the reclaimed land was used for agriculture but, with the growing population of the country, by about the middle of the twentieth century, Holland began to build cities on them. This practice has continued ever since. These developments mean that more and more people have become exposed to the dangers of flooding so the need to maintain their dikes increases year by year. This is why, periodically, as happened in 1928 and 1934, the condition of the dikes is examined in detail. As has already been noted, not all the recommendations of these reports are attended to because of the costs involved.

The outstanding example of land reclamation in Holland was the closure of the Zuider Zee in the 1930s, involving the construction of a twenty-mile dike that would cut off an area of ocean measuring twelve miles by thirty-five miles in extent and create from it in due course an inland sea. Four polders were drained once the ocean had been completely cut off and Holland had added to its territory more than 400,000 acres of land, most of them subsequently used for agriculture. The main reasons for extraordinary efforts like these lie in the limited amount of land available nationally and the rapid growth of population over the past hundred years. Netherlands presently has a population of more than sixteen million. In 1900 there were five million people. The total area of the country is a little more than 20,000 square miles and much of this consists of rivers, canals, and lakes. Even with the additional land reclaimed from the sea Holland ends up with a population density that is one of the highest in the world. With more than 25 percent of the land area of the country being below sea level a very effective system of water control is needed to keep the land dry and habitable. Modern pumping stations work day and night to make sure that these conditions are maintained.

In the 1934 report it was pointed out, as one example, that the large city of Dordrecht at the estuary of the Rhine, had inadequate protection from flooding. Almost every dike was too low. Something had to be done about them. In response to the 1934 recommendation it was proposed, as a cost-saving measure, that walls of a few inches high be added to existing dikes so this measure was implemented on seventy-five miles of the dikes that protected Dordrecht. In 1943, water levels overtopped these dikes and Dordrecht as well as its surrounding lands was flooded. From the outbreak of World War II to 1945 there was nothing that could be done about the condition of the dikes. The country was under foreign occupation. During this time Zeeland suffered a tremendous amount of damage. Some of the dikes were bombed by British and American forces as part of their attack on the German occupying forces and the land was flooded. Repairs started in March 1945 when the country was free and in February 1946 all the gaps were filled in. These unforeseen repairs also helped distract the attention away from raising the dikes.

It is easy to understand why people were not too interested in spending money on improving the dikes. There had not been a flood in many years and the best immediate return on investments for Holland, an impoverished country in 1945, was the agricultural sector. The land had been contaminated by salt for several years following the wartime bombing with the result that crop yields were very low. Whatever money was available for investment was therefore spent on agriculture. In addition, the damages from the war demanded attention. For a few years everything seemed to be going well even though the dikes had not yet received the attention that had been demanded for them. On January 31, 1953, however, an unusual and unexpected set of circumstances profoundly changed everything for the citizens of Holland. A mid-latitude storm of great strength had moved south from Iceland on the previous day, then along the east coasts of Scotland and England with a breadth of coverage that included the whole of the North Sea. This storm reached Holland as the local tide was at its peak. The combination of the two events raised the ocean water level sixteen feet above normal, overtopping the dikes and, with the weight of the water being thrown against the dikes, forcing them to collapse.

The dikes had not been designed to withstand such height and pressure from water and by 3 A.M. on January 31 the first of the dikes was broken. The next to fall was not what was expected. In the design of the system of polders there are several lines of dikes extending landward from the sea. The first line is made strongest because it has to withstand the first and biggest blow from the sea. The others are progressively less massively built because it is assumed that the water reaching them will have less momentum than it had when closer to the sea. What happened on January 31 was not typical, and certainly not the conditions for which Dutch engineers had planned. The sixteen-foot wave of water than overtopped the first one or two lines of dikes was so powerful that it hollowed out the foundations of the weaker dikes farther inland so that they collapsed. It was almost an exact repeat of the way the levees collapsed in New Orleans. Thus, from an early stage of the tragedy, the cities and farms that should have suffered last became the earliest victims. They had no time to escape inland and large numbers of them lost their lives. Before the end of the day and long before anyone could put corrective measure in place eighty-nine dikes had been broken through.

Many woke up in the middle of the night as the water reached them.

They quickly found themselves isolated, shut inside their homes. Many homes collapsed and a few managed to hold on to floating debris until they were rescued. Most were drowned. Where homes remained in place, people climbed on to the roofs, hoping that they could stay above the final water level. All telephone and radio communications were cut off. By the morning of February 1 the tide had receded and the water level dropped. There were individual rescue operations taking place. Villagers in boats looked for victims and brought them to higher land. The severity of the tragedy was still unknown to outside places because of the total breakdown of communications. Conditions worsened when a second flood occurred in the afternoon of February 1. This flood cost even more lives. Because the dikes had already been breached, the water flowed into the polders with ease. Many houses that survived the first flood collapsed during the second. For many people the help came too late.

On February 1, the dikes that protected areas of north and south Holland showed signs of giving way and there was widespread fear that three million people might be a risk. One section that had not been reinforced with a stone layer began to break and, despite attempts by volunteers to repair it, it gave way, leaving a huge gap into which water rushed. The mayor of Nieuwerkerk took action immediately. He ordered a ship that was nearby to sail into the gap in the dike and this plugged the gap, providing enough time for supplementary work to be done. Such has always been the story of Holland. Every child in that country knows about the boy, whether apocryphal or not, who put his finger and then his hand in a dike to prevent a leak developing into a flood. By February 2, large-scale relief was slowly getting under way and the severity of the situation better understood. Helicopters flew over the disaster-hit area and started to drop supplies and sand bags. Aid from abroad was also offered. Belgium, England, the United States, Canada, Denmark, and France sent materials and soldiers. February 3 saw the end of the crisis as far as water levels and storm activity were involved. In some places people were still stuck but evacuations had begun and it was possible to start inspecting the damage and begin restoring the dikes.

After the disaster a new and comprehensive plan was initiated to protect the areas of high-density population around the Rhine estuary. A network of barrier dams would be built to seal off most of the large sea inlets. By so doing the exposed coastline of the country was reduced in length by more than four hundred miles. The construction work on this new and very big project began in 1958 and the last part of it was finished in 1986. It remains to add to the tragedy of Holland that other coasts than those of Holland were affected by this flood, albeit to a much less extent. Before the surge of water reached Netherlands it had already caused devastation in the United Kingdom. Along its coastline more then a thousand miles of coastline and seawalls were damaged. At many places they breached, inundating as much as five hundred square miles of land. More then 24,000 properties were seriously damaged and over 30,000 people were forced to evacuate. At Felixstowe in Suffolk many people were killed when their homes were destroyed by water. Thirty-eight people lost their lives in that community. In Essex the damage was even bigger. Canvey Island was completely inundated. Over fifty-eight lives were lost. The Seafront village of Jaywick near Clacton lost thirty-seven inhabitants when it was flooded.

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Waco, Texas, tornado

May 11, 1953
The deadliest two tornadoes to hit Texas
were Waco and Goliad

The high death toll, 114, and the other high costs were partly due to the rarity of powerful tornadoes in the Waco area of Texas, and a lack of readiness for the unexpected

According to local folklore, tornadoes could not touch down in Waco. Most storms in the area, it was said, travel from west to east and split around the Waco area, making tornadoes and extreme weather rare. All of that thinking changed when the F5 Waco tornado hit the city on May 11, 1953, with circulating winds of more than three hundred mph; 114 people lost their lives, 597 were injured, and damage to property added up to $50 million. Over half of the deaths occurred in a single city block bounded by 4th and 5th streets and Austin and Franklin avenues.

In the afternoon of May 11, the tornado formed three miles north of Lorena and leveled a home there. It moved up the I-35 corridor and at 4:30 P.M. entered the city limits of Waco from the southwest traveling at a rate of 30 mph. The funnel cloud was two blocks wide and it made a direct hit on the downtown area of the city. Because it was daytime there was some advance warning. Many people crowded into local business offices and stores for shelter but few of the buildings were constructed sturdily enough to withstand the winds, and they collapsed almost immediately. Even a six-story structure, a furniture store, collapsed and killed the thirty people inside. A few buildings with steel reinforcements were still standing when the storm had passed. Five people were killed in two cars that were crushed by falling debris. Bricks from the collapsed structures piled up in the street to a depth of five feet. Some survivors were trapped under rubble for four-

Figure 70 The May 11, 1953, tornado destroyed numerous buildings in downtown Waco.

teen hours, and several days were needed to remove the bodies. Over six hundred homes and other buildings and 2,000 cars were seriously damaged.

This tornado remains tied with the 1902 Goliad tornado as the deadliest in Texas history and the tenth deadliest in U.S. history. It was one of the primary factors spurring development of a nationwide severe weather warning system. Within the city of Waco it had long-lasting effects on the city's economy. Waco's population was approximately 85,000 in 1953 but it failed to grow substantially in subsequent years while nearby cities like Austin greatly increased in size. In 2003, the National Oceanic and Atmospheric Administration (NOAA) commemorated the fiftieth anniversary of the third deadliest year for tornadoes in the United States. Killer tornadoes claimed 519 lives in that year, a death toll exceeded only twice in U.S. history. While 1953 saw less than half of the annual average number of tornadoes, it spawned some of the deadliest on record, including the last single tornado to kill more than one hundred people. Of the 519 people killed in 1953, approximately half of that number was caused by two tornadoes, Waco and Flint.

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Flint, Michigan, tornado

June 8, 1953
Michigan's worst natural disaster was a tornado that touched down near Flint

The Flint tornado was the last in U.S. history to cause the deaths of more than one hundred persons. Better advance preparations and better forecasting have greatly reduced the death tolls since 1953

June 8, 2003, marked the fiftieth anniversary of Michigan's worst natural disaster, in terms of deaths and injuries, the Flint tornado. This was the last tornado to kill over one hundred people in a single strike anywhere in the United States. It was responsible for the deaths of 116 people and injuries to 844. It was one of eight tornadoes that struck the eastern portion of Michigan in 1953. The other seven resulted in an additional nine deaths, fifty-two injured people, and extensive damage. Flint touched down near the intersection of West Coldwater and North Linden roads, just north of Flint about 8:30 P.M. on the evening of June 8. It left behind it a one half mile wide track of destruction.

Severe storms developed over southeast Lower Michigan in the afternoon when a moisture-laden warm front moving from the Ohio Valley collided with a strong cold front moving east across Wisconsin. The Flint-Beecher tornado touched down at about 8:30 P.M. (CDT) two miles north of Flushing, Michigan, and tracked eastward across Genesee and Lapeer counties to about two miles east of Lapeer, Michigan, clipping northern portions of Flint. The tornado destroyed approximately 340 homes and damaged 260. An additional fifty farmhouses and businesses were destroyed and sixteen damaged. The total replacement value of the resultant damage amounted to $19 million. Most people living in the area were at home. By the time they heard the storm's roar their houses were being torn apart. This slow-

Figure 71 Damage from the Flint-Beecher tornado, the last tornado in the United States to claim more than one hundred lives.

moving F5 tornado, with circulating wind speeds in excess of two hundred mph, was ranked the ninth deadliest tornado in U.S. history. At its greatest intensity, the tornado path was more than a half-mile wide as it swept through a four-mile stretch of the community, causing 114 of the total number of deaths.

So many had been killed by the storm that the National Guard Armory building and other shelters were turned into temporary morgues. The scene of bodies coming in to these buildings was incredibly bleak and horrifying for the families and friends of the victims who waited outside until they were able to go in to identify the dead. Captain James Berardo of the state police warned people that the tornado had horribly battered some victims so they would present a gruesome sight. Out of the 116 who were killed, fifty-five were under twenty and out of those fifty-five, five were less than a year old and thirty-two were under ten. Many families had suffered multiple deaths. There were many heroes on that night and in the days, weeks, and months that followed. First aid, food, and clothing were quickly made available to the tornado victims.

The State Troopers and National Guard worked feverishly after the tornado. Within twelve hours, all 684 of the available National Guard personnel were mobilized and on duty at the disaster scene. This was the second time they had been mobilized since World War II. The Red Cross went into action immediately after the tornado. In addition to the local needs they had to deal with 12,000 messages from worried relatives across the country. Flint supported a "Red Feather" campaign to gather relief and rebuilding funds. With the help of both this community money and assistance from the Red Cross the community was able to make a strong start of rebuilding. Many volunteers helped in the construction work.

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Fallon-Stillwater, Nevada, earthquake

July 6, 1954

A magnitude 6.8 earthquake struck southwest Nevada

The area hit, Fallon-Stillwater, is about one hundred miles southeast of Reno, largely deserted in 1954 so there were no casualties and damage was mainly to buildings

In Fallon, the town nearest the epicenter of the magnitude 6.8 Fallon-Stillwater, Nevada, Earthquake, several old and poorly built concrete-block structures and un-reinforced brick structures were damaged severely, and many brick chimneys fell. Several people were injured at the Naval Auxiliary Air Station, about five miles southeast of Fallon, when the shock knocked heavy steel lockers on to them. Two areas outside Fallon that also sustained damage were the Lone Tree district to the south and the Stillwater district to the east. Ground motion and surface breakage were heaviest in Stillwater.

Canals and drainage systems of the Newlands Reclamation Project near Fallon were damaged extensively. Many box-type culverts were damaged or collapsed. Failure of the Coleman Diversion Dam cut off irrigation water to most of the project. Paved highways in the Fallon-Stillwater areas settled, cracked, and buckled in several places. One of the largest ground movements occurred in the Lone Tree area. One road dropped about three feet for a distance of a thousand feet and lurched about three feet horizontally toward a canal. In the Lone Tree and Stillwater areas, canal banks settled as much as three feet, and bottoms of canals were raised as much as two feet. The quake was felt in California, Idaho, Oregon, and Utah.

The state of Nevada is earthquake country. It lies within the Basin and Range structural and geomorphic province, a region that is actively extending, or being pulled apart in roughly a northwest-southeast direction. The Basin and Range province is riddled with active faults and is one of the most seismically active regions in the United States. Nevada, along with California, has been subject to many large earthquakes in the last 150 years. The average occurrence of earthquakes of magnitude 6 and greater in Nevada is about ten years. The average occurrence of earthquakes of magnitude 7 and greater that have strongly shaken the state is about twenty-seven years. The range in time between earthquakes of magnitude 7 or greater is seventeen to forty-four years, and the last one occurred thirty-five years ago.

On December 27, 1869, an earthquake of magnitude 6.7 shook down walls in Virginia City and Gold Hill, and is referred to as the Olinghouse earthquake, after the mining district northwest of Wadsworth where the earthquake is thought to have originated. The largest earthquake in Nevada's history, a magnitude 7.6 one on October 3, 1915, was centered in Pleasant Valley, south of Winnemucca. This earthquake broke the surface in four different places over a distance of thirty-seven miles. The largest offset of the ground was nineteen feet of vertical movement. In 1932, a magnitude 7.2 earthquake originated in the Gabbs area and was felt throughout Nevada and beyond, over an area of 500,000 square miles. This earthquake involved several faults failing in sequence.

Four earthquakes occurred in 1954 that caused damage to buildings in Fallon and ruptured the ground in a spectacular fashion in Dixie Valley and near Fairview Peak, 30–35 miles east of Fallon. The July and August 1954 earthquakes occurred along the same fault at Rainbow Mountain, east of Fallon, and had magnitudes of 6.6 and 7.0. On December 16, 1954, two large earthquakes of magnitude 7.2 and 6.8 occurred only four minutes apart at Fairview Peak and Dixie Valley. Faulting of the surface occurred discontinuously from northern Gabbs Valley to Dixie Valley, a distance of sixty-three miles. The largest fault scarp was about twenty-three feet high, near Fairview Peak. Faulting of the ground surface is commonly associated with large earthquakes of magnitude 5.5 or greater. One major goal of earthquake hazard mitigation is to avoid locating buildings or other important structures across such faults.

It has been years since the last large earthquake in Nevada, in 1954, and many Nevadans don't appreciate how high the earthquake potential is. We cannot prevent earthquakes but many steps can be taken to minimize or eliminate their potential hazards. Mitigation measures include building with sound lateral or shear support, anchoring objects inside a home that might topple or fall and injure someone, and being prepared to respond to an earthquake, no matter where you are. For the past fifteen years the Nevada Bureau of Mines and Geology has had an earthquake hazard program designed to provide the public with information to understand, evaluate, and mitigate earthquake hazards. The University of Nevada Seismological Laboratory maintains a seismographic network in western Nevada and records, analyzes, and catalogs earthquakes in Nevada and eastern California.

It has also published an earthquake epicenter map of Nevada, and a number of fault and related hazard maps which are available for urban areas in Nevada including the Carson City, Las Vegas, and Reno areas at scales of 1:24,000. Regional maps are available at a scale of 1:250,000. Other specific seismic hazard investigations include studies of the Dixie Valley fault, studies of the Quaternary tectonics and faulting at the potential site for high-level nuclear waste storage at Yucca Mountain, and research on the large Basin and Range earthquakes. If people are aware of the tectonic forces responsible for the spectacular landscape of Nevada, and spend a little time preparing for the earthquakes that these forces can produce, we can live safely with the earthquakes that will eventually occur.

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Thalidomide drug tragedy

October 1, 1957

The drug that caused severe deformities in newborn children

Thalidomide was launched by Celgene Corporation to help pregnant women. Before it was withdrawn three years later thousands of babies had been born with severe physical deformities

Thalidomide was launched in Germany on October 1, 1957. It was an effective hypnotic drug capable of inducing drowsiness and sleep so it was introduced as a sleeping pill for calming the symptoms of morning sickness and nausea in pregnancy. It was introduced into general worldwide use in 1958 but, before it was withdrawn in 1960, thousands of babies had been born with severe deformities.

Celgene Corporation launched thalidomide as a drug that was nontoxic, with no side effects, and completely safe for use by pregnant women as a sedative. However, soon after its launch, reports emerged that thalidomide had caused peripheral neuritis. Peripheral neuritis does not itself point to reproductive damage, but many scientists would take such an assault on the nervous system as grounds for concern. One did, Dr. Frances Oldham Kelsey of the U.S. Food and Drug Administration (FDA) and, as a result, the United States had only seventeen deformities compared with an average of over two hundred for the forty-six countries affected. By the time the FDA was persuaded to give conditional permission for thalidomide, two and a half years later, warning flags were going up all around.

Dr. Kelsey was born and educated in Canada; she took bachelors and masters degrees in pharmacology before moving to the United States where she married another pharmacologist. The couple then went to work in Washington, D.C. In 1960, Kelsey was at work in the FDA when she was given the job of assessing the new drug, thalidomide. She had read that thalidomide caused some peripheral neuritis in patients and she was also concerned about the lack of evidence about its safety. There was strong pressure on the FDA to approve the drug because of its widespread use throughout the world. However, Kelsey refused to approve it without more information. Even when additional data arrived she refused again. By that time the news of the drug's terrible consequences was out and Kelsey was honored as the person who saved the United States from the disasters that overran many other countries. She was still doing research for the FDA in the year 2001 at the age of eighty-seven.

Celgene's statements about thalidomide hid problems that were far worse than the danger of peripheral neuritis. Not one of the claims the company made in October 1957 was true for pregnant women. Animal studies did show that the drug was nontoxic in some instances but, unbelievably for a drug that was being recommended for use by pregnant women, there were no tests on pregnant animals. Such tests as were done on animals are, in any case, inconclusive. Doctors and scientists have long warned that similarity to the human condition in animal experimentation may be a coincidence and can never be applied to humans until the experiment is scientifically carried out on a human population.

Warning flags may have been going up in 1960 but government agencies failed again and again to take action. In Japan, mothers were allowed to take the drug for a whole year after it had been withdrawn in other nations. Several countries failed to take action for periods of time ranging from three to ten months. Britain did not withdraw the drug until November of 1961. To some extent these failures were due to a tragic assumption that the drug had been thoroughly tested before reaching the market and that the tragedies were due to some mistake that no one could have foreseen. Assumptions of this kind led the British distributor, The Distillers Company, to reject claims for compensation for years. Ultimately, The Distillers Company paid a final settlement of $15,000.00 for each deformed child. The knowledge and procedures that could have prevented every one of these tragedies were well known.

One example of how Celgene distorted information to promote the sale of thalidomide illustrates these points. Dr. Blasiu, a doctor who was paid by Celgene to test the use of thalidomide with three hundred adults in a nursing home, reported back that no side effects were observed. Celgene then used the content of this report in a letter to 40,000 doctors, assuring them of the safety of the drug for pregnant women. There was absolutely nothing in Dr. Blasiu's report on the subject of the drug's use with pregnant women. When he was contacted later, Blasiu was shocked to learn how his report had been used. He added that it was his basic rule never to give sleeping pills or tranquilizers to pregnant women. In addition to this example of deliberate error, there were numerous cases of omission, awareness of tests that could and should have been done to ensure the safety of the drug.

Beginning approximately a year after it became widely used in 1958, baby after baby was born with the same type of problem—limbs or fingers missing. When one child enters the world with a deformity as serious as this, the news spreads quickly and many questions are asked. When a number appear, all very similar, the cry reverberates around the world. It took only a few weeks of simple research to discover the common element in the parents of the babies. Each had taken thalidomide, or distaval as it was called in Britain, in the early phases of the pregnancy to induce sleep, at the very stage when limb buds begin to form in the fetus. Before it was banned in 1960, more than 12,000 babies had been born with severe deformities. They would be known thereafter as the thalidomide children.

Reactions from parents ranged from desperation to passivity. Some who were still pregnant and knew the likely outcome thought of abortion; they were convinced that their child did not have a worthwhile future. A few parents with new babies contemplated mercy killing their children for the same reason. Better judgment prevailed with all of these as a variety of community and national organizations stepped in to provide assistance. The problems they faced were immense. Missing limbs and fingers were the most obvious disability. Some children were born with one arm complete while the other was just a small stump. Other children had both arms missing and were left with only a small protrusion at each shoulder. These more obvious visible limitations were only the beginning. Some babies were deaf or blind and some had cleft palates. Others had no hips or ears and there were also internal troubles such as poorly-developed lungs.

One-third of all the affected babies were born dead. Many died later while in their teens. Operation after operation was carried out on quite a number to rectify damage. Where children had flippers rather than arms, parents often chose to have them amputated and replaced with artificial arms. As these children grew and mixed with other children they had to cope with the pain of being stared at or, worse still, being avoided. One successful agency dedicated to coping with disabled children was Chailey Heritage Craft School and Hospital. It was located in the countryside south of London and consisted of several buildings and a hospital all working as a single unit to prepare the children for life. Chailey took the babies soon after birth and cared for them until they were sixteen unless parents preferred to take them home before then.

The fact that thalidomide children formed only a minority of the two hundred at Chailey allowed them to get acquainted with a larger world and minimized to some extent the stigma that had become associated with the word thalidomide. Chailey had wards, classrooms, living quarters, a workshop with all kinds of mechanical aids, and specialists in speech as well as physical and occupational therapy. A baby with no limbs was first placed in a cylindrical piece of molded plastic with a seat at the base. The truck of the body was thus held upright and the baby was placed alongside a low table having all kinds of things like toys, blocks, and clay to explore. The next stage of experience was a low platform on wheels and the child was soon able to propel itself along just by movements of the trunk. This provided access to the range of objects and children around the room. For a majority of them, intellectual abilities had not been impaired.

Around the age of two, when children want to walk, Chailey insisted that they try even though the staff knew there would be falls and accidents and tears. It was felt that the alternative was a vegetable existence and the staff felt that this was not acceptable. A rubber-like hat was put on the youngster to cope with falls and rigid struts on rockers were provided for whatever form of limb they had on their feet, and with these the children were able to maneuver by a series of jerks. For those whose parents were able or disposed to provide them, this was the beginning of using artificial legs. Some who did get artificial legs employed an intermediate step in their development. They had an object on wheels ahead of them that they pushed rather like the practice of older people using walkers.

As the children reached an age of responsibility they were introduced to an entire range of objects and tools, all specially designed for their unique needs. Simple devices like lengths of wire to get hold of objects and pieces of plastic shaped to make it easier to feed oneself were introduced to begin the long road toward independence. There were devices to help them get in and out of a bath, and toilets carried a spray bidet. The classes at school were small, never more than twelve, and again there were special aids that would never be available in the average school. Teaching machines, tape recorders, and typewriters were on hand, all operated remotely using a variety of hand and mouth devices. It is easy to imagine today, with the hindsight of thirty years, the huge difference it would have made if computers had been available for them in the 1960s. Even with all their limitations they were able to write letters to their parents, either by hand, slowly and tediously, or with a typewriter.

By the year 2001, most of the more than 12,000 thalidomide children worldwide were still alive. Those who had entered the workplace in the 1980s and 1990s found that the stigma remained in new forms. There were jobs they could do and there were those that were beyond them. Often an employer wants people who can do a variety of tasks. The tough road they had already traveled, learning to eat and do all the other things of daily life, continued to challenge them. Some married and had normal children. Many found satisfying careers and rewarding relationships in niched situations, writing their stories or training dogs. One worked with an automobile company as its liaison officer for persons with disabilities. Another who had neither legs nor arms produced and marketed a talking machine for the blind.

In many countries the victims were able to sue their governments or the distributing agencies for financial compensation and they won in most cases. Evidence that the United States delayed approving the drug for good reason was a legal help in fighting these cases. In the early 1990s, one frightening claim emerged and received wide publicity before it was squashed. It purported to show that scientists in research labs found thalidomide-like deformities in rats in a second generation. That meant, if it were true, that the devastating drug not only caused problems for the first pregnancies in which it was used but also for all future pregnancies. In other words, the drug had changed the genes and forever afterward abnormalities would keep recurring. The research on which this finding was based was subsequently totally discounted. Fortunately, not all the news about thalidomide is bad. A new use received a lot of attention in the last few years of the twentieth century.

Multiple myeloma is a cancer that has resisted the best efforts of scientists in their search for a cure. The chances of a patient being able to live on with this disease are not good. Chemotherapy is normally used as the best method available but even its success rate is very poor. After reports that thalidomide might be a cure for this cancer, extensive studies were conducted at the University of Arkansas for Medical Science in Little Rock. Support for pursuing this research came from the experiences of New England doctors who used thalidomide in gradually increased doses with patients who had myeloma cancer. Under this regime, one-third of eighty-four patients showed substantial improvement within a year. In 1999 and 2000, the researchers at Little Rock saw some success. Over a period of a year the cancer in two patients went into complete remission while six others showed considerable decline.

The keys to success seemed to lie in the dosage rates and the length of time the patient had the cancer. One specialist calls it the first new class of drugs in thirty-five years for this particular cancer. Some tests are being conducted using a combination of chemotherapy and thalidomide. One reason for optimism lies in the fundamental difference between the two treatments. The former destroys cancerous cells in bone marrow but it also kills the healthy cells too. The latter inhibits the formation of the new blood cells which are essential to tumor growth. Given the history of thalidomide and the behavior of the company, Celgene, that marketed the drug in 1957, specialists are slow to make a final recommendation on this new use of the drug. Early in 2001, the Federal Drug Administration had to write a letter of reprimand to Celgene for misleading advertising regarding its possible value as a cure for cancer. In the light of its earlier history the company certainly needed to be reminded of the dangers implicit in errors of this kind.

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Lituya Bay, Alaska, earthquake

July 10, 1958
An earthquake in Lituya Bay, Alaska triggered a massive landslide and a tsunami

This was the largest earthquake in Alaska since the quake in Yakutat, near Lituya Bay, in 1899

At the head of Lituya Bay, Alaska, on July 10, 1958, an earthquake of magnitude 7.3 triggered a gigantic rock fall, later estimated as measuring forty million cubic yards, at the headland of the bay and a resultant 1,700-foot-high tsunami wave because of the water that was displaced. This tsunami inundated the shores of the bay and, then swept out into the open ocean. This was the largest earthquake in southeast Alaska since the Yakutat shocks of 1899. The only permanent settlement in the epicentral region was Yakutat. Hence, there was little effect on human settlements. Three persons were killed in Lituya Bay, and two people were missing and presumed dead who were caught in the tsunami.

At Yakutat, bridges, docks, and oil lines were damaged, a water tower fell, and a few cabins were destroyed. Many sand blows and ground fissures were observed on the low coastal plain southeast of Yakutat, and large landslides were reported in the mountains. Submarine cables were severed in the Haines–Skagway area and at Lena Point, north of Juneau. The quake impacted places in California, Idaho, Oregon, and Utah. Lituya Bay was a mass of floating debris of all kinds in the wake of the exit of the tsunami: floating blocks of ice from surrounding ice fields, some as big as one hundred feet long; huge logs covering much of the Bay but other logs extending out over the ocean for five miles, having been carried there by the tsunami; and almost everywhere on neighboring slopes the land stripped bare of trees for many hundreds of feet above sea level.

Figure 72 Southeast Alaska earthquake, July 10, 1958. Northwest along Fairweather fault trench at the head of Lituya Bay. August 29, 1958.

Those in boats that happened to be in Lituya Bay as the tsunami began to move were unlucky. Two men who were in one boat were able to escape when their boat sunk and they managed to launch their eight-foot dingy, climb into it, and somehow survive the huge waves before reaching shore. Twenty-five Canadian mountaineers had a lucky escape. They had just returned from a successful climb on nearby Mount Fairweather, the 15,000 plus feet highest peak in British Columbia that is on territory shared with Alaska, and were camping close to Lituya Bay's entrance on July 9. The mountaineers flew out of the area on an amphibious plane late in the evening of that day, hours before the earthquake struck. Another lucky party of sixteen men, all geologists, happened to be camped on the shore of Lake Crillon, about eight miles southeast of Litiuya Bay on July 9. They were preparing to move to an island in Lituya Bay next day. News of the earthquake reached them early on July 10.

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West Yellowstone, Montana, earthquake

August 18, 1959

An earthquake at Hebgen Lake, Montana, caused major changes in several parts of Yellowstone

Yellowstone National Park is the site of a supervolcano in times past, as evidenced by the huge caldera that lies just below the surface

An earthquake of magnitude 7.3 at Hebgen Lake, Montana, on August 18, 1959, made quite an impact on the West Yellowstone part of Yellowstone National Park. New geysers erupted and massive slumping caused large cracks in the ground from which steam emitted. Many hot springs became muddy. The earthquake led to extensive fault scarps, subsidence and uplift, a massive landslide, and a seiche in Hebgen Lake. It caused twenty-eight fatalities most of them the result of rockslides that covered the Rock Creek public campground on the Madison River, about six miles below Hebgen Dam. Total damage amounted to $11 million, almost all of it related to the damage done to highways and timber. This was Montana's largest earthquake ever as far as its documented history shows.

The most spectacular and disastrous effect of the earthquake was the huge avalanche of rock, soil, and trees that cascaded from the steep south wall of the Madison River Canyon. This slide formed a barrier that blocked the gorge and stopped the flow of the Madison River and, within a few weeks, created a lake almost 150 feet deep. The volume of material that blocked the Madison River below Hebgen Dam has been estimated at many millions of cubic yards. New fault scarps as high as twenty feet formed near

Hebgen Lake. The major fault scarps formed along pre-existing normal faults northeast of Hebgen Lake. Subsidence occurred over much of an area that was about fifteen miles from north to south and about twice as long from east to west. As a result of the faulting near Hebgen Lake, the bedrock beneath the lake was permanently warped, causing the lake floor to drop and generate a seiche.

Maximum subsidence was twenty feet in the Hebgen Lake Basin. About seventy square miles subsided more than nine feet, and an area of more than two hundred square miles subsided more than one foot. The earth-fill dam sustained significant cracks in its concrete core and spillway, but it continued to be an effective structure. Many summer homes in the Hebgen Lake area were damaged: houses and cabins shifted off their foundations, chimneys fell, and pipelines were broken. Most small-unit masonry structures and wooden buildings along the major fault scarps survived, with little damage when subjected only to vibratory forces. Roadways were cracked and shifted extensively, and much timber was destroyed. Highway damage near Hebgen Lake was due to landslides slumping vertically and flowing laterally beneath pavements and bridges, causing severe cracks and destruction. Three of the five reinforced bridges in the epicentral area also sustained significant damage.

Yellowstone National Park is often referred to as the nation's jewel of

Figure 73 Hebgen Lake, Montana, earthquake, August 1959. Red Canyon fault scarp east of Blarneystone Ranch. Jeep stands on the road which is on the footwall. August 19.

Figure 74 Hebgen Lake, Montana, earthquake, August 1959. Slump of former State Highway 287 into Hebgen Lake. The main residence of Hilgard Lodge is almost wholly submerged in the lake. View is northwestward. August 1979.

the park system. It was the first to be established in 1872. It was also the world's first national park. Yellowstone is perched on a series of volcanic plateaus in the northwest corner of Wyoming. Average elevation in this area is about 4,500 feet. Because of its elevation and northern latitude the climate is cold and humid. Center of interest in the park is the collection of hot emissions from deep inside the earth, geysers, mud pots, hot springs, and fumaroles. They constitute one of the greatest number of geothermal features to be found anywhere. Traditionally, a geyser in Yellowstone, such as Old Faithful, would thrust its jet of boiling water high into the air about once every hour, and this was always a major attraction for visitors. Then in 1959, the earthquake at Hebgen Lake, about forty miles northwest of Yellowstone Park's center, changed all that. The patterns of eruption of many of Yellowstone's geysers were permanently altered. Now they are less frequent. Such are the unpredictable nature of volcanic activities. Over geological time they are even less predictable.

The entire Yellowstone Basin is a volcanic caldera, what is left of a gigantic eruption that occurred in the distant past. Geologists estimate that an eruption of this kind happens approximately every 600,000 years. The last two were 1.2 million and 600,000 years ago, the last one having ejected a volume of gas more than a thousand times the amount of ash thrown up by Mount St. Helens in 1980. By all available evidence, this area is due for another massive explosion like the previous two, sometime within the next few hundred years! At some depth beneath ground level is the magma pool and above it in the rock layers closer to the surface are numerous fault lines. Water from rain and meltwater seep down into these cracks. The water expands as it gets superheated and is forced up to the surface. Depending on the shape and size of these underground faults the superheated water takes different forms: it may be a fumarole, that is a jet of steam; or a hot spring, which is a boiling pool of water; or it could be a mixture of steam and hot water, known as a geyser, an eruption that occurs in fits and starts under the influence of different types of pressures from below.

There are many other variations in the activities taking place within the caldera. There are mud pots, which are acidic hot springs that hold large amounts of minerals in suspension underground because they cannot flush away the minerals before they reach the surface. As a result they appear as muddy waters, with their bubbles making a glop-glop sound. Hence the name mud pot. Mammoth Hot Springs rises up through rocks that contain easily dissolved minerals. One of these minerals is calcium carbonate and as it precipitates out of the hot water on cooling it forms terraces around the mouth of the hot spring. All of these volcanic activities occur inside the thirty by forty-five mile surface area of the caldera. Yellowstone is a very significant place, unique in the conterminous United States, for quite a different reason than its volcanic history and present state. It represents what has come to be called a hot spot, like the others in different places around the globe: Hawaii is one example where the long chain of former volcanoes that lies across the Pacific provides evidence of a hot spot's existence. Over the past few decades it became clear to geologists that it is almost impossible to fix permanently, say the latitude and longitude, of a place on the surface of the earth. Everything seems to be in motion and the only thing we seem to be able to say is that such and such a place is fixed relative to some other. Plate tectonics revealed all this.

Hot spots are the one exception to this idea of constant motion. Over millions and millions of years hot spots preserve their locations with respect to the deeper part of the earth's mantle. Continents and ocean plates move over them and leave them where they are. In the case of Hawaii, which is located over a hot spot, we know from the chain of undersea mountains that were formerly volcanic mountains that the Pacific Plate has been moving over it for the past seventy million years. It was a similar story with Yellowstone but the evidence is not nearly as clear as in Hawaii. Continental movements are far more complex than those that take place in the ocean because the crust is far thicker on land.

The theory behind hot spots is that they are the surface expressions of what are called mantle plumes. Heat is continually radiating out from the earth's core into the mantle where, though solid because of the overlying weight of rock, some movement is possible. Over long periods of time masses of rock deep in the mantle become so hot that they rise close to the surface. Heat expands them, makes them lighter, and therefore they are able to move higher within the mantle. One of these masses, it has been estimated, could have a volume of millions of cubic miles, enough to maintain a link with the deeper parts of the mantle and, at the same time, provide magma for a hot spot for millions and millions of years.

Searching for evidence that demonstrates Yellowstone's hot spot history is difficult though many scholars work on it. About one hundred miles to the southwest of Yellowstone's present position, lava that was dated as being six million years old was located. This fits what we know about the direction of movement of the North American Plate. It moves a little more than one inch very year toward the southwest. Farther to the southwest in Idaho, lava aged ten million years was located and, still later, more than four hundred miles to the southwest, lava flows thirteen million years old were identified. These locations and times are in the right direction and very close to what would be expected. Beyond these places, tracings have been few. In Oregon, lava sixty million years old was found. The latest finding is indicative of the whole problem of tracing hot spot origins in continents. A geologist is convinced that the seventy million year-old lava found on the borders of Alaska was once over Yellowstone. Yellowstone is still very active. There is a high rate of heat coming from the various vents, much higher than from other parts of the United States. In total, if it were converted into electricity, there would be enough to supply the electrical power needs of five million people. The question has to be asked: Why has this power supply not been developed? Would it not be good for the environment if it replaced an equivalent amount of coal? What are the down sides to transforming Yellowstone into an electrical generating station? Other countries like New Zealand and Iceland make good use of geothermal heat.

There is another side to the story about large quantities of heat. The heat source is shallow, no more than a few kilometers beneath the surface. About thirty years ago it was found that the floor of the caldera was rising. Then less than ten years later it was found to be falling. These movements were accompanied by swarms of earthquakes just as happened in other similar places. All these are indicators of seismic activity. The history of eruptions here, however, does not suggest imminent volcanic action but no one is taking that for granted. Studies and measurements go on continually.

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Japan typhoon

September 26, 1959
Nagoya in Japan was hit with the nation's worst ever typhoon

Nagoya is a city of a million people and this extreme storm caused the deaths of 5,000 people plus the destruction of all kinds of homes and public buildings

On September 26, 1959, Nagoya, a Japanese city of more than a million people, as well as much of the rest of Japan, experienced the most severe typhoon of modern times. Typhoon Vera struck the southern part of Nagoya with winds of more than 135 mph, flooding the entire area. The west bank of a river collapsed, and 1,851 residents were killed, 118,000 buildings were damaged or destroyed, and over 530,000 people were made homeless. In central Japan, rain-choked streams surged over their banks. Railroads, cut in more than a hundred places, became useless. As Vera continued its destructive traverse across the country, the numbers of dead and homeless increased. By the time the storm had moved out into the Pacific the country had to face the tragedy of 5,000 deaths, 32,000 or more injured, and a million and a half homeless.

Vera was number fifteen in the series of typhoons that Japan had already experienced in 1959, most of them fortunately much weaker than Vera which began as a tropical depression in the Mariana Islands on September 20, more than two hundred miles away from Japan. Japan's Meteorological Agency (JMA) issued a warning about Vera while it was still in the Marianas and only a tropical depression because its direction of travel was toward Japan's Honshu Island and the surrounding high and low pressure systems indicated that Vera would maintain its direction of travel. From September 20 to 26, Vera continued in the same direction, just as the JMA had predicted, gathering strength and moving from depression status to tropical storm and then to typhoon. Late on Saturday September 26 it roared into Nagoya. The Japanese are quite accustomed to typhoons and they had already experienced several in 1959 so, as warnings of the storm's approach came to them early in the day, they put up storm shutters and purchased extra supplies of food and water, assuming that this typhoon would be like many others, troublesome and costly in terms of physical damage but not a serious threat to human life. This time their assumptions were wrong.

The tide was at its maximum as the storm hit Nagoya so the city received a wall of water seventeen feet high. The weight of this volume of water, coupled with the pressure of the wind, was sufficient to knock down every obstacle in the path of the storm, including sea walls, dikes, dams, and buildings of all kinds. Homes were quickly overwhelmed with water and most of the people within were drowned. A few escaped to higher ground. The typhoon continued its rampage across the city for two or three hours before moving on into the rest of Honshu. Everywhere there were scenes of confusion and despair. All communications with the rest of the country had been cut off so there was considerable delay in getting information to Tokyo and initiating relief work. Furthermore, there was an assumption by the government of Japan that a city of the size of Nagoya could handle its own needed relief measures. Some U.S. military forces that were still stationed in the country joined in the rescue work and dropped supplies of food, clothing, and medicine to accessible points on higher ground. They also rescued by helicopter as many people as they could from the roofs of houses. Elsewhere on Honshu, Vera caused several landslides that in turn destroyed many homes. About a half million acres of cultivated farmland, and acres of oyster beds where cultured pearls were grown, all were devastated. It would take more than a year to restore them to service.

Typhoon Vera was named "Isewan Typhoon" by JMA. It was the equivalent of a category 5 on the Saffir-Simpson scale and was the strongest typhoon to hit Japan in recorded history. With winds at times as high as 160 mph, Vera will likely be recorded as one of Japan's worst natural disasters. Vast areas of crops were destroyed, sea walls ruined, roads and railways greatly damaged, and rivers transformed into lakes, all contributing to a damage estimate of $261 million. The storm weakened over northern Honshu and finally moved into the northern Pacific Ocean on September 27. The combination of the death toll and the great number of people left homeless were responsible for large outbreaks of various diseases. Nagoya implemented a comprehensive relief effort and, at the same time, received help and support from its sister-city, Los Angeles. At the time of the storm Nagoya was busy making arrangements to celebrate its seventieth anniversary and delegates from Los Angeles were in the city for the occasion. Other U.S. cities also provided relief assistance. In order to prevent a recurrence of this disaster, Nagoya launched a program of reconstruction to make its protective barriers much more resistant to storms than they had previously been. Breakwaters and embankments along rivers were built to a stronger code and to greater heights.

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Chile earthquake

May 22, 1960

The largest earthquake ever recorded

This earthquake of magnitude 9.5 hit an area of Chile close to Concepcion, two hundred miles south of the country's capital of Santiago. There was a death toll of 5,000 people

On May 22, 1960, an earthquake of magnitude 9.5, the largest earthquake ever instrumentally recorded and the twentieth century's most powerful quake, shook southern Chile near Concepcion, two hundred miles south of the capital Santiago. A 750-mile stretch of the fault line involved was ruptured and extensive destruction followed to both human life and property. There were aftershocks, as many as a dozen of magnitude 6 or higher. There was also a tsunami. It was estimated that more than 5,000 people lost their lives, 3,000 were injured, and damage costs amounted to more than $400 million. The tsunami was destructive along the coast of Chile and it also caused numerous casualties and property damage in other places around the Pacific Ocean.

The Pacific Rim, often known as the Ring of Fire because so many of the world's greatest earthquakes occur there, experienced the world's most powerful earthquakes, those of magnitude 9 or greater, between 1950 and 2005: Chile 1960, 9.5; Alaska 1964, 9.2; Sumatra 2004, 9.1; and Kamchatka 1952, 9.0. The places where all of these huge quakes struck were subduction zones; that is, places where huge tectonic plates are constantly moving beneath other tectonic plates. From time to time, as they move, an obstruction of some kind stops plate movements and tensions build up. Later, when the plates snap free from the obstruction, the release of energy causes the earthquake. The location where the ocean plate subducts beneath the continental one in Chile is some distance offshore; hence, the epicenter of the quake was there. The land area north of Concepcion rose three feet as a result of the earthquake and land south of it was pushed up in elevation by five feet. These were indications of the dislocations that occurred in the ocean depth at the epicenter, dislocations that created a tsunami. Concepcion soon discovered the power of that tsunami when a twenty-foot wave swept ashore, damaging or destroying half a million homes.

We are fortunate to have an account of what it is like to experience a major earthquake in Chile. The account comes from a famous scientist who happened to be in Concepcion when another big earthquake struck that city in 1835. Charles Darwin was sailing around South America in the Beagle and his ship reached Concepcion on March 4, 1835, a day after a strong earthquake struck. It was not as strong as the 1960 quake, but the damage it caused appeared from Darwin's reports to be just as great. Darwin was told that seventy villages had been completely destroyed by the earthquake and the big ocean wave that followed it. As he looked around and saw heaps of bits of furniture and wood he thought it looked like the wreck of a thousand ships. He could not imagine what it had looked like before the earthquake. Fortunately, the total death toll was less than a hundred. Darwin's description of the tsunami is particularly interesting. Despite his great ability and achievements, he knew nothing about the forces that create tsunamis because there was nothing understood at that time about tectonic plates and their interactions.

Villagers told him that a small ripple was observed on the surface of the ocean about four miles from shore. It moved quickly toward the shore and as it did so it rose higher and higher until it crashed on to the shore as a twenty-foot-high wave. We know now why the wave rose higher and higher above the general level of the ocean as it approached land but, to the people of Concepcion in 1835, it must have seemed a mystery. The greater mystery in their eyes must have been the subsequent behavior of the tsunami. People told Darwin that after the first wave of the tsunami reached the shore the sea retreated away from the land for some time before returning with a second wave. This second wave was thirty feet high, ten feet higher than the first one. Again the sea receded from the land, leaving the seabed bare but only to return as it did before with a bigger wave than either the first or second one. There was a fourth retreat from the land and then a final wave, the highest of all. Throughout history, until our understanding of tectonic plates, thousands of people lost their lives during tsunamis by running out on empty beaches after the first wave to catch the stranded fish.

Darwin was also told by the villagers that great flights of sea birds were seen moving toward the mountains away from the sea about an hour before the earthquake struck. It is particularly important for us today to know that this aspect of earthquakes was well known more than 170 years ago. It may have been known much earlier too because occasional accounts like the one that Darwin received do exist. For example, Lisbon was hit with an earthquake of magnitude 9 in 1755. In the archival records of that time there is a description of birds and animals leaving the area before the earthquake struck. When the great earthquake and tsunami occurred off the coast of Sumatra in 2004, people noted that many forms of wildlife were not affected by the disaster. They had moved away from the danger area before the earthquake struck. Similar stories were told by people in other parts of Asia that had been hit by the tsunami. Japanese research geologists recently proved experimentally that all forms of wildlife do sense impending earthquakes and move away from them. They seem able to respond to warning signals from the environment, signals that we do not receive, and respond accordingly.

In Chile in 1960, along its coast, the tsunami brought forty-foot waves that in some places rose as high as seventy-five feet. Dunes were washed away and sand was transported inland as far as 1,500 feet. In one location where the tsunami reached forty-five feet a thin layer of sand was found six miles inland. Over the twenty-four hours that followed the earthquake places all around the Pacific Rim felt the tsunami. It reached Alaska after eighteen hours, Japan after twenty-two hours, and Hawaii after fifteen hours with a wave height of ten feet, rising at times to thirty feet. This tsunami traveled at speeds of four hundred–five hundred mph depending on the amount of friction experienced below sea level. There were three waves in the tsunami, each separated by substantial amounts of time, and the third one did most of the damage to Hawaii. The state was well prepared. Two years after a 1946 tragedy that resulted from a tsunami an

Figure 75 Damage in Japan caused by tsunami of the coast of Chile.

Figure 76 Waterfront street in Quellon (located on the eastern shore of Isla Chiloe). The half-demolished building was the city hall. This part of Isla Chiloe sank about 6.5 feet. Some houses near the sea had to be evacuated; water reached the main street of the town.

elaborate warning system was installed. It included observation posts throughout the Pacific Ocean so that initial indications from tidal gauges could be noted and the information relayed to Hawaii or any other island nation affected. The very moment that a seismic disturbance severe enough to cause a tsunami is now observed anywhere in the Pacific Basin it is recorded at the Honolulu Observatory. Epicenter location and times of arrival at affected shores are estimated and warnings passed on. Other nations supplement this information. The Japanese Meteorological Agency for instance has five tsunami forecast centers and these also give advance warnings.

Unfortunately, a change in the way the Hawaiian warning signal was broadcast by radio left islanders puzzled. A decision had been made to move from a three-stage signal to a single-stage signal, but many people had forgotten about the change and so they waited for a second and third siren before acting. This led to a much smaller number than local recommendations required of people evacuating from dangerous shore areas. As in 1946, the town of Hilo on Big Island suffered more severely than anywhere. Other islands experienced only moderate damage. At Hilo Bay, the highest wave towered more than thirty feet above normal sea level and raced inland at 30 mph. Boulders as heavy as twenty tons were picked up from the bay front seawall and carried five hundred feet across a park without leaving a mark on the grass. Two-inch diameter pipes supporting parking meters were bent over parallel to the ground. Entire city blocks were swept clean, buildings being wrenched from their foundations and deposited as piles of debris three hundred feet away. Over five hundred buildings representing

$25 million of value were destroyed. At Hilo alone sixty-one people were crushed or drowned by the waves and an additional forty-three required hospitalization.

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New York City, New York, mid-air collision

December 16, 1960
Two airliners collided over New York City

A United Airlines DC8 and a Trans World Airlines Super Constellation collided over New York and bodies and debris fell all over the downtown area

On the morning of December 16, 1960, two airliners were approaching New York City, a United Airlines DC8 jet and a Trans World Airlines Super Constellation propeller plane. Suddenly there was silence from both planes as the controllers at La Guardia and Idlewild, now John F. Kennedy, airports tried to establish contact. The two aircraft had collided a mile above the city and debris and bodies plunged to the ground. Many of the 134 passengers and crew who lost their lives on that snowy New York morning were students returning to the city for the holiday. On the ground, six people were killed by falling debris.

The TWA flight fell to the ground from a mile above Staten Island while the United continued on a trajectory towards Brooklyn. It was, at that time, the worst air disaster in U.S. history. The TWA flight was heading for La Guardia Airport while the United Airlines plane was about to land at Idlewild, now known as John F. Kennedy Airport. As it approached the city, the United jet was told to take a holding pattern at 5,000 feet over Preston, New Jersey, until it could be cleared for Idlewild. The TWA plane was told to stay at 6,000 feet over Linden, New Jersey, until it was cleared for La Guardia. The planes would thus be several miles apart and separated by 1,000 feet of altitude. One of the air controllers at La Guardia suddenly called out to the TWA pilot that he had jet traffic nearby on his right.

There was no response. At the same moment the United's DC8 told Idlewild that it was at 5,000 feet. It was given landing instructions from the tower but there was no response. The DC8 crashed into a heavily populated district of Brooklyn, burying itself twenty feet into the ground and demolishing a church that stood there.

The DC8's tailplane continued along a street, crushing cars and ending up a hundred yards away. Gas spilled all around and several buildings and a car caught fire. One eleven-year-old boy, Stephen Baltz, crawled out of the plane, his clothing on fire. Two policemen pulled him away from the flaming wreckage and rolled him in the snow. After a few hours, despite being badly burned and having a broken leg, he was able to sit up and talk at the Brooklyn Methodist Hospital. He died two days later. He had breathed in lethal flames that seriously damaged his lungs and, although several doctors and nurses tried everything they could to save him, they were not able. In his short span of life after the crash he described the collision as an explosion after which the plane began to fall while people screamed. He held on to his seat as it came down.

Figure 77 The tail section of United Airlines airliner which crashed in a heavily populated section of Brooklyn, New York, December 16, 1960, rests at the intersection of Sterling Place and 7th Avenue.

Emergency teams from the army, navy, and air force arrived and fought the fires, trying to prevent them spreading. Shops in the vicinity became temporary mortuaries. Everyone became involved. The church that was demolished by the DC8 was a gray three-story structure known as the Pillar of Fire Church. The ninety-year-old caretaker, Wallace E. Lewis, who lived on the third floor, was killed. Ten residential buildings along with the church were set ablaze. Part of a wing was caught in the torn roof of an apartment building while a thirty-foot section of the tail was sprawled across a street intersection. Firemen waded through water carrying body after body to temporary morgues in garages.

As dusk approached, the fire department switched on its emergency searchlights and firemen continued to search for bodies both from the plane's wreckage and among buildings destroyed on the ground. They also collected as many personal items as they could to aid in identification of victims. The wet streets began to freeze and this added to the difficulties of the task. A further hindrance came with the hundreds of motorists, sightseers, and those homeward-bound from work stopping to witness the event. Red Cross and Salvation Army staff gave out hot soup, donuts, and coffee to the exhausted disaster workers.

TWA's fuselage landed in three pieces on Staten Island across New York Bay from Brooklyn. The pilot tried to land the plane on Miller Field nearby but it broke up and exploded before it reached the ground. Wreckage was scattered all over the airfield. Bodies were seen falling into the water. Rescue boats searched for survivors. They found six but all died before they reached a hospital. Rescue work went on through the day. By evening friends and relatives of those who had been on the planes arrived seeking answers, often slowing down the rescue work. The inevitable questions soon arose. How could a disaster like this happen? Explanations began to come out when the Federal Aviation Administration released transcripts of the conversations between control officers at the two airports.

The captain of the DC8 was found to be at fault. At the time of the collision his plane was nine miles off course. Furthermore he was flying at 346 mph instead of 207, the approved speed for a plane at 5,000 feet. Final death toll was 134 from the planes and 6 killed on the ground, for a total of 140. It was the worst air disaster up to that date and it happened on the fifty-seventh anniversary of the first flight in 1903. Added to eight other accidents involving scheduled airlines in the United States in that same year, it would make 1960 the worst year ever in terms of deaths from airline accidents. Fortunately, the destruction to people and places on the ground was much less that might have been feared but the message to authorities from the tragedy was clear: a metropolitan area like New York must do everything in its power to ensure that a disaster like this never happens again.

While a tragedy like this one over a major city is an unusually disastrous one, the problem of air crashes involving human error remains as a continuing challenge. As the numbers of people traveling keep increasing there is a corresponding increase in accidents and in almost every one human error is found to be the cause of the accident. On July 17, 1996, TWA 800 left New York for Europe and as it gained altitude off Long Island it exploded and fell into the sea. There were no survivors. Later investigations showed that the cause of the accident was faulty wiring. On October 31, 1999, Egyptair 990 left New York for Egypt but soon afterward crashed into the ocean off Long Island. Following extensive studies of possible causes the only possibility left was that the co-pilot decided to destroy the plane and everyone in it. On July 25, 2000, Concorde AF 4590 took off from Paris en route to New York. Within a few minutes it crashed in flames. No one survived. The cause of the accident was a piece of metal that someone had left on the runway. The metal had slashed a tire on one of the plane's landing wheels and then cut into a fuel tank.

In 1960, the degree of sophistication in jet travel was at a very early stage. The many safety features of today had yet to be developed and installed and pilots needed exposure to various climatic conditions in order to learn how to cope with them. Thirty years later, by 1998, travel was still commonplace but jet airliners were fitted with numerous technical aids to make travel easier for both pilots and passengers. This was especially true for Swissair, an airline that frequently flew from New York to Switzerland and had an excellent safety record. Pilot error, however, just as it had been in 1960, or perhaps pilot inability to cope with unusual emergencies, were still very much a danger to be considered as was found in Swissair flight 111 in 1998. It left New York's JFK Airport between eight and nine in the evening of September 2, 1998, en route to Geneva, Switzerland. On board were people from the United Nations, scientists, and tourists.

The plane was into its flight for less than an hour and had almost reached its cruising altitude when smoke was detected in the cockpit. The route over the Atlantic lies along the coast of New England and eastern Canada and at the time of the smoke alarm Halifax in Nova Scotia, Canada, was the nearest airport. Arrangements to land there were quickly made. It was then that a number of extraordinary things happened. With fire developing rapidly to the point that pilot and co-pilot had to wear oxygen masks, the captain began to follow a list of more than two hundred procedures to try and locate the source of the fire. Swissair's rules required him to do this. At the same time, convinced that the plane was too heavy to land, he circled the airport twice in order to dump fuel. All of this took time, far too much time as it turned out. Maybe the captain seriously underestimated the amount of time he had before the fire completely overwhelmed him. Maybe his training never prepared him for an event of this kind. The co-pilot urged him to land immediately but he refused.

As it turned out, it took less than fifteen minutes for the fire to grow into an inferno. Meanwhile passengers had put on their lifejackets as they expected the plane might have to land on water. The list of more than two hundred procedures involved checking all the electrical circuits one at a time and the captain made every effort to do this. Experts later concluded that this activity might have accelerated the fire by creating a surge of electricity. In any case, both the checking of electrical circuits and dumping fuel took too much time. The fire cut off all power and at half past nine in the evening radio communication with Halifax was lost. A few minutes later Swissair 111 plummeted into the ocean forty miles east of Nova Scotia, off Peggy's Cove, killing everyone aboard. This disaster, like so many others, had resulted from human failures whether deliberate or not. The wiring used in both TWA 800 in 1996 and Swissair 111 in 1998 was known to be faulty but had not yet been replaced.

The Rescue Coordination Center in Halifax, Nova Scotia, had been alerted about a possible accident. Within minutes of the crash it sprang into action. Planes scoured the Swissair's last known location and ships began the surface search aided by flares. For some time it was not known how the plane had come down so search and rescue was the order of the day. The largest hospital in the area, the Queen Elizabeth Two Health Sciences Center, cleared its emergency rooms and prepared for a flood of casualties. Ambulances and fire trucks took up positions as near as possible to the shore. All through the night the search for life went on. By morning it was obvious to all that everyone on board had died. The airline's head office in Zurich issued a statement saying that there were no survivors. The plane had gone down at a steep angle so both bodies and wreckage were concentrated in a small two-hundred-foot-deep area.

One of the top authorities on aviation commented after the crash that the plane could have descended from 33,000 feet when seventy miles from Halifax, and landed with minimum risk. Swissair 111's triple-engine MD-11, similar to the DC 10, was well below its maximum load when it left New York. Many other experts said that even if the MD-11 been only thirty miles away from Halifax and cruising at 33,000 feet it could still have landed safely. So convincing was the evidence against Swissair that the first insurance settlement of damages on behalf of one passenger was reached in the fall of 1999, long before a final decision was made on the cause of the accident. Other claims followed but three years after the crash there was little progress on the sixteen billion dollars of claims that had been assembled.

All kinds of valuables came down with the plane. They included diamonds, jewels, millions of dollars in cash, and a Picasso painting worth more than a million dollars. The last-named was probably destroyed in the crash, as it had not been packaged to withstand a serious accident. The initial focus of the rescuers was on human remains and aircraft parts, not on these treasures. First priority was to discover the cause of the disaster. Later a search for the valuables was made. The U.S. salvage ship *Grapple* was brought in at once to help with the recovery work off Peggy's Cove. The two black boxes, which contained flight data and cockpit conversations, were the first things to be taken from the water.

The remains of only one of the 229 passengers and crew could be identified visually. The rest depended on dental and medical records and samples of DNA. The plane and its contents had been shattered because of the sharp angle of impact with the water. There were 15,000 body parts recovered and over a million pieces of the plane. One outcome of the accident was a new ruling by Swissair that the huge checklist should never be a top priority for a captain in any future similar event. The captain, said Swissair officials, must always have the freedom to use his best judgment in such circumstances. Swiss investigators finally concluded that the Swissair Flight 111 crash was caused by a fire that was thought to have started when a spark from a damaged wire ignited insulation material in the in-flight entertainment system. The final report of the Canadian Transportation Safety Board in 2003, at a cost of $30 million, the largest and most complex that the Board ever undertook, came to a similar conclusion. These entertainment systems draw large amounts of electric power.

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Tristan da Cunha volcanic eruption

October 8, 1961
An isolated "hot spot" island erupts

The eruption forced all the islanders of Tristan da Cunha to evacuate from their homes in mid-Atlantic and remain away for several years

Tristan da Cunha is the main island of a group of small volcanic islands on the eastern flank of the Mid-Atlantic Ridge, an undersea mountain range running from North to South Pole in the middle of the Atlantic Ocean. Tristan's origin is known as a hot spot, a place where magma periodically erupts from the depths of the earth. Over time the main island grew up from a depth of almost 10,000 feet to 6,800 feet above sea level, its present condition. As the peak of a volcano, Tristan had an almost circular outline with a diameter of eight miles and a surface area of less than forty square miles. On October 8, 1961, this volcano erupted for the first time in living memory, not from the top of the crater but through a vent, a thousand feet away from the settlement. It was not a violent eruption, about two on the VEI index, but magma quickly began to spread toward the settlement. Emergency messages were sent out and within a few days a ship arrived to take everyone off the island. It remained deserted for two years.

Letters that arrived in England with the residents from Tristan, and had been written and placed in envelopes for mailing days before the eruption, tell the story of the warning signals they had received. From different parts of the island big and small tremors had been experienced daily for two months and people had gone to various locations to try and find out if the

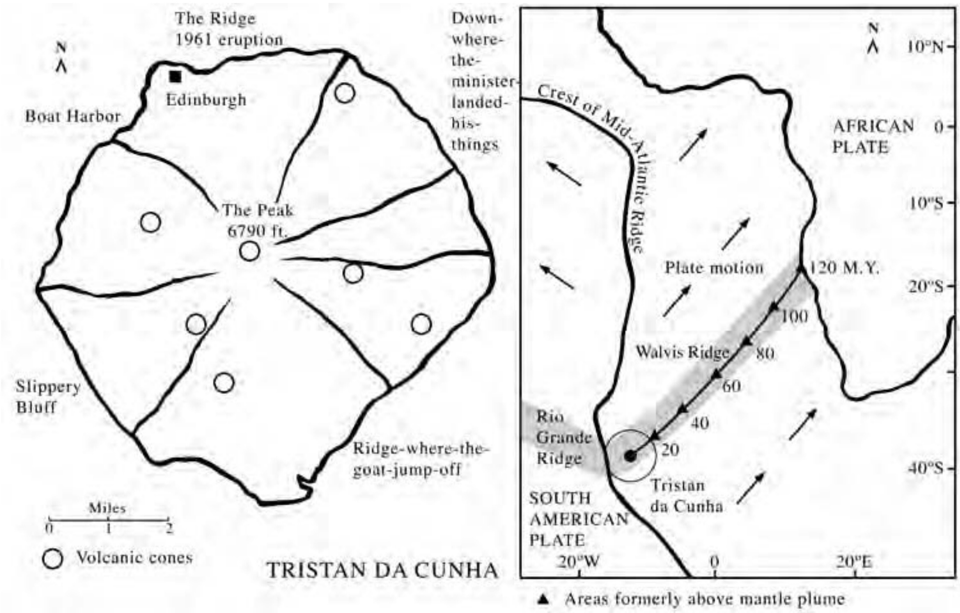

Figure 78 The site of the 1961 eruption at a hot spot or mantle plume.

tremors were the same everywhere. Since there was no memory or historical evidence of a previous eruption, no one thought very much about the possibility of an eruption. In fact, as was discovered later, there had been an eruption about 250 years before the 1961 eruption but no record was kept of that event. It probably happened in a period when there were no residents on the island. Everyone knew that their island was the result of a volcanic eruption but they assumed that the volcano was now dormant. We can imagine their surprise on the eighth of October 1961. Hot spots like Tristan are found all over the world and their history is told in the trail they leave as tectonic plates move across them.

In the case of Tristan there is evidence of the hot spot having been stationary for at least 120 million years. As the major tectonic plates move east and west from their origin in the Mid-Atlantic Ridge the volcanic materials that had erupted were carried along with the plates. On the eastern side we can see today a trail of volcanic rocks, or islands if above the surface, that date from three million years old at Tristan, suggesting that the hot spot is beneath or near it at the present time, to a 120 million year old spot on the west coast of Africa. In the other direction there is a similar trail from Tristan to Brazil. This age-old and complicated geological history was unknown to the people who lived at Tristan in 1961. It was also unknown to geologists everywhere at that time. The great revolutionary discovery of the world's oceans being covered by huge moving volcanic plates, plates that brought continents together and then separated them over periods of time measured in hundreds of millions of years, was still in the future when the people of Tristan encountered their volcanic eruption.

The sudden appearance of a seven hundred foot long rift in the ground on the eighth of October, quite close to the settlement of Edinburgh, was enough to trigger emergency alarms. It was followed by a flow of magma from below that quickly began to cover the settlement area. In areas closer to the ocean land had been elevated and in one spot, before the end of the day, there was a twenty-foot-high mound, the beginning of a new volcano. By the following morning the mound had reached a height of fifty feet and some smoke was coming from it. Edinburgh was the only place on the island where any kind of community life could be sustained and, by the evening of the ninth, it was obvious to all that they had to evacuate Tristan. The equivalent of a town hall meeting was held. They decided to go to one of the smaller islands of the Tristan Da Cunha group, Nightingale, and wait there until a ship arrived to take them to England, of which they were a colony, the only place in the world where they had a right of residence.

Everyone collected his or her personal possessions for the trip. These amounted to little more than the clothing they wore and a small bundle of miscellaneous things, the contents of their homes. They made their way down the cliffs to the fishing boats but wind and waves were too high for boarding so they had to huddle down for the night wherever they could find shelter. Behind them, the new volcano lit up the night sky as smoke and flames came from it. Next day they were able to board their small fishing vessels and so they got to Nightingale. Fortunately there was a Dutch ship nearby and they were able to communicate with it and make arrangements for their immediate rescue. This ship was on its way to Cape Town, about 1,750 miles way and the nearest place to Tristan, so the entire community of Tristan was taken there. About ten days later they were taken from Cape Town in a British ship to England where they would stay for two years, not happy ones as it turned out. On arrival in England they asked that they be allowed to live together and so the local authorities sent them to a place in the south of the country that was formerly an army camp. It was an isolated location and as it was built as an army camp there were no provisions for individual privacy. The search began almost at once for a better place.

The small group of islands called Tristan Da Cunha of which the name is given to the biggest island, the only occupied one, was discovered in the sixteenth century by Tristao Da Conha, a Portuguese admiral. The present name of the island is based on his name. There were no people living there at that time, nor did anyone settle on the island for the following three hundred years. The first settlers were four Americans from Salem, Massachusetts. They landed there in the year 1810 hoping to make profit by selling food and water to passing ship traffic. Three of their number lost their lives in a fishing trip but the surviving member of the party remained on Tristan for a few years. In the year 1816, Britain established a military garrison on the island because they were concerned that the French might try to use this island as a base for rescuing Napoleon, who had been sent into exile on the island of St. Helena, almost 1,000 miles farther away to the north. The British removed the garrison after a few years because they realized that it would be quite impossible to do a rescue over such a distance. It was at that point that one of the officers from that garrison and members of his family and some others decided to settle permanently on Tristan Da Cunha and that became the foundation of the population that remained right up to the present time.

In 1961, there were approximately 240 people living on the island. It was a colony of Great Britain and there were a total of seven family names among the residents. The settlement where they congregated was called Edinburgh, a cluster of sixty stone houses with thatched roofs on a relatively flat plateau bordering the ocean at the northwest corner of the island. The community was still no more than eleven flax-thatched cottages built from blocks of volcanic rock when, in 1867, HRH Prince Alfred, Duke of Edinburgh and second son of Victoria, visited the island while voyaging around the world and gave the settlement of Edinburgh its present name. Edinburgh is a site that is almost free from wind. The houses have no electricity, no telephones, and no central heating. Potatoes were grown on small plots and grain used to be grown until a rat-infested ship was wrecked on the island. The rats destroyed the grain and also the bird population. As a result, insects frequently overrun the settlement. Once a year a campaign is launched to destroy the rats but the inaccessibility of many parts of the island makes the task very difficult.

Over the years the islanders lived a kind of idealistic lifestyle. There was no government on the island, nobody in charge of affairs as a whole. Everyone was the equal of everyone else and each person went about his or her affairs independently. Cooperative efforts helped with common tasks such as gathering food and building homes. There were no roads, no motor vehicles, and no other modern conveniences. The only trees were stunted, wind-twisted evergreens. Narrow ravines radiated outward from the central peak, which more often than not was obscured with clouds. Ocean waves crashed on to the four hundred-foot high basalt cliffs. There was no natural harbor. Ships had to anchor off shore until favorable weather allowed access by small boats. It is easy to imagine the culture clash that must have accompanied their move to England. After their first crisis of being placed in what was a massive single room building with no provision for privacy they were taken to another former military location, this time one that had a number of individual buildings so each family had a separate house.

By this time their story and their plight had been publicized in the media and different charitable agencies began to contribute to their needs. Jobs were found for some members of the group and all were inoculated against what was called the diseases of civilization. They did not help very much because, within a few months, everyone caught cold or flu bugs and four people died from pneumonia. Their biggest worry was how and when they could return to Tristan. They had been told from the beginning that they could go back once the island was safe but there was delay after delay, even after reports reached England that all volcanic activity had ceased. Crime, something that was completely new to them, became a terrifying experience and they were increasingly reclusive because of it. In fact, they seemed to appreciate very few of the benefits of civilization. When they finally were able to leave Britain and return to Tristan, one writer described them as a people who had tasted and tested the civilized lifestyle and decided that it was a failure.

Since their return to the Island in 1963 there has been no evidence of volcanic activity. Potatoes are grown as before and some sheep and cattle are also still reared. Mail is taken to the island every three or four months from Cape Town in South Africa. The population is now about three hundred and a number of modern conveniences that were missing in 1961 and 1963 have been added. There is a school, a hospital, a post office, a village hall, a museum, a swimming pool, and a number of new activities. These provide a certain amount of income to make the community as self sufficient as possible. A tourist ship visits the island once a year. The ship stays for a few days and the passengers are free to visit the island during that time if the weather allows them to land.

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Vaiont Dam, Italy, collapse

October 9, 1963

A three hundred-foot-high wave from the Vaiont Dam destroyed everything in the valley below the dam

A landslide within the Vaiont Dam in northern Italy displaced a massive volume of water from the dam that flooded the valley below

On October 9, 1963, between 10 and 11 P.M., a massive wave of water crashed over the top of the Vaiont Dam destroying everything in its path and killing 2,600 people. At a speed of 70 mph a massive slide of 350 million cubic yards of rock and ruble from one mountain had collapsed into the dam, displacing huge volumes of water that, like a tsunami, then descended into the valley below. It was the worst disaster of this kind in history and was caused by inadequate geological investigations prior to construction.

More than once in modern society events serve as reminders of what we know but fail to put into action; namely, that those who choose to forget the past are doomed to relive it. The Vaiont Dam failure is one more example where knowledge of earlier cases like the St. Francis and Teton dam failures could have prevented failure at Vaiont. The flaws in all three of these dam failures were the same—the absence of adequate geological assessments before work on the dams began. Even as construction went ahead at Vaiont there were signs of trouble in the steep mountainsides on either side of the Piave River valley, the site of the dam. Instead of delaying construction until thorough geological studies were completed, engineers decided to use a trial and error method, measuring the rates of rock movements on both sides of the valley in relation to water levels. They finally arrived at what they considered a stable condition and went ahead with the project.

The Piave River flows through limestone mountains in the Italian Alps, about sixty miles north of Venice, near the towns of Longarone and Castello Lavazzo. The purpose of the dam was to provide hydroelectricity for Milan and other big industrial cities of the north. The heights of the surrounding mountainous ranged from 7,200 feet to 8,200 feet. The valley floor was steep on both sides and so a very high dam was necessary. It had to be almost nine hundred feet above the valley floor, the second highest in the world. Limestone rock is formed in layers and if the cohesion of the layers is weakened by water, or by changes in pressure from neighboring rocks, landslides are possible. Planners knew this and were also aware that landslides had taken place in the past in the very spot where the dam was being built.

Construction was completed by 1960. As the finished structure began to fill with water, and sides of the dam were being monitored for any slide movements, engineers noticed that the amount of water and rate of filling affected the stability of rocks and soils on both sides of the valley. People began to notice large cracks in the earth near the top of one of the mountains bordering the dam. The thousands of villagers who lived in the valley below were far from being at ease with the nine hundred-foot-high edifice looming above them. For three years following completion in 1960 there was a significant element of fear pervading the homes and villages beneath the dam.

Some of the technicians who were involved in maintenance work on the project also expressed continuing concern over the danger from landslides. They pointed out that the mountainsides were dry and inclined to crumble because there was no vegetation to hold the soil in place. Their fear was that a heavy storm or some large rocks hitting the reservoir could cause water to cascade over the top of the dam into the valley. From such a height even a small flow of water could be disastrous. Concerns mounted as slippage along the face of the mountains became more and more evident. The technicians sent a report on this to the relevant government department in the country's capital city, Rome. While waiting for a response from Rome there was a sudden change in the weather. After weeks of dry, hot conditions there came heavy rain and high wind.

By early October of 1963 the mountainsides changed dramatically as they became saturated with water. The groundwater table in the area also rose, saturating the ground and decreasing its strength. Slow creep of the valley sides was noticed in September. By October 8, the day before the disaster, these movements reached an alarming rate of sixteen inches a day. The last measurements on the ninth indicated double that rate over some areas. Animals sensed the danger and began moving away. Engineers became alarmed and lowered the water level but even as they did so the reservoir level continued to rise because soil and rocks were entering the lake in increasing quantities. Thus the water in the dam was being displaced by the slow creep of an impending landslide.

Late in the evening of October 9 a large block of rock, soil, and debris—a mile wide and more than a mile long, and about a thousand feet thick—roared down the mountainside into the reservoir displacing huge quantities of water. A gigantic three-hundred-foot wave was generated and this mass of water, like a tsunami, swept over the top of the dam and down into the valley. The dam remained in place but destruction in the valley was catastrophic. The water rushed down the valley like a solid wall hundreds of feet high, destroying everything in its path. Village after village and one home after another all disappeared leaving behind a mass of mud mixed with bodies and bits of building materials. Some people farther down the valley heard the sound of the approaching wave as if it were a tornado and managed to get out of its way in time. They knew at once what had happened. Longarone, the largest community, experienced the greatest amount of damage.

A day later, onlookers compared the scene with the two-thousand-year-old ruins of Pompeii, the only other event they could recall that caused comparable devastation. That event happened more than two thousand years earlier. In Longarone, as in all the other places along the Piave Valley, records of local residents were lost because the official buildings were destroyed, so it took some time to assess the loss of life. Gradually, as

Figure 79 Modern day view of the Vaiont Dam.

survivors met, the full toll became clear. There were 2,600 dead. Even as the enormous scale of the tragedy was being grasped there was more terror. On October 15, there was another slide of rock into the reservoir. This time authorities were fully prepared. An evacuation plan was in place and buses quickly carried people to safety.

In the technical inquiry that followed, it was determined that the area was geologically unsuitable for a dam. In addition, the building work that took place further weakened the surrounding mountainside, thus making slips inevitable. Nine men were accused of gross negligence. Five years later, on the night before their trial, the leader of the nine took his life. The others received sentences ranging from fines to years in prison. One final outcome was that authorities launched a series of investigations into all dams in Italy's alpine region.

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Price William Sound, Alaska, earthquake

March 27, 1964

The biggest Alaskan earthquake in living memory

The epicenter was close to the coast in Prince William Sound, halfway between Portage and Valdez. Destruction was widespread and massive

Late afternoon on March 27, 1964, it struck, the Good Friday earthquake of magnitude 9.2, ironically so named because it happened close to Easter. It was a subduction earthquake like all the others that have so often shaken Alaska's Peninsula and the Aleutian chain of islands over the past century. This one, however, was exceptional, the biggest in living memory. The epicenter was close to the coast in Prince William Sound, about halfway between Portage and Valdez, and from the fishing port of Cordova all the way to the Island of Kodiak there was one swath of destruction. The death toll from the earthquake and the ensuing tsunami was 125, almost all of the deaths being due to the tsunami.

In the course of the three-minute quake, numerous landslides occurred, huge rocks crashed down the mountainsides, high-rise buildings and bridges collapsed, and tidal waves as high as 150 feet swept over coastal communities, carrying away everything in their paths. One small island, Middleton, was uplifted fifteen feet. An old ship that had been sunk nearby many years earlier and was normally out of sight when the sea level was at its lowest suddenly was pushed upward and left high and dry above sea level. Fortunately, population density here is low so the death toll was light. It would be a very different story if the quake had happened in San Francisco or Los Angeles.

One landslide overwhelmed Turnagain Heights, a subdivision of seventy-five homes, many perched on a bluff with an excellent view of the ocean. The bluff disintegrated and tumbled down the slopes into Knit Arm, taking the seventy-five homes down as it went. All roads and utility lines were rendered unusable. Strange as it may seem, after the earthquake private developers were allowed to rebuild on the slide mass provided they assumed full responsibility, including liability in case of accidents, for constructing and maintaining new roads and utilities.

Anchorage was hit harder than any other city. People still remember the way the shocks persisted, each minute feeling like an hour and the dislocation of everything worsening by the seconds. Underneath each building and everywhere around on the outside the ground rose and fell like the waves of the sea. Blocks of houses slid about, pavements burst open, and huge fissures opened up in the ground. People clung to lampposts and anything else that had any degree of stability. Broken glass covered the ground. Concrete slabs breaking off buildings killed some who were walking below. Others were killed in their cars as they drove past disintegrating buildings.

At Valdez where a ship was unloading the dock where it was berthed suddenly collapsed as the whole structure was sucked under taking twenty-four people with it. None of them survived. The shoreline all along the waterfront had also collapsed and water surged violently backwards and forwards within the harbor, crushing whatever was left of shore instal-

Figure 80 Alaska earthquake, March 27, 1964. Government Hill Elementary School in Anchorage which was destroyed by the Government Hill landslide.

lations. The first crest of the tsunami had arrived about thirty minutes after the earthquake, but few noticed it because it was low tide and the water reached only as far as the high water mark. Then, about four hours later, wave after wave poured in, at intervals of thirty minutes each, flooding the town of Valdez and wrecking all of its commercial buildings and half of its homes. Fortunately, almost everyone had fled into the surrounding high ground by this time. They stayed there all night in temperatures that dropped below zero, returning to town in the morning to search for lost relatives.

West of the epicenter, at the town of Seward, a similar story to the one at Valdez unfolded with devastation from both earthquake and tsunami. Seward is an oil port and rail terminus. Again the waterfront structure disappeared beneath the water taking the installations on the dock down with it. Farther back diesel locomotives weighing more than one hundred tons were thrown on their sides. To make matters worse, there were storage tanks of gasoline at the dock that caught fire and added to the confusion. Most of Seward's residential and commercial buildings and all of its industrial areas were obliterated.

Liquefaction had caused widespread damage to railroad tracks and bridges to a degree that geologists had never before observed. There were landslides, ground cracks, and warping of the surface almost everywhere but the geologists were surprised by the degree of twisting in different directions along railroad tracks and the contortions in bridges. Under pressure from ground failure on both sides of streams, as liquefaction allowed these pressures to build up, bridges buckled in their centers. Perhaps liquefaction played a part in the failure of Turnagain Heights.

In summary, the amount of Alaska and its neighboring coastal waters deformed by the quake was more than 100,000 square miles. Some of it had been pushed upward while other locations were dropped down. In places extending as far as one hundred miles inland the land had dropped by six feet while toward the sea land was raised six feet and in some places thirty feet. Along the subduction line a wide stretch of sea floor was heaved up forty-five feet and it was this sudden displacement of water that created the huge tsunami. Furthermore, there were lateral movements of land toward the sea from the west and north, 30,000 square miles in all.

The main tsunami generated by the earthquake moved out across the Pacific. Once the wave reached deep water its speed accelerated to more than four hundred mph. Within six hours it was in Hawaii and after a few more hours in Japan. The range of the earthquake's influence was evident in other ways. Buildings swayed in Seattle, some ground movement was observed in Texas and similar though weaker movements were felt in Florida. In Alaska, because of the enormous power of the event, hundreds of aftershocks occurred within a few days. The low-lying area in the town of Port Alberni on Vancouver Island's west coast was one of the first places to be flooded. A whole subdivision of homes was destroyed there. Port Alberni is forty miles from the ocean at the head of a sea inlet and the narrowing of the inlet as it reached Port Alberni gave added impetus to the incoming wave. One local resident at the subdivision, standing in her home in a foot of water watched a neighbor's home being picked up and sailing away in the inlet before it disintegrated into floating debris.

South of Port Alberni, a tsunami wave swept up the Fraser River for thirty miles to the Pitt Meadows area, a rich low-lying agricultural region that floods easily in times of heavy rain. Water from the tsunami was equivalent to several inches of rainfall and the farms were flooded for some time. Damage to the west coast of Vancouver Island was greater than anywhere else in Canada. One thirty-eight-foot boat that had been carried out to sea with the retreat of one wave was deposited by a second one in a different inlet. A whole Indian village of twenty homes was washed away and carried out to sea. Only two damaged buildings remained. Seiches in lakes, sometimes causing chunks of ice to be thrown up on to the surface, were commonplace all across southern British Columbia. As the tsunami continued to the south, Washington state suffered very much the same as British Columbia. Again it was the west coast that experienced the greatest damage. Six-foot-high waves shot up over the sand dunes, picking up logs and throwing them around like matchsticks. All along the coasts of British Columbia, Washington, and Oregon, forestry is a major industry and destruction of processed logs a major economic loss.

At Beverly State Park, Newport, Oregon, a family was camping. The tsunami caught them asleep on the shore in their sleeping bags. Four children were washed out to sea and drowned. The worst effects of the tsunami on America's west coast came in California. There, failure of authorities in Sacramento to pass on the warning to coastal areas, especially to Crescent City, a location particularly sensitive to tsunamis, was disastrous. Crescent City, because of offshore underwater seamounts, has always been hit with higher waves than anywhere in coastal California whenever it experiences a tsunami from the north. This time no one there knew of the tsunami until near midnight when the first wave, a fourteen-foot one, struck. One hour later, a common time delay when the tsunami is exceptionally powerful, a sixteen-foot wave arrived and it was followed by a very big withdrawal. That should have warned local people that even bigger waves were yet to come, but it was already nighttime and little information about destruction had reached them. At 1:40 A.M. another wave arrived, twenty-one feet high, and destruction of boats and buildings followed. Several people in different locations lost their lives.

In Hawaii, due to the orientation of the generating fault, the wave heights were smaller than previous tsunamis and caused little damage. Maximum wave heights reached 12.5 feet at Hilo, eleven feet at Kuhului, and only one foot a Kanai. It was a similar story in Japan where the maximum wave height was ten inches. However, while the explanation for Hawaii and Japan seems clear, the question has to be asked, why did a place like Kitimat on Canada's west coast and so close to Alaska not suffer damage? An answer to this question was provided by an expert at Canada's earthquake hazard center. He pointed out that fjords and other inlets along the west coast of North America are able to amplify or dissipate a tsunami by what is called the "natural oscillation frequency" of the fjord or inlet. This natural oscillation factor is the frequency of the natural flow of water in and out of the fjord or inlet and it can either amplify or dissipate the incoming wave. In the case of Port Alberni it amplified the incoming wave.

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Hurricane Betsy

September 9, 1965

Major damage to New Orleans by a hurricane in 1965

Hurricane Betsy was, for its time, the costliest and deadliest hurricane in U.S. history

Hurricane Betsy was a powerful hurricane of the 1965 Atlantic hurricane season, causing enormous damage in the Bahamas, Florida, and Louisiana. While it make its first landfall at Key Largo in Florida, Betsy did its greatest damage after the second landfall on September 9 near the mouth of the Mississippi River, causing significant flooding of the waters of Lake Pontchartrain into New Orleans. Betsy was, for its time, the costliest and deadliest hurricane in the history of the United States and, as the first hurricane with damages over a billion dollars, earning it the nickname "Billion-Dollar Betsy." It killed seventy-six people in Louisiana.

It had formed east of the Windward Islands, and moved north through the island chain as a tropical storm. On September 7, Hurricane Betsy continued moving toward the very south of Florida. It passed over Key Largo at the eastern end of the Florida Keys, and then continued west along the Keys, as a category 3 hurricane. Hurricane-force winds were experienced in the Miami area for roughly twelve hours. At its landfall on Key Largo, Betsy had an exceptionally large eye, forty miles in diameter. After crossing Florida Bay and entering the Gulf of Mexico, it strengthened into a category 4 storm with winds up to 155 mph, only one mile per hour short of category 5 status.

It continued northwestward and, on the evening of September 9, made its second landfall at Grand Isle, Louisiana, just west of the mouth of the Mississippi River, where it destroyed almost every building. At this time it was a strong category 3 storm, causing the Mississippi at New Orleans

Figure 81 Helicopter hovers over flooded area following passage of Hurricane Betsy. Approximately 164,000 homes were flooded in this storm. Little loss of life occurred as residents heeded warnings.

to rise by ten feet. It slammed into New Orleans with wind speeds of 110 mph. Power failures were reported in the city. The Baton Rouge weather bureau, operating under emergency power, warned residents to get extra food that would not have to be cooked, or with little preparation. They also warned residents to store a water supply, have flashlights or other emergency light sources, and keep them at the ready. In addition, residents were told to fill the gasoline tanks of their cars, and check to make sure their battery powered radios had full charged batteries in them, and to secure any small boats immediately.

The storm surge continued into Lake Pontchartrain, just north of New Orleans, and the Mississippi River Gulf Outlet, a deep-water shipping channel to the east and south. Levees for the Mississippi River Gulf Outlet along Florida Avenue in the Lower Ninth Ward and on both sides of the Industrial Canal were overtopped and failed. Water reached the eaves of houses in some places and over some one story roofs in the Lower Ninth

Ward. Some residents drowned in their attics trying to escape the rising waters. It was ten days or more before the water level in New Orleans went down enough for people to return to their homes. It took even longer than that to restore their flooded houses to a livable condition. Those who did not have family or friends with dry homes had to sleep in the shelters at night and forage for supplies during the day, while waiting for the federal government to provide emergency relief in the form of trailers. In all, 164,000 homes were flooded at the second landfall.

As had happened so many times before in New Orleans, the levees proved to be inadequate even for a category 3 storm. The Army Corps of Engineers' Hurricane Protection Program came into existence as a result of Betsy. The Corps built new levees for New Orleans that were both taller and made of stronger material, designed specifically to resist a fast-moving category 3 hurricane like Betsy. The resulting levee improvements failed once again when Hurricane Katrina, a large and slow-moving category 3 hurricane, made a hit close to New Orleans on August 29, 2005. Finally, because of the amount of damage it had caused, the name Betsy was retired from the recurring list of names for Atlantic hurricanes and replaced by Blanche.

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134

Aberfan, South Wales, Britain, landslide

October 21, 1966

A British coalmine tragedy destroyed a school, killing all the children inside

Aberfan, in south Wales, Britain, was a coal mining area. Coal waste was stored on a neighboring site above the elevation of the town. Inadequate care of this waste site caused the devastating landslide

On the morning of October 21, 1966, as school began in the village of Aberfan, South Wales, a heap of coal waste that stood hundreds of feet above the village slipped and swept down on to the school and a row of small houses. One hundred and forty-four were killed by the mass of rock, most of them school children. It was an accident that should never have happened because the heap, known as tip number seven, was known to be unstable. Neighboring mines closed down as soon as it was known what had happened and miners joined in efforts to free the ones buried beneath the rubble.

Every mine has a waste heap—a deposit of the material brought to the surface with the coal then left behind as the coal is taken away. Aberfan was located in one of Britain's biggest coal-mining areas and waste heaps dotted the landscape around it. It was a small village on the banks of the River Taff in South Wales and above it towered the steep slopes of Merthyr Mountain, the site for disposal of the wastes from Merthyr Vale Colliery. Perhaps the very familiarity of these heaps made people less sensitive to their danger. The one that overshadowed Aberfan had been around for about eight years.

The accumulation of waste heaps dated from the early 1900s when

Figure 82 Rescue workers toil in the huge pile of rubble, after the collapse of a slag tip at Aberfan, Wales, October 22, 1966. Many of the local children were killed when the rubble engulfed the village schoolhouse.

mechanical methods of mining became common. It was easy to extract smaller dirtier coal seams by these methods and as a result there were larger than usual heaps of waste. In other countries such material was often taken back down to fill in discarded shafts. In Britain the tendency, at least in this part of the country, was to create artificial hills. Later they were often seeded with grass or shrubs to mask their unsightly appearance. There were no clear regulations in place at the time of Aberfan for periodical inspection of these waste deposits and this was one of the weaknesses later addressed by the Public Inquiry.

Number seven tip was first used in 1958. It lay across some streams from the mountain, unlike others that stood between streams, and this should have alerted authorities immediately. There were several instances in the past when water flows beneath tips had triggered small landslides. As far back as 1927 a mining expert had given a lecture on the dangers of allowing water to accumulate or flow beneath tips. He pointed out that if the South Wales mining authorities did not pay for drainage to draw water away from tips they would have to pay for the higher costs of landslides at a later time. The priority, however, among mine managers was coal and little thought was given to the design of tips. The men who selected the location of number seven tip had no expertise for making that choice.

Waste went up the sides of Merthyr Mountain on rail tracks and then was emptied sideways and backwards on to the tip which gradually rose in height. It was an efficient and cheap storage method. Land costs were negligible and because of the slope more material could accumulate than on level ground before the height raised questions of instability. By the time of the accident, tip seven was over a hundred feet high. Unlike previous heaps it contained tailings—the throwaway material from a froth-flotation process that extracted additional fuel from the mine's output. These tailings tend to harden when dry so workers soaked them before taking them up the slope for ease of handling and dumping. By the time of the accident large quantities of tailings had been deposited here.

The critical factor with tailings is their ability to lower the angle of rest that they finally assume. Because they were made almost fluid in order to transfer them to the tip they flow and create gentle slopes, usually as low as a four-degree angle instead of the twenty-seven degrees that occurs with dry material. All kinds of regulations had been circulated regarding the danger of gentle slopes giving way. Plans were in place to remove tailings permanently from these tips because of this danger and deposit them underground. Nevertheless, the low priority given to the care of waste heaps delayed action on this recommendation and tailings continued to accumulate on tip seven. Local residents continued to express their fears especially after a slide in 1963 washed away the foot of tip seven leaving a steep eighty-foot-high face.

In the months before it finally collapsed, number seven tip displayed further evidence of its basic instability. Its front edge moved downhill thirty feet in six months and its interior collapsed several times over the same period of time. These serious indicators of danger were reported but as in earlier warnings nothing was done about them. On the morning of the massive slide, one more report of this kind was made by workers on the site and this time a manager decided he would start another tip on the following Monday, three days later. He did not have the opportunity to do this but there was more to this event than his reaction. The same decision had been made, for the same reasons, a year before, but was delayed because of difficulty getting the right gauge of railway track.

Within an hour of the manager's response to the workers, 140,000 tons of saturated black rock and mud roared down the mountainside. Men working near the heap saw it begin to slide away but they were not able to see what was happening down the slope because of a heavy fog that day. They also knew that this heap had a history of giving way from time to time and nothing very serious had happened when it slipped in 1963.

Two water mains were broken by the slide and this added momentum to the mass movement of material. The slide began shortly after nine and by eleven o'clock schools and homes had been overwhelmed and all within killed. Intense activity was triggered at once throughout the area especially when it was known that children were the principal victims.

One man whose daughter was reported dead ran to the school from his place of work three miles away and dug down into the ground all day until forced to stop by darkness. At times there were as many as 5,000 people digging away to reach the school beneath. The high level of noise made it difficult to hear cries of help from below. Army units were brought in to control movements of people and cars especially to ensure easy passage for ambulances. Rescuers went on working through the night after floodlighting was brought in. All the time there was the fear of further slippage from above because the rain had been heavy for the previous few days.

For almost three months, the inquiry into Aberfan held meetings and heard from numerous witnesses. The National Coal Board (NCB) bore the brunt of the blame, mainly for continuing indifference to the danger signals that had been obvious for so long to so many. Their inspectors, said the report, were like moles being asked about the habits of birds. No inspector had visited Aberfan for four years prior to the disaster. It was no surprise for the public to be told in the final report that the accident was due to bungling ineptitude by men who were charged with tasks for which they were totally unfitted. A completely new organizational structure was recommended for the NCB to ensure proper care and safety at all levels.

The inquiry urged the immediate digging of tunnels inside the heaps in order to remove the danger of waterlogged slides. It also proposed the re-contouring of these same heaps to remove what had become an eyesore to the villagers. The worst damage of all came much later, the psychological effects on the villagers. More than 150 residents, half adults and half children, needed psychiatric help. Large numbers experienced nightmares for years. Ten years after the tragedy Merthyr Mountain looked very different. All the tips had disappeared and a special hillside cemetery and memorial stood at Aberfan commemorating the victims of the 1966 landslide.

The events at Aberfan featured a few years later at a U.S. coal mining location involving the Buffalo Mining Company, a subsidiary of Pittston Coal, one of the nation's biggest coal producers. This company began using Buffalo Creek as a dump in 1957 just as the companies in Aberfan had done on higher ground. Over the succeeding years it made use of additional sites farther upstream. By the early 1970s the creek consisted of a series of dams behind each of which was a pool of black waste slurry. The Buffalo Mining Company, like others in the region, had a history of ignoring environmental safeguards. In 1967, the U.S. Department of Interior warned state officials that Buffalo Creek dams and twenty-nine others throughout West Virginia were unstable and dangerous. This warning was the result of the Department's intensive studies throughout the state, inspired by the news of the accident in Aberfan, Wales, a few years earlier.

The new method of extracting coal in use by the Buffalo Company had been in operation for some time. It is known today as strip mining, reaching coal from the surface instead of from underground. It can be done where coal seams are close to the surface. The earth and overlying rock is removed and the coal seam is then broken up into smaller pieces by explosives and taken to nearby preparation plants for refining. The coarser waste rock is piled up next to the mined area and the finer coal wastes, including the tailings from the preparation plant, are discharged into an impoundment pond behind the heap of waste rock. Environmentalists are opposed to this method of mining because it destroys large tracts of the land. Mine companies contend that they will restore the ground surface to its original appearance once the mine is closed down.

Mountaintop mining is a variant of strip mining and is common in West Virginia. Here the valleys and their streams adjacent to mining operations serve as repositories so the waste materials are dumped there. Buffalo Creek, in Logan County, is one valley used in this way. This creek flows through sixteen small communities on its seventeen-mile journey to the town of Man. The sides of the valley are steep. The various communities sprang up over the years in response to the changes occurring in the local coal mining industry. From the time of the earliest operations in the 1940s there were many changes in the productivity of the mines with the highest outputs coming in 1970.

Despite frequent warnings in the wake of inspections, nothing was done to make the dams safer. A drainage bypass system that would protect the residential areas was recommended but not done. By February of 1972, concern was widespread as heavy rains deluged the area and the streams and ponds behind the dams and ponds on Buffalo Creek began to rise. These ponds by this time had millions of tons of sludgy material on their bottoms and half a million gallons of waste liquid kept pouring in daily from the preparation plants. The state of West Virginia had cited the coal company in 1971 when a failure occurred in one dam but no action was taken to provide an overflow channel.

Finally on February 26 one big dam on the upper reaches of the creek gave way, taking all the others with it. One hundred and thirty million gallons of water and thirty-five million cubic feet of waste materials roared down the valley at 30 mph. A twenty-five-foot-high tidal wave of slurry, rock, and soil descended on the communities below. There was no time to give warnings to either residents or local authorities; the coal company did not even try. The dam had collapsed at the same spot where it had broken a year earlier. A canyon forty-five feet deep in places was carved out of the valley as home after home was washed away. In all, a thousand dwellings were lost, leaving 6,000 people homeless and 125 dead. Some were able to scramble up the valley sides before the tidal wave reached their location. Others were carried to safety on the tops of their homes as the force of the black water swept the buildings off their foundations. All forms of communication were cut off. This included telephone lines and rail tracks. The high school in Man was set up as a relief center.

Some residents were able to come back and build new homes, aided by modest financial assistance from the coal company. Many of the victims, however, were unhappy with the compensation provided and, aided by a lawyer from a major Washington, D.C. firm, launched a legal claim in federal court. In the course of the legal proceedings it was discovered that this was not the first lethal accident by Pittston and other coal companies in this part of the country. In 1924, a waste pile gave way in Crane Creek, West Virginia, killing seven people and devastating a wide tract of land. Another failure occurred in neighboring Virginia in 1955 when a Pittston Company's waste pile gave way destroying homes and property. The end result of the legal challenge was an award of $13,000 to each of the six hundred claimants, an award far in excess of the amounts given to those who accepted the coal company's offer.

It took years to rebuild the communities along Buffalo Creek at a cost to the state of a hundred million dollars. A memorial monument was built and annually the tragedy of 1972 is remembered in a special service. In response to the Buffalo Creek and other disasters, the U.S. Congress enacted the National Dam Inspection Act, authorizing the United States Army Corps of Engineers to inventory and inspect all non-federal dams. In addition, President Carter issued a memorandum on April 23, 1977, directing a review of federal dam safety activities by an ad hoc panel of recognized experts.

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Hurricane Camille

August 17, 1969

Hurricane Camille, a violent storm, destroyed much of the coast of Mississippi

Camille was one of only three hurricanes in the history of the United States to make landfall as a category 5. It killed 250 people, injured 8,900 more, and did extensive destruction

Hurricane Camille was one of the most violent storms of the twentieth century and only one of three in that century to make landfall as a category 5 hurricane. It arrived from western Cuba on August 14 and entered the warm waters of the Gulf, reaching Bay St. Louis on the evening of August 17 with sustained wind speeds of 190 mph and almost totally destroying the Mississippi coast. Before it left mainland United States it had caused the deaths of more than 250 people and injured 8,900, destroyed 6,000 homes and damaged 14,000. The total costs of the destruction it caused were in excess of a billion dollars.

Millions of Gulf residents were made aware of the strength of the storm before nightfall on August 17. It was seen to be one of the strongest hurricanes ever observed in the Gulf of Mexico since 1947. Before it struck about 200,000 residents had fled the coastal areas into sheltered places. As the storm moved across the coast in darkness, homes, motels, apartments, restaurants, and other buildings were swept off their foundations and deposited in mountains of rubble. It was the same for almost everything movable and for much, like trees, that was not as Camille maintained its hurricane strength for ten hours. On the morning after the storm, thousands searched among the wreckage for anything that might have been left. There was no semblance of normal life in the region around New

Orleans for days but, fortunately, the levees around the city were not affected because the storm was centered a few miles away to the east. About 15,000 people were homeless. There was no water, food, or fuel. The storm had wiped out all means of communication, and roads, bridges, airports, and even railways were impassable or destroyed. Gulfport Hospital had closed down and evacuated all of its patients to hospitals up state.

Adding to the devastated landscape there was a serious vermin problem. There were thousands of dead animals of all kinds, and insects and rodents had quickly overrun the stricken area to feed on these and on the rotting food that quickly accumulates in a hot place like the Gulf Coast. Rattlesnakes, fire ants, and rats bit dozens of victims who were sifting through the rubble. In an attempt to control these ants, low flying planes roared up and down the Mississippi coast, dropping quantities of mirex. At the time of Camille this product was not considered dangerous to humans, but eight years later the federal environment protection agency banned it as a possible carcinogen. President Nixon sent a thousand troops to help and the state governor declared a state of emergency in order to control crime. Using federal troops and state police, all roads leading into the area where the eye had crossed the coast were sealed off. Military and

Figure 83 Fishing vessel driven ashore by Hurricane Camille.

Figure 84 Strengthening levees on the Mississippi as Hurricane Camille approaches.

local police imposed a curfew. The first problem to overcome was the thousands of dead farm animals, pets, and wildlife. Camille's incredible twenty-five-foot storm surge had drowned thousands of animals. Heavy equipment was brought in to bury these thousands of animals and wildlife.

The National Hurricane Center took note of Camille's weather data because of the unusual ferocity of this storm. The lowest barometric pressure recorded on land during the evening of August 17 was 26.85 inches, as recorded at Bay Saint Louis. This was the second lowest barometric pressure ever measured in the United States. Only the 1935 hurricane produced a lower pressure in the middle Keys. That figure was 26.35. The highest tidal surge ever recorded in the United States also belongs to Camille. It was officially recorded as 22.6 feet above mean sea level but high water marks on buildings, still clearly visible long after the storm had passed, showed water heights of twenty-five feet. Camille moved inland and then gradually weakened to a tropical depression over northern Mississippi on August 19. It had picked up a lot of moisture over the Gulf and this led to torrential rain over the mountains of Virginia. In eight hours, twenty-eight inches of rain fell on Nelson County, an amount that more than tripled the state's twenty-four hour record that was set in 1942 and has not been broken since. In other parts of the state, fourteen inches came down during the night. Afterward, Camille turned eastward to emerge into the Atlantic near Virginia Beach on August 20.

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Peru earthquake

May 31, 1970
A Peruvian earthquake overwhelmed and buried
the city of Yungay

The earthquake in west-central Peru triggered a massive avalanche that swept downhill from a height of 18,000 feet

On the afternoon of May 31, 1970, an earthquake of magnitude 7.9 struck an area of more than 30,000 square miles in west-central Peru near the town of Chimbote about three hundred miles north of the capital, Lima. Earthquake-triggered slope failures of all types in the white and black mountain ranges of the Ancash region extensively damaged transportation routes and irrigation canals and temporarily dammed some rivers and lakes. The geologically most important and most spectacular disruption was a massive debris avalanche from an altitude of 18,000 feet on the north peak of Mount Huascaran that overwhelmed and buried the city of Yungay. Altogether 70,000 lives were lost, 140,000 injured, 800,000 lost their homes, and 160,000 buildings were destroyed. Property damage amounted to more than half a billion dollars.

The debris avalanche consisted of one hundred million cubic yards of rock, ice, snow, and soil. The earthquake that lasted less than a minute destabilized the northern wall of Mount Huascaran and created the avalanche, a sliding mass of glacial ice and rock, 3,000 feet wide and one mile long. This mass of ice and rock traveled downhill for ten miles from source to Yungay at an average speed of two hundred mph. Eyewitness accounts of the event told of topographic obstructions as high as five hundred feet being overridden by the avalanche and boulders weighing several tons being thrown forward as far as 3,000 feet. The valley between the two mountain ranges experienced the greatest overall damage, especially in the val-

Figures 85 and 86 Photo (top) shows a city street in Huaraz before the earthquake. This adobe construction is typical of much of the housing that underwent complete collapse in the Andean townships. Photo (left) shows a city street in Huaraz after the earthquake.

ley of the Santa River. Coastal towns were hit very hard with Chimbote having 90 percent of its buildings destroyed. The Pan-American Highway was damaged and that made the provision of humanitarian aid difficult. Most of the fatalities from the earthquake were caused by the collapse of buildings. The buildings, unfortunately, were often located on alluvial fill, and they were made of adobe construction.

This earthquake, the worst natural disaster in the history of the Western Hemisphere up to that time, had an epicenter that was located twenty miles offshore and at a depth of twenty-five miles below the ocean surface. Peru is no stranger to violent earthquakes. There have been many in the past and there will be more in the future. The great heights of the Andes Mountains are a consequence of these earthquakes as the Nazca Tectonic Plate subducts beneath the South American Plate. This movement between the two plates is continuous and the additional continuous westward movement of the continental block of South America, at the same time, speeds up the rate of interaction between these two plates. The Nazca at Peru dips under the continent at an angle of sixty degrees, and earthquakes occur at increasingly greater depths toward the east, reaching a maximum of 380 miles near the Peru–Brazil border. The rupture that created this 1970 earthquake extended one hundred miles to the south. The absence of surface tectonic displacements or of a significant tsunami and the spatial distribution of the main shock and aftershocks suggest that the earthquake originated by movement on a fault, or faults, beneath the continental shelf.

The River Santa flows through a narrow valley, 125 miles in length, one mile wide at its widest point, and all of it at an elevation of 14,000 feet. It lies between the black and white mountain ranges. For centuries the lifestyle of the people who lived in this valley changed very little. The farmland is rich, regularly irrigated with water from the neighboring mountains, providing pasture for rearing sheep and soil for growing corn, wheat, and barley. The people of the valley frequently speak both Spanish

Figure 87 Statue of Christ at Cemetery Hill overlooking Yungay, which together with four palm trees, is all that remains of the city. Peru. 1970.

and the ancient Inca language, Quechua. Some own land and many others are workers employed by large landowners. All of this traditional way of life changed as a result of the earthquake. New communities and new opportunities took the place of the old. The Peruvian government has forbidden excavation in the area where the town of Yungay is buried, declaring it a national cemetery. The few survivors from the Santa River valley were resettled and the government declared May 31 as Natural Disaster Education and Reflection Day, in memory of the deadliest seismic disaster in the history of Latin America.

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Bangladesh cyclone

November 9, 1970

Deadliest cyclone in the history of Bangladesh

Cyclones that strike land from the Bay of Bengal, India, have always caused high death tolls. This cyclone was the worst of all

High tidal waves and tropical storm surges constantly strike the northwest shores of the Bay of Bengal around the delta of the Ganges River. However, the cyclone that struck on November 9, 1970, surpassed all the others in terms of fatalities. It was the worst tropical cyclone disaster in history. The area receiving the main thrust of the storm was Bangladesh, known in 1970 as East Pakistan. The total death toll was estimated to be between 300,000 and 500,000 and it was indicative of the low standards of living and public administration that the range of uncertainty was so great. At the time of the cyclone, tensions were building up between East and West Pakistan because the eastern half was losing out economically and poverty was widespread. Within four months of this storm the two parts of Pakistan would be at war, leaving little hope for effective reconstruction after the storm.

The powerful tropical cyclone made landfall on East Pakistan in the middle of the night with winds of 140 mph and a storm surge of twenty feet that was unusually high because the storm arrived at high tide. The whole area on which the storm struck is low-lying, only a few feet above sea level, so destruction was total. Places just vanished. Bamboo dwellings were carried away and their sites replaced with masses of mud. The low earth barriers that marked off rice paddies and homes provided no protection against the flood of water. Survivors tried to hold on to palm trees until the storm passed. Warnings of the approaching storm had been issued but there were no ways of communicating them to the many living on islands and more distant coastal areas. Large numbers were asleep when the storm surge reached them and they had no chance of escape. Because so much of the land is close to sea level, one quarter of East Pakistan's total landmass was under water for a time.

As news of this disaster reached the outside world, relief began to arrive from both nearby and distant countries. Ferrying in supplies to remote locations by air and rescuing those needing medical attention helped to save many, but the scale of the disaster was too big to reach all who were in need. Starvation, exposure, and disease kept adding to the death toll. A million head of cattle died and an unknown number of fishing vessels had been washed out to sea. More than a million acres of rice paddies were lost with their crops of rice just two weeks away from harvesting. Governments and private agencies decided that cyclone shelters were essential because of the frequency of cyclones. Over the following four years, more than two hundred of these were built with aid money from the World Bank. Another storm arrived in 1985, killing more than 10,000 people. Shelter construction continued, each structure being able to house 1,000 people, until by the early 1990s there was sufficient shelter provision for a third of a million people, a valuable help but far from sufficient for a nation that has many more than one hundred million people.

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Iraq mercury poisoning

August 1971
Seed grain poisoning in Iraq

A donation of seed grain from the United States to Iraq was wrongly consumed by Iraqis because of language difficulties, leading to widespread mercury poisoning

A large shipment of seed grain was sent from North America to Iraq in August of 1971. The vice president of Iraq at that time was Saddam Hussein. He came to that position when the Baath Party he led gained power in 1968. Ten years later he became president of the country and remained in that position until overthrown by the U.S. invasion of 2003. As vice president, in 1971 he was in charge of all military as well as all other government operations. To preserve the grain shipment from damage by insects or rot, it had been treated with a mercury fungicide, harmless if the seed is used as seed but poisonous if eaten. The grain was sprayed with a pink dye to indicate the presence of poison and the Iraqi government warned people not to eat any of it. For various reasons many Iraqis ignored the warnings with the result that hundreds died and many thousands more were seriously injured.

As a part of the Baath Party, Saddam Hussein was vice president of Iraq in 1971. Years before the Baath Party came to power, Iraq, one of the first places in the world to grow wheat, often experienced extended times of low rainfall that ruined its wheat. Iraq in 1971 was still mainly an agricultural economy. Oil had not yet reached the proportions that give it such economic power today. The year 1971 was one of those very dry years and the country decided to change to a new strain of wheat that would be more resistant to climatic shifts. Mexico, also a country of low rainfall, had developed wheat of this kind so Iraq ordered a large quantity of it in the late summer of 1971. A huge shipment of more than 70,000 tons was delivered to the port of Al Basra in southern Iraq and from there it was distributed throughout the country.

The grain was treated with an organic mercury compound, a fungicide to protect against rot or attacks from insects. This treatment is harmless if the grain is used for seed but poisonous if eaten. The sacks of grain were marked against consumption but, unfortunately, the lettering was in Spanish. The grain was sprayed with a red dye as an additional warning but this, like the Spanish words, carried no significance for the Iraqi workers. All who handled the grain shipments were warned of the dangers of consumption and this warning was also relayed to all districts of the country receiving deliveries. The quantities allocated to different parts of the country were in keeping with the amounts used for seed in previous years. Nevertheless, it soon became quite clear that substantial quantities of the grain had been taken into homes and was being baked into bread or fed to animals.

Symptoms of trouble were not evident for some weeks but when they did appear they were catastrophic, the worst ever recorded for this type of poisoning in terms of numbers killed and injured. The epidemic was so great that the government appealed for medical help from European countries. At that early stage, no one knew exactly what had happened. When medical teams arrived they quickly diagnosed the epidemic as due to mercury poisoning. The situation was difficult to monitor as grain had been shipped to several places inland and there was concern that people might panic. Radio blackouts were enforced to keep the information from spreading in order to allow the government time to take control of the situation.

Mercury poisoning is not a new problem. It was well known in England in the nineteenth century among workers in the hat-making industry. A mercury-based product was in use at that time to stiffen the brims of beaver-skin hats. As they worked from day to day, hatters inhaled the mercury fumes and in time suffered brain damage, in some cases to such an extent that they became insane. Lewis Carroll, the author of Alice in Wonderland knew all about this when one of the strange characters in that book was named the "Mad Hatter." In Canada, in the Province of Ontario, between 1962 and 1970, a chemical company dumped tons of mercury into the English–Wabigoon River, a river that was a source of food for the local Indian population of Grassy Narrows. The mercury found its way into the food chain and the fish became toxic. The people of Grassy Narrows regularly ate fish from the river and soon began to show the symptoms of mercury poisoning. The Canadian government took immediate action to help the people of Grassy Narrows and to stop the pollution but the damage had already been done.

In Japan, thousands were affected when a major petrochemical company dumped tons of mercury compounds into the Minamata River over a long period of time beginning in the early 1930s. Nothing was done about this disaster for twenty years despite the evidence of serious health problems in the neighboring town where fish from the Minamata River was a big part of the local diet. Unusually large numbers of mentally-retarded children along with equally disproportionate numbers of young people with other illnesses were noted but nothing was done about it. Autopsies on those who died revealed significant loss of brain cells. The whole tragedy became known as the Minamata Disease. Some indication of the level of mercury poisoning taking place can be gauged if the average amounts found in ocean fish is compared with those caught in the Minamata River, three parts per million in the ocean and fifty parts per million in Minamata. A level of nine parts per million is usually considered very dangerous to health.

Some people in Iraq knew that the grain was poisonous but they thought that if they washed away the red dye they would get rid of the poison. They did this and made bread from the grain. Some seed was fed to animals and when these were killed for food there were significant quantities of mercury in the meat and so the level of mercury that had entered their bodies from the bread was further increased. The compounding of the problem through the food chain did not end with the animals. When the Iraqi authorities were finally able to convince their people that the whole shipment was poisonous, grain that they did not intend to use for seed was thrown into the Tigris River. Once again, as happened with the animals, fish ate what was thrown into the river and when fish were caught from that same river, additional quantities of mercury were ingested.

The consumption of bread from treated grain became the main source of all that transpired. All the recorded cases of poisoning occurred in rural areas where bread was made at home. In the bigger cities where bread is prepared commercially from government-inspected flour there were no cases of contamination. Within three months of the initial outbreak the number of cases peaked with hundreds arriving in hospitals daily. Males and females of all ages were affected with the largest number coming from those under the age of nine. There were equal numbers of males and females. Death rates were highest among the elderly and the very young. In order to minimize the destructive effects of the poison a type of resin was given to patients orally to hasten the elimination of mercury. The longer the poison stayed in the body the worse became the results.

First signs of poisoning were numbness in fingers and toes and other extremities of the body. This was followed by unsteadiness of gait and, where the quantities ingested were substantial, loss of coordination to the point that the person was unable to walk. Eyes were frequently affected with difficulties ranging from blurred vision to blindness. Slurred speech and loss of hearing were present in many cases. In all of these instances it is evident that brain damage was the focus of symptoms. Fatalities were the result of failure of the central nervous system. There was little evidence of damage to the cardiovascular or digestive systems. Those who were severely poisoned died in spite of the medical treatment they received.

There were numerous recoveries among those who had lesser doses of mercury. Among them were people who had become bedridden because they could not walk and who did learn to walk but were unable to regain full control of their body movements. Partial sight was recovered in a few cases where there had been blindness initially. The most persistent symptoms were in the extremities. Even when improvements took place in other damaged organs the sensations of pins and needles on peripheral nerves persisted. Hair samples provided dramatic evidence of the speed with which mercury was absorbed into the body after eating contaminated bread. It happened very quickly and it began to disappear slowly from the body as soon as eating stopped.

The mercury from treated grain can enter the human body orally, by inhalation, or just by skin contact. Oral contamination, the main mode of reception, came from contaminated bread, from meat and other animal products obtained from livestock that had consumed treated grain, from vegetation stored in sacks that had contained the treated grain, and from game birds and fish that had eaten the treated wheat. Unborn children of mothers who ate the contaminated bread received greater amounts of mercury than their mothers, proving that the damage to the unborn is the greatest of all affected populations. In one newborn the mercury concentration was three times that of the mother.

The wheat from Mexico was to be used as seed for the following year and the amounts allocated to the various regions of the country matched the quantities seeded in the previous year. Analyses of the amounts diverted in the rural areas to preparing bread showed that only a tiny portion of the total was used up in this way. On average, a maximum of five pounds of grain were consumed by each of the 6,000 who were admitted to hospitals. That total only amounts to one pound of grain from every six hundred pounds stored for seed, a negligible amount but a dramatic demonstration of the destructive power of mercury when it is wrongly used.

In summary, wheat was purchased by Iraq for use as seed but too many things went wrong. The lessons from Japan's Minamata tragedy were well known and this should have alerted authorities to the dangers of mercury poisoning. The final outcomes of that disaster were published only nine years earlier and they showed that methylmercury was the source of the poison, the same substance that was used to protect the Iraqi shipment. Careful supervision of deliveries and more intensive efforts to alert people to the dangers of consumption could have prevented the disaster. The official figures for casualties listed 6,500 as being admitted to hospitals with severe problems. In total five hundred deaths were recorded but unofficial sources put the numbers very much higher.

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Hurricane Agnes

June 19, 1972
Widespread flooding along the Eastern United States from Hurricane Agnes

Flooding from hurricanes is not the most common concern from these storms but in the case of Agnes it was the main source of all the damage

Hurricane Agnes arrived in June, very early for a hurricane. It made landfall in Florida on June 19, 1972, where its impact was minor, before moving northeastward. The worst damage occurred in parts of northeastern Pennsylvania and upstate New York in the form of heavy rainfall. In Pennsylvania, Agnes combined with a low-pressure area to produce widespread rains of 6–12 inches with local amounts up to nineteen inches in western Schuylkill County. There was widespread severe flooding from Virginia northward to New York, with other flooding occurring over the western portions of the Carolinas. The death toll from this storm was 122 and damage costs amounted to $3 billion.

The large disturbance that became Hurricane Agnes was first detected over the Yucatan Peninsula of Mexico on June 14. It drifted eastward and became a tropical depression later that day and a tropical storm over the northwestern Caribbean on June 16. Agnes turned northward on June 17 and became a hurricane over the southeastern Gulf of Mexico by June 16 and its continued northward motion brought it to the Florida Panhandle coast where it made landfall on June 19 as a category 1 hurricane. As it moved northeastward, Agnes regained tropical storm strength over eastern North Carolina and moved into the Atlantic later that day and so on to its disastrous rainfall regime over Pennsylvania and New York. There was a final landfall near New York City on June 22.

There was severe flooding along the Genesee River, the Canisteo River, and the Chemung River in southwestern and south central New York. The latter two flowed into the Susquehanna River that was already swollen due to winter snow runoff, and flooding continued all the way down this river. It set a flood record at, and threatened to overtop, the Conowingo Dam near the mouth of the Susquehanna in Maryland. The worst damage occurred in Elmira, New York, and Wilkes-Barre, Pennsylvania, but many other communities along the rivers suffered great losses. The Delaware River and Potomac River basins also had some flooding. So much fresh water was flushed into Chesapeake Bay that its seafood industry was badly damaged for several years. The James River in Virginia experienced five hundred-year flooding levels. Downtown Richmond was inundated.

The impact of Agnes on Pennsylvania was highlighted in the events at Wilkes–Barre on June 22. This industrial city on the River Susquehanna suffered a flooding when the river rose thirty-three feet above its normal level in 1936. Dikes were subsequently built to cope with a possible future rise of thirty-seven feet. On June 22, with water nearing the tops of the dikes, volunteers rushed to install a levee of sandbags on the dikes. It was in vain. The river reached forty feet and overtopped everything. By nightfall Wilkes–Barre's downtown was under several feet of water, mud, and debris. Those who were able left for higher ground. The rest climbed to upper stories or roofs to await rescue. Electrical short circuits started fires in commercial warehouses, creating clouds of smoke that hung over the inundated city. Rats, flushed out of their holes, scuttled to the same rooftops that were serving as refuges for people.

People began to name hurricanes in the middle of the twentieth century and meteorologists decided to choose this as a more attractive method than using latitude and longitude for identification. First, women's names were used then, in response to criticisms, names of men and women were employed alternately. An agreed list is established for each season. However, if a storm happens to be particularly destructive, its name is often taken off all lists permanently. The name is listed as retired. Agnes became a retired name after 1972.

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Munich, Germany, terrorism

September 5, 1972
Beginnings of modern terrorism at the Munich Olympics

Eleven Israeli athletes were massacred in a terrorist attack

The beginnings of the modern phase of terrorism exploded into global consciousness on the morning of September 5, 1972, in the German city of Munich during the summer Olympics of 1972 that were being held there. Early in the morning of that day, six days before the games ended, eight Palestinian terrorists broke into the residences of the Israeli athletes. They were dressed in sweat suits and their guns were hidden in athletic bags so for a short time no one noticed them. Before the day was over eleven Israeli athletes, one German policeman, and five terrorists were dead. The remaining three terrorists were taken into custody.

In 1972, the summer Olympics returned to Germany for the first time since 1936 when Adolf Hitler was head of state with his extreme notions of racial purity. This attitude greatly shocked people at the 1936 event when he refused to congratulate a successful black runner from the United States because he thought that blacks, like Jews, were part of an inferior race. Everyone hoped that the Olympics in 1972 would help to remove the bad memories associated with Germany from Hitler's time.

However, six days before the end of the games, Palestinian terrorists killed eleven athletes. The terrorists attacked around 4:00 A.M., and two athletes were killed at the beginning of the attack while nine others were taken hostage. A long day of negotiating followed immediately after. The terrorists were in a hurry to get results and kept threatening to kill the hostages if their demands—the immediate release of two hundred Palestinians from Israeli jails—were not met. German police kept stalling for time and were able to let three of the terrorists' deadlines for results pass without risking the lives of the athletes.

Figure 88 A member of the Arab Commando group which seized members of the Israeli Olympic Team at their quarters at the Munich Olympic Village September 5, 1972, appears with a hood over his face on the balcony of the village building where the commandos held several members of the Israeli team hostage.

Israel traditionally refuses to enter into any negotiations with terrorists and this was no exception. German authorities were in constant touch with the government of Israel throughout the day and knew that there would be no concession from the athletes' home country. The Israeli authorities did immediately offer to fly in a group of their antiterrorist soldiers; unfortunately, the German government did not accept the offer. This was unfortunate because the German police on hand at the Olympic site were ill equipped to cope with terrorism.

Late in the day, German authorities decided to let the terrorists take the nine hostages with them to Egypt. They were taken to the airport but, in a parallel move, the German police made preparations to free the hostages by force. Gunmen were stationed on roofs at the airport and they opened fire as soon as there was some space between terrorists and hostages. The tactic did not work. The gunmen were poor marksmen, they had no night lights, the Palestinians had shot out all the lamps around the area and, to make matters worse, the police thought there were only five terrorists, not the eight that were actually present.

A free-for-all firefight broke out and went on for more than an hour. In the course of the fight, one Palestinian, knowing that he had been double-crossed, threw a grenade into one helicopter where five hostages were being held, blowing it up and killing all five. A second terrorist went into another helicopter that held the other four hostages and shot them. The final death toll was nine hostages, one policeman, and five terrorists.

Three terrorists were taken into custody. The Olympic games were cancelled for a day, then resumed by the decision of the International Olympics Committee (IOC) President, a move that greatly angered many people all over the world.

About a year later, while the three hostages were still in a German prison, some of their friends hijacked a German plane and demanded the release of the three. German authorities gave in and released the men. Israel took note and, over a period of time, hunted down and killed the three along with all but one of the others who had helped in planning the coup. Beginning with plans for the next summer Olympics in 1976, a new and much stricter approach to security began to appear. The IOC insisted on it and such security changes have been evident in all succeeding games. The new face of terrorism, however, did not change and soon the world at large learned that terrorism constantly changes its tactics and its locations, always with the same goal of securing a surprise event that will get global attention. The Pan American flight of 1988 was one of these surprise events.

The flight left London's Heathrow Airport on December 21, 1988, on a nonstop flight to New York. Less than hour after takeoff it exploded over Lockerbie, a small town in the south of Scotland, killing 259 passengers and crew and a further eleven people on the ground. Memories of the tragic fate of Air India 182 three years earlier were still fresh, so terrorism was the first thought on peoples' minds. It was soon confirmed. At the time, terrorist cells from the Middle East were quite active and first suspicions focused on Iran. Earlier in 1988 the U.S. Navy, which was patrolling the Gulf, accidentally shot down an Iranian passenger plane, killing all aboard, so many assumed that this was a revenge attack. Wreckage from flight 103 was scattered over a wide area and the first task for investigators was assembling an army of searchers to scour the area for every fragment of the plane and its contents. It was a massive task and it took a lot of time.

Within a few weeks an area of eight hundred square miles had been thoroughly searched and toward the end of that time the first significant clue came to light. Someone found a tiny piece of the bomb's timer circuit board from a Toshiba radio-cassette player. Very few details were available to help find the places where these instruments were sold. Intensive worldwide inquiries were launched and these led to a European retailer but what followed was an even greater surprise. Most of the sales of the type of player found on Pan Am 103 had gone to government officials in Libya. The focus of the investigation suddenly switched to that country, one that was already well known for its support of terrorism.

While the source of the Toshiba player was being investigated, the picture at the crash site was becoming clearer by the day. The container for the player that carried the bomb was found to be a solid-sided Samsonite case. The case had been loaded into a forward compartment below the cockpit and that meant it was put on Pan Am 103 at Frankfurt. The investigators now knew that the bomb must have been in the suitcase on a flight to Frankfurt on the day of the crash. Had Pan Am 103 not been delayed for about forty minutes at London, the bomb would have gone off over the ocean, making it almost impossible to get sufficient evidence to catch the criminals. A net was beginning to tighten on the terrorists.

Security conditions at Frankfurt Airport on December 21 were anything but good. Despite evidence from the Air India tragedy, only three years earlier, and the new stringent regulations that had followed, passengers and baggage were not properly checked. The critical procedure of matching passengers with luggage was not followed. Whether or not the terrorists knew of this laxity at the airport, it was clearly easy for them to have a suitcase transferred to Pan Am 103 at Frankfurt without anyone accompanying it. The deadly suitcase traveled on a flight from Malta and was put on 103. No one seemed to know about the serious breach of protocol.

The discovery of the Toshiba player and its connection with Libya was a key piece of evidence. It helped at a later time to convict one of the two terrorists involved, but the critical bit of information came along several months later. Searchers at the crash site found the manufacturer's label from a baby's jumpsuit and bomb experts identified it as having been inside the famous Samsonite suitcase. Further investigations traced this jumpsuit to a Maltese clothing manufacturer. There were also other fragments of clothing discovered at Lockerbie that, like the jumpsuit, came from the same location in the plane as the bomb. Investigators went off to Malta to search for answers.

In Malta they had an extraordinary piece of luck, one of those things that happens frequently in television detective stories but rarely in real life. They found a store where the owner not only recognized the list of clothing items as having come from his shop but also remembered when the purchases were made. He explained it was easy to recall the details because they were so unusual. The buyer wanted a tweed jacket, umbrella, and a baby's suit along with a few other things. He paid no attention to the sizes. The storeowner was particularly glad to sell the Harris Tweed jacket. It had been in the store for years because no one wanted it in Malta's warm climate. The description of the buyer closely matched the man who was later convicted, Abdel Baset Ali al-Megrahi, a Libyan intelligence officer.

The story gradually unfolded in 1989 and 1990. Al-Megrahi, aided by another Libyan national, a former airport manager for Libya's Arab Airlines, booked in at Malta's airport on December 21 for a flight to Frankfurt and checked his suitcase. Malta's security was worse that Frankfurt's and the high status of the two men, especially the airport manager, made it easy for them to bypass normal procedures. The role of the Libyan government quickly came into question. Few countries of the world have Libya's strict central control. Nothing of any importance ever happens there without the personal knowledge of the country's president, Colonel Moammar

Gadhafi. In the view of many countries, if two senior Libyan nationals were involved, then others at the very top levels of government were also involved. Most observers were convinced that this was an act of state terrorism.

British and American courts indicted the two suspects in 1991 and asked Libya to hand them over for trial in a Scottish court. Libya refused, so the United Nations Security Council, after making its own request of the same kind, imposed sanctions. Air travel to and from Libya and sales of arms were forbidden as part of the sanctions. Finally in 1999, inspired in part by a desire to remove sanctions, the Libyan leader agreed to release the men. The United Nations Secretary General, accompanied by Nelson Mandela of South Africa, a long time friend of Colonel Gadhafi, were key influences in persuading Gadhafi to release the men. They were able to arrange an internationally neutral site in Holland at which Scottish judges would conduct the trial.

Gadhafi, as part of the arrangement to release the two men, was able to limit the scope of the trial so it focused only on the two men. No accusations against Libya or any other country were permitted. The trial in Holland went on for a year and on January 31 2001 the verdict was handed down. Al-Megrahi was found guilty, mainly on the circumstantial evidence of the Toshiba recorder and the clothing purchases in Malta, and sentenced to life in prison in Scotland. His fellow criminal was set free due to lack of evidence. Additional perpetrators of the bombing have yet to be identified and punished. Few believe that the two men who were indicted were the only terrorists.

State terrorism was a common feature of several countries in the 1980s and Libya was one of these. Despite the sophistication of terrorist acts that had the support and resources of a state, the bombing of Pan Am 103 showed that persistent investigation and skill can find and convict the culprits. One outcome of this tragedy was the awareness by rogue states, as those who condone terrorism are known, of the high cost to themselves of their actions. A second outcome was a renewed determination by airport authorities worldwide to improve security.

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Managua, Nicaragua, earthquake

December 22, 1972

Managua, Nicaragua, experienced a destructive earthquake

The city of Managua suffered extreme damage from the shaking and from fires

On the evening of December 22, 1972, the city of Managua, Nicaragua, was hit with an earthquake of magnitude 6.2. Because the city was hosting a major baseball tournament that had added additional festivities to the pre-Christmas season, little attention was paid to the first tremors. Small tremors are commonplace in this Central American country. As midnight approached the tremors increased in both frequency and strength and homes were shaking with such violence that many people moved out of their homes. Soon fires broke out all over the city, triggered by the earthquake, and a state of near panic developed. All lights had gone out and the smoke and fires made it difficult for anyone to know with any accuracy what was happening. Next morning the details of the tragedy became clear: 5,000 people had lost their lives, 20,000 had been injured, and the whole city looked like a place that was at war.

Two elements in the site of Managua add to the terror of earthquakes. First, the foundation of the city is not solid rock as one might suppose but rather fragments of volcanic material that together add up to a sort of rock cushion, easily disturbed and shaken by seismic vibrations. The other problem is the type of material used in housing construction, a local resource consisting of rough wood frames with adobe and stone infilling and with clay roofs. This type of house collapses easily when an earthquake strikes, as happened here on a grand scale. People were running around, screaming, searching desperately for children and friends who were caught in the collapsed buildings. Medical personnel coped as well as they could

Figure 89 Nicaragua earthquakes December 1972, Managua, collapsed the three-story, reinforced concrete Customs House office building.

as the city's eight hundred-bed hospital broke apart, killing over ninety adults and children. At the local prison, an ancient building, eighty of the prisoners were crushed to death when the building collapsed. About four hundred others managed to escape through the open walls.

Nicaragua like other nations along the western coasts of North and South America is under the influence of subducting ocean tectonic plates and these are the causes of the earthquakes and volcanic eruptions that occur. In Nicaragua's case the subducting plate is the Cocos and it is always moving beneath the Caribbean Plate at a rate of about three inches a year. From the middle of the nineteenth century, when instruments were available for the first time to detect seismic activity in this region, Nicaragua has experienced ten major earthquakes, all of them of relatively small magnitude but, because of the nature of the underlying rock, nevertheless able to do enormous damage. In March of 1931 an earthquake of magnitude 5.6 struck the western part of the city and killed a thousand people. The December 1972 event is regarded as the second most disastrous earthquake in the history of this Central American region.

On the morning after the quake rescuers began the difficult task of disposing of the thousands of unclaimed corpses. Because of the prevailing high temperature, even in December, some bodies had to be doused with gasoline and set on fire. Three days later, because all the bodies had not yet been incinerated or buried, a large part of downtown Managua was declared a contaminated area. It was leveled and covered over with lime.

Help for the stricken city came from many places. Costa Rica, Nicaragua's nearest neighbor nation to its south, sent in a medical team on the day after the quake. On the same day aid arrived from Cuba and Honduras. The United States sent doctors nurses and supplies. Reconstruction began at once and a significant amount of improvement had been achieved in the succeeding five years before political change slowed down the work. Today much of the damage from the 1972 earthquake can still be seen in Managua's downtown area.

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Iceland volcanic eruption

January 23, 1973
People of Iceland save fishing port by pouring water on flows of lava

Iceland stands on the mid-Atlantic volcanic ridge and is constantly experiencing eruptions. The 1973 one was one of the most destructive in the country's history

One of the most destructive volcanic eruptions in the history of Iceland began in the early morning of January 23, 1973, near the town of Vestmannaeyjar, Iceland's main fishing port. It is located on the Island of Heimaey, the only inhabited island in the archipelago of the Vestmann Islands on Iceland's south coast. The strength of the eruption was 3 on the VEI scale, about one-tenth that of Mount Pelee in 1902, but its destructive power was enormous, obliterating one-third of the town of Vestmannaeyjar. It might have been much more destructive were it not for the unique corrective approach taken by the islanders. They sprayed the advancing flows of lava with large volumes of seawater. The result was that the lava flows were slowed down or stopped and on occasion diverted from the undamaged portion of the town.

Iceland is one of the most active volcanic regions in the world, with eruptions occurring on average every five years. This one was the fifth eruption within a decade. About a third of all the basaltic lavas erupted in recorded history have been produced by Icelandic eruptions. Iceland's location astride the Mid-Atlantic Ridge, where the Eurasian and North American tectonic plates are moving apart, is partly responsible for this intense volcanic activity, but there is an additional reason for the presence of so much volcanic material above the surface of the ocean. It is because Iceland stands over a hot spot, just as Hawaii and Yellowstone National Park

Figure 90 View of fishing village in Iceland during volcanic eruption of 1973. Dark, tephra-covered ground is in the foreground, with lava flows into the town and harbor in the background.

do. The mid-ocean ridge where lava emerges from deep within the earth and spreads east and west across the Atlantic is an underwater mountain range extending for 82,000 miles around the earth. However, because of the larger amount of lava being erupted above a hot spot, erupted material from the mid-ocean ridge at Iceland rises high above sea level.

Thus, the state of Iceland is a volcanic island built almost completely of cooled basaltic lava and through the middle of the Island runs the mid-ocean Atlantic ridge, a rare coincidence and a location that is ideal for studying the behavior of the ridge. The speed at which the two plates move away from each other can easily be measured on a site like this using GPS technology. The speed is less than an inch a year. Accordingly, on the east and west sides of the Island of Iceland geologists can locate rocks that are fifty million years older than those emerging from the ridge. If they examine still farther away from the ridge, say on the shore of Greenland for the North American Plate and the west coast of Scotland for the Eurasian one, they can identify rocks that are fifty million years older that the lava that is just emerging from the ridge. Because of its close proximity to the mid-ocean ridge, Iceland has been able to capitalize on the geothermal resources that lie close at hand. In Reykjavik, the capital, all of its heating needs are met from this resource. Approximately 10 percent of all the nation's electrical requirements also come from this same source. The government is working toward making the country completely free from the gases that harm the environment.

The eruption of Mount Eldfell began on the eastern side of the Island of Heimaey, only a thousand yards from the center of the town of Vestmannaeyjar, and soon a fissure more than a mile long opened up. Within two days the lava and tephra cone from the eruption was over three hundred feet high. Volcanic ash and bombs were being emitted at a rate of 130 cubic yards a second. Within a few weeks the cone had doubled in height. The islanders watched as their town was being steadily destroyed, homes wiped out, buildings of all kinds collapsing, and the harbor filling in. The international economy of Iceland was being threatened by the destruction of its key fishing port. The island's 5,300 residents had already been evacuated to the main part of the country. One surge of lava into the eastern part of the town destroyed a large fish-freezing plant, damaged two others, and destroyed the local power-generating facility. Within two months the costs of the eruption had risen to tens of millions of dollars, this for a country that has a Gross National Product of half a billion dollars.

Several Icelandic scientists proposed spraying the lava with seawater to stop it or at least slow it down so that some of the town could be preserved. This decision proved to be the most ambitious program ever attempted to control volcanic activity and thus it became an event that attracted the attention of many other countries facing volcanic eruptions. Efforts were directed at two locations, the northwest of the town where many fish-processing factories were sited, and the entrance to the harbor. Early on it was discovered that the water slowed the advance of lava and also made the front of the flow thicken and solidify. Pump ships were brought it to provide a greater volume of water and their combined output ensured sprays of 40 cubic feet per second. This was sufficient to cool half of the lava flow to a temperature that was below the point of solidification of basalt. The cooling of the lava flow was matched by the creation of diversion barriers of scoria beside the lava. Thus, the partly cooled lava tended to pile up against the barriers rather than burrow under them. Overall water-cooling and construction of lava barriers had a marked effect on both the character and the movement of lava. The eight million cubic yards of water converted five cubic yards of molten lava to solid rock.

Even after the devastation and disruption of lives and livelihood there were some peripheral benefits. The lava and tephra added a square mile to the area of Heimaey. Over a million cubic yards of tephra were cleared away from the town and used to extend the runways on the island's only airfield and to provide landfill for the construction of two hundred new homes. The worldwide interest in what happened in Heimaey meant that Mount Eldfell became one of the most photographed volcanic eruptions in the world.

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Brisbane, Australia, flood

January 21, 1974
Brisbane, Australia, was overwhelmed by floods
from Cyclone Wanda

Brisbane received twelve inches of rain within one twenty-four-hour period and, as a result, both the city and a large area far beyond the city limits were flooded and disconnected from the rest of the country

Australia is quite well acquainted with extremes of climate. It has a very large desert area and its location in a tropical zone means it gets the full effect of the unexpected heavy rains and high temperatures that are commonplace in that part of the world. During the summer of 1974, there happened to be one of the wettest seasons that Australia had ever known. The climatic variation called La Niina had been one of the most extreme of the entire twentieth century. As result of both of these conditions, rainfall was torrential and continuous through most of January 1974, as the inter-tropical zone settled over northern Australia. On January 25 of that same year, Cyclone Wanda moved over the interior of Queensland and New South Wales, dumping more than twelve inches of rain in twenty-four hours over a very wide area. As a result, because of the desert conditions commonplace in Australia, massive flooding occurred on all the nearby river systems because of the lack of soil and vegetation to absorb excessive rainfall.

The city of Brisbane was the worst hit. It had not experienced a major flood for more than seventy years and few suspected that anything like this would ever happen. Sadly, after the last occasion when a major flood had hit the city, in 1893, very strict regulations were established for building on areas below a certain elevation. These restrictions were laid out for the parts of the city that would be at risk in the event of a major flood. These regulations were not maintained for one reason or another and subdivisions were allowed to develop on the areas on which no homes or other buildings were to be built. It is a story that is similar to what we have seen in the aftermath of the San Francisco earthquake, where areas that should never have been built on were once again rebuilt. Throughout Brisbane on January 25 there was a general collapse of disaster warnings. There was no central authority that was able to receive details on the amount of flooding that occurred in different areas, so that local flooding in key areas were never notified to the authorities. About 70 percent of the residents who were questioned afterwards about the flood said that they had received no official warning whatsoever.

January 25, 1974, will be remembered as the time of the worst urban floods that Australia had ever known. Flooding covered an area slightly larger than the entire drainage basin of the Mississippi River. It reached from the dry interior at Alice Springs to the Pacific Ocean and from the extreme north of the country to the areas around Sidney, including the Murray River system. Military air lifts had to be arranged to supply isolated towns that were all cut off by the floodwaters so that emergency food for both humans and animals could be provided by air. In Brisbane all bridges across the Brisbane River were damaged or destroyed and thirty-five people had drowned. At its height, the river broke its bank and ran through the central business district of the city. In one of the subdivisions 1,200 homes were destroyed. Overall, 20,000 people were left homeless. There was no adequate relief organization at this time and about half of the victims depended on church contacts and a large number of volunteers for the help that they did receive. By the end of January much of Australia, normally the dry continent, had vast areas of the inland submerged in water or weeks. Crops were destroyed and there were outbreaks of disease.

Major flooding is not a frequent event in Australia so the disasters of January 1974 stand out in the history of the country. Elsewhere in the world, especially in the mid latitudes, flooding is often experienced. The Mississippi River drainage basin is one of the largest in the world and the largest in North America. Floods have been a constant feature of it since historical records began to be kept, about two hundred years ago. In the early part of that period, perhaps because state rights have always been a top priority in the political life of America, floods on the Mississippi were regarded as the responsibilities of the states affected despite the obvious fact that no state could control conditions up river in other states. All that changed after 1927 when a massive flood occurred. It began when heavy rains pounded the central basin of the Mississippi in the summer of 1926. By September, the Mississippi's tributaries in Kansas and Iowa were swollen to capacity. On New Year's Day 1927, the Cumberland River at Nashville topped levees at 56.2 feet. The Mississippi River broke out of its levee system in 145 places and flooded 27,000 square miles. The area was inundated up to a depth of thirty feet. The flood caused over $400 million in damages and killed 246 people in seven states. Arkansas, Illinois, Kentucky, Louisiana, Mississippi, and Tennessee were all affected. Arkansas was hardest hit, with 14 percent of its territory covered by floodwaters. By May of 1927 the Mississippi River below Memphis, Tennessee reached a width of sixty miles.

The Flood Control Act of 1928 brought the problem of Mississippi floods under joint federal and state control. About 1,800 miles of levees and floodwalls were built along the river's course and floodways were provided to divert water into storage areas or into the Gulf of Mexico. For a time it seemed that these measures were a solution to the problem of repeated flooding but subsequent floods proved that there was no single set of solutions to Mississippi River flooding. The flood of 1993 was far bigger and more destructive that the 1927 flood. It was among the most costly and devastating ever to have occurred in the United States, with $15 billion in damages, an area of flood around 750 miles in length, five hundred miles in width, and with a total flood area of 500,000 square miles. Some locations on the Mississippi River flooded for almost two hundred days while locations on the Missouri neared 100 days. On the Mississippi, Grafton, Illinois, recorded flooding for 195 days, Clarksville, Missouri, for 187 days, Winfield, Missouri, for 183 days, Hannibal, Missouri, for 174 days, and Quincy, Illinois, for 152 days. The Missouri River was above flood stage for sixty-two days in Jefferson City, Missouri, seventy-seven days at Hermann, Missouri; and for ninety-four days at St. Charles in the St. Louis metropolitan area. On October 7, the Mississippi River at St. Louis finally dropped below flood stage–103 days after it began. Approximately 10,000 homes were destroyed as a result of the flooding, with fifteen million acres of farmland inundated, and the whole towns of Valmeyer, Illinois, and Rhineland, Missouri, had to be relocated to higher ground. The floods cost twenty-eight lives and fifteen billion dollars in damages.

If the Mississippi is the main source of flooding in the United States then the Hwang Ho is the principal location for China's tragic history of floods. Officially it is named Hwanghe but, because of its tragic history of floods it is often referred to as the river of sorrow. It has another name too, the Yellow River, and this is the name that best explains the cause of frequent flooding. Along its extensive course it travels through territory where the yellow loess soil is dominant. This soil is easily eroded and then transported by the river. From time to time the amount of soil that builds up in the bed of the river raises the level of the river. A sudden rainfall can then push the river to overtop its levees and flooding occurs. The Yellow River has overtopped its banks ten times within the historic record, often changing course later as it resumes its flow. Historically, after each flooding, the levees are raised to ensure that the next big rainfall will not allow the river to burst its banks. As a result of these successive increases in the height of levees the river flows across the farmland at a high elevation above the surrounding territory. Thus, when a flood occurs

Figure 91 Flooding along the Missouri in the 1970s.

thousands of square miles are flooded and hundreds of thousands of people are drowned. Even as recently as 1887 a single flood took the lives of a million people.

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Kalapana, Hawaii, earthquake

November 29, 1975
In 1975 the island of Hawaii was struck with its strongest earthquake since 1868

The southern part of the Big Island sustained massive ground movements and some smaller tsunamis

A magnitude 7.2 earthquake, the largest experienced in the state of Hawaii since 1868, struck the island of Hawaii on November 29, 1975, killing two people, injuring several, and inflicting property damage estimated at $4 million. The epicenter was two miles offshore from Kalapana. Structural and nonstructural damage in Hilo, thirty miles north of the epicenter, was slight to moderate but was more extensive than elsewhere on the island. Structural damage on the southeast part of the island included minor cracks, slight floor-to-wall separations, and bending of walls at a hospital, at schools, and at libraries. While most of the buildings in the epicentral area sustained little or no structural damage from ground shaking, there were massive ground movements, hundreds of aftershocks, and a brief, small-volume volcanic eruption. The earthquake was felt throughout the island of Hawaii and on the islands of Lanai, Molokai, and Oahu.

The exceptional feature of this earthquake was the damaging tsunami that followed it. Hawaii is a frequent recipient of tsunamis from earthquakes around the Pacific Rim, but rarely does it experience tsunamis from the numerous earthquakes generated within the islands of the State of Hawaii. This particular tsunami consisted of five or more distinct waves. It was the only locally generated destructive tsunami in Hawaii in the twentieth century. It killed two people at Halape, where it reached a height of twenty-five feet and caused property damage. Tsunami damage was also severe at Honuapo, with twenty-foot waves. At one site a mile east of Halape a height of forty-five feet was recorded. Farther away, across the Pacific, the tsunami impacted Alaska, California, Japan, Okinawa, Samoa, as well as the islands of Johnston and Wake. A one-foot wave struck Oahu thirty minutes after the earthquake. This same wave height was recorded at Los Angeles more than six hours after Oahu, representing a tsunami speed of 350 mph. In Japan, eight hours after the earthquake, a wave height of two feet was registered.

Questions were raised by geologists in the wake of the earthquake concerning the origin of the tsunami. Why was there a tsunami following this particular earthquake and not after many others? Kalapana's predecessor, the 1868 quake, was investigated again in search of an answer. Its epicenter had been near that of the 1975 earthquake. They found that it had triggered a landslide on the slopes of Mauna Loa, close to the places affected by the 1975 event, that it had destroyed a village, killing many people and animals, and that it had triggered a tsunami. The final confirming data came from measurements of a slump that was known to exist on the south flank of Kilauea Volcano, an area close to the epicenters of both the 1868 and 1975 events. The slump was found to move regularly in a southerly direction at a rate of four inches annually. From time to time it had an acceleration in its movement, perhaps triggered by an earthquake,

Figure 92 Aerial view of Halape coconut grove on Hawaii Island, Hawaii, after a tsunami was generated by a magnitude 7.5 (Mw) local earthquake. The photo shows the permanent subsidence of between nine and eleven feet at Halape. The local earthquake generated the largest local tsunami of the twentieth century in Hawaii.

and masses of rock rushed down into the sea, creating a tsunami. This was what happened in 1968 and 1975, just as had occurred in the Grand Banks, Nova Scotia, earthquake and landslide on November 18, 1929. Since the events of 1975, geologists have concluded that these recurring slumps are essential stages in the life of volcanic islands. They apply therefore to the entire landscape of the state of Hawaii.

The impact of the combined earthquake and slump on Kilauea Volcano was to distort its southern flank. Both vertical and horizontal displacements occurred, some by as much as ten feet. There were numerous ground cracks and new fault lines were exposed. Roads in the Hawaii Volcanoes National Park were damaged by extensive ground cracking. Landslides occurred on Coast Road. Some displacements of faults caused substantial subsidence, as much as eleven feet in the vicinity of Halape. Farther inland an almost continuous zone of ground was observed cracking and faulting, with five-foot vertical offsets in places, over an area of fifteen square miles. A large part of the coastal area between Cape Kumukahi and Punaluu subsided during or soon after the earthquake. A leveling survey of the bench marks near the Keauhou tidal gauge indicated that the coast had subsided by about ten feet. At the location where two lives were lost there had been a group of thirty-two campers spending the night at the base of a large cliff near Halape. They woke up when a small earthquake shook their place shortly before the main one and decided to move closer to the ocean. As the main quake hit, nineteen of the thirty-six suffered injuries tying to escape both the rocks falling down and the tsunami waves from the ocean.

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Guatemala earthquake

February 4, 1976
Guatemala City was hit with the most destructive earthquake in fifty years

The epicenter was one hundred miles northeast of the city and the earthquake, with a magnitude of 7.5, was powerful enough to kill 25,000 people and destroy most of the homes

In the early morning hours of February 4, 1976, an earthquake of magnitude 7.5 hit Guatemala City. It was the most destructive that the country had experienced in more than half a century. The epicenter was one hundred miles northeast of the city. There were numerous aftershocks, some of them as lethal as the main one. In all, 25,000 people died, 80,000 were injured, 250,000 homes were destroyed, and about one and a half million were left without homes. Damage was extensive.

Most of the adobe-type structures in the outlying areas of Guatemala City were completely destroyed by the earthquake. Access to or out of the city was stopped by many landslides. Food and water supplies were severely reduced. Some of the areas were without electricity and communication for days. The main shock was followed by thousands of aftershocks, some of the larger ones causing additional loss of life and damage. Shock waves were felt as far away as Mexico City. In neighboring Honduras, the earthquake destroyed parts of three towns near the Guatemalan border and caused flooding and power failures. The U.S. government provided an immediate \$3.6 million in emergency aid, and an additional \$15 million came in voluntary contributions from the United States within six days of the quake. The Organization of American States contributed \$500,000, and most other Latin American countries sent food, clothing, medical supplies, doctors, and relief experts.

Figure 93 Guatemala earthquake 1976. Collapse of the Hotel Terminal in Guatemala City, caused by the failure of reinforced concrete columns in its third story. 1976.

Figure 94 Guatemala earthquake 1976. Sustained building damage in the town of Tecpan. 1976.

The fault associated with the quake runs east to west from a point about fifteen miles north of Guatemala Cit to Puerto Barrios near the Gulf of Honduras. During an air reconnaissance of the fault zone, USGS scientists observed fault breakage along a one hundred-mile stretch of the fault. The epicenter of the main shock, where the rupture began, was identified at latitude 15.27 North and longitude 89.25 West, about twelve miles west of Los Amates and south of Lake Izabal. A shorter fault, at right angles to the main one but only four miles west of Guatemala City, added substantially to the damage. In terms of the total amount of energy released by this earthquake, it was only one-sixteenth of the 1906 San Francisco quake. Like California, Guatemala is known as earthquake country. The fault that caused this one separates the great North American and Caribbean tectonic plates so, when these plates slide past each other as these two did in Guatemala, and as two plates do in California along the San Andreas, faults break and the earth shakes.

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Teton Dam, Idaho, collapse

June 5, 1976

Within a year of completion Teton Dam collapsed and devastated a large surrounding area

Through neglect of the advice of geological experts, this dam was built on unstable ground that failed when the dam was filled with water

Discussions about a dam on the Teton River began in the early years of the twentieth century. It would provide additional water resources, flood control, and electrical power. Discussions intensified in the 1930s and again in the 1960s. Then in 1964 the U.S. Congress gave approval for a dam, but construction was delayed for a decade by objections from environmentalists and geologists. By October 3, 1975, construction of the dam was completed and filling began. Eight months later it collapsed and eighty billion gallons of water burst out, devastating everything before it. Eleven lives were lost, 180 square miles flooded, and damages of $400 million incurred.

The project would provide additional water resources to 111,210 acres of land in the Fremont–Madison Irrigation District, local and downstream flood control benefits, water to operate a 16,000 kilowatt power plant, and major recreation developments. Groundwater pumping in dry years would supplement the water supply when surface flows were inadequate. Design called for a 130-foot-high earth-fill structure with a crest length of 3,100 feet including spillway, and a crest elevation of 5,332 feet. The total capacity of the reservoir created by the dam would be 200,000 acre-feet.

For about ten years objections from various groups delayed the start of construction. Environmentalists argued that the dam would destroy seventeen miles of the Teton River, a popular haunt of trout fishermen, and

Figure 95 Failure of the Teton Dam.

remove 2,700 acres of deer and elk habitats. The response to these concerns by the Bureau of Reclamation, the U.S. government agency responsible for the project, was that the benefits from flood control and irrigation would more than compensate for these losses. The objections from geologists were quite different. They insisted that the rock on one side of the proposed dam was weaker than on the other and that a dam on such a site was a formula for disaster. Later events proved them right.

It seems that even as recently as the 1970s, the critical roles of geologists and geology were still seriously underestimated. These neglects were the main causes of the failures of St. Francis Dam in California in 1928 and Vaiont in Italy in 1963. From these tragedies came strong recommendations that geological expertise needs to be given the highest priority in all designs of dams, especially in places where the rock is extensively faulted and where there is a history of earthquakes. The Teton Dam site was a location where both of these conditions were found. The consistent claim of geologists was that one side of the dam was weaker and, therefore, when compacted by the weight of water it would rupture. This in turn would create a leak, progressively eroding the earth structure. Those responsible for the construction of the dam minimized this risk.

A U.S. Geological Survey (USGS) team sent a memo to the Bureau of Reclamation in January of 1973, after construction of the dam had begun, expressing immediate concern for the safety of the project. One member of that team, Harold J. Prostka, returned to the site after the tragedy and pointed out that the site of the dam was in a geologically young and unstable area. He then identified numerous fractures and faults at the site. Other geologists added their comments in the aftermath of the dam failure. Dr. Robert Curry, a professor of geology at the University of Montana, testified that poor site selection and an inadequate approach to design and construction led to failure. He noted that the Bureau of Reclamation's regional study in 1961 dealt with site hazards in a broad manner, barely mentioning permeability. Curry was quite sure that the data on which Congress authorized the Teton Basin Project was inadequate.

Dr. Marshall Corbett, a geologist from Idaho State University, agreed with Curry that the site selection for Teton Dam was wrong. He pointed out that good site selection was important, but the good dam sites had long been used up. Steven S. Oriel, another USGS geologist, voiced concern about the inadequacy of scientific information about the site of the dam. In a final report to the Department of Interior these fears of geologists were confirmed. The report concluded that the design of the dam failed to take adequate account of the foundation conditions and the characteristics of the soil. Following the years of delay, work on the dam was speeded up in the 1970s. This included speeding up the rate of filling from one foot per day to two. The reservoir was completely filled during the months of October and November of 1975. Generator installation followed a month later and then the spillway three months after that. On June 1, 1976, Teton Reservoir contained ten million cubic yards of water with surface dimensions of 3,100 feet by 1,700. The dam, an earth structure, stood 130 feet high. Barely had the work of construction been completed before questions of stability surfaced.

Early on the morning of the June 5, 1976, the first signs of trouble appeared. A hole was seen to be leaking water near the right abutment at 7:30 A.M. and the flow of water was increasing but no one felt the problem was serious. This sort of thing was seen as normal in a new dam. A second leak appeared at 10:00 A.M. and one hour later a whirlpool formed inside the reservoir. A couple of bulldozers were brought in and loads of loose rocks were pressed into the area of the leak. It soon became clear that there was a huge eroded area beneath the leak. Both bulldozers sank down into it and the drivers were just able to escape in time. By the middle of the day no one was in any doubt about the danger. Warning messages were sent out to all places downstream.

Three minutes before noon the dam collapsed and a high wall of eighty billion gallons of water swept down the canyon of the Teton River, taking power and telephone lines, power station and pumping plant, and everything else in its path. Millions of cubic yards of mud and rocks were taken away in the flood and these added greatly to the power of the water when the flow encountered any obstruction. Residents downstream acted as quickly as they could and were able to evacuate the towns of Sugar City, Teton, and Newdale in half an hour. The water rushed through the canyon, largely bypassing Teton, St. Anthony, and Newdale because they were on high ground.

Outside of the canyon the water spread to a width of about eight miles and sped along at ten to fifteen miles per hour. The rushing water hit the town of Wilford and obliterated it, literally wiping it from the map. Sugar City, between the two forks of the Teton River, received the full force of a fifteen-foot-high wall of water crashing down on it. Rexburg was the largest city in the immediate flood area, most of it on the valley floor. The debris-laden water swept past a log mill on the outskirts of town, adding large logs to the flotsam. The logs acted as battering rams, and along with the rushing water, severely damaged buildings throughout the city.

In the evening of June 5, officials of the Mormon church that owned Ricks College, unaffected because of its location on higher ground, offered to help. It supplied food and housing to anyone affected by the flood and Ricks College became a temporary home for many flood victims. On June 6, President Ford declared Bingham, Bonneville, Fremont, Madison, and Jefferson counties federal disaster areas. The water rushing out of Teton Reservoir threatened the venerable American Falls Dam that lay downstream on the Snake River. In an effort to save it, the outlets were opened to full bore in the hope of emptying it in time.

It had to release more water that it ever had to do in the past in order to receive more water than ever before. Concern focused not only on the American Falls Dam, which was an old structure, but also on the smaller dams farther downstream. Water reached the dam on June 7, and fortunately it was able to absorb the full volume of the Teton Dam's flow. When the waters receded, the extent of damage began to be assessed. Eleven deaths were attributed to the dam failure and subsequent flood. Final estimates were approximately one billion dollars. After the flood, repair of damages became the first priority. The Federal Emergency Management Administration (FEMA) was one of the first on the scene. By August 6 all the emergency repairs were completed and the remaining tasks handed over to standing local authorities.

On the twenty-fifth anniversary of the failure of Teton Dam, the Regional Director of the U.S. Bureau of Reclamation spoke of the things that happened in the intervening years. Teton became a new point of departure in the work of the Bureau, profoundly changing all aspects of its work. The Reclamation Safety of Dams Act of 1978 was a beginning, providing funds to analyze and modify structures likely to be unsafe. Thirteen dams in the Pacific Northwest have already been modified under this program. Beyond the 1978 Act, there were many other changes introduced as lessons were painfully learned from the mistakes at Teton.

Since 1976, independent peer reviews are required for all studies of dams and for all designs and design changes. Redundant measures to control seepage and piping (tunnel erosion of soil), special treatment of fractured rock foundations, and frequent site visits by design engineers during construction have become essential parts of the planning and construction of dams anywhere in the nation. Furthermore, dams must be inspected annually and in detail every three years. Every six years dam performance must be assessed under different load conditions, that is with varying volumes of water in the reservoir. The results are measured with new instruments that have already been installed at dams, replacing the uncertainty of visual inspections.

The devastation that followed the failure of Teton Dam is a part of the U.S. Bureau of Reclamation's institutional history but the lessons learned from it are now being lived out all over the country. When the area around Tacoma, Washington, was hit with a 6.8 earthquake on February 28, 2001, it immediately triggered on-site visual inspections of thirty-two reclamation sites, all within a radius of 316 miles from the earthquake's epicenter. There were no reports of damage to dams and no hydroelectric power operations were affected. Further inspections will be carried out on these dams in the springs of the succeeding two or three years, as they experience differential volumes of water, to ensure that the earthquake did not weaken them.

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Seveso, Italy, dioxin spill

July 10, 1976

Seveso is in northern Italy, near the city of Milan

Due to faulty understanding of the chemical processes involved, workers allowed substantial quantities of dioxin to escape into the community of Seveso. This accidental release of dioxin had a revolutionary and costly series of consequences for the people of Seveso

One of the most serious problems facing chemical factories is change from an original design. The reason for a change may be entirely justified but unless the implications are fully understood and the personnel involved informed of the change the result can be catastrophic. The explosion at Oppau in 1921 would never have happened if workers at the plant had been informed of the character of the new compound that had been introduced. The explosion at Icmesa's chemical plant in Seveso on July 10, 1976, was another example of a change in the mode of production, one that led to terrible consequences. It was not a dramatic event when it happened, but its effects were devastating. Observers said that a white cloud shot up from the factory and very soon thereafter they could smell an unpleasant odor. The odor belonged to a highly toxic organic compound known as dioxin that had escaped from the Seveso factory.

The managers of the Icmesa chemical plant at Seveso, near Milan in northern Italy, made a change in the production process after several years of production with the original design. The workers of the factory were very familiar with the original process and some of them had difficulty understanding some key parts of the new process. In particular, they failed to note that temperature control at all stages was absolutely essential. The original plan for the factory was to produce TCP for herbicides and medicines at low temperatures. The chemical process by which the TCP was manufactured created quite a lot of heat and this heat had to be dissipated as quickly as possible as part of the chemical cycle. The method used to accomplish this involved evaporating another chemical, one that was able to cool the immediate environment. In order to lower the temperature even further, as soon as a batch of TCP was completed all parts of the chemical processes involved in production were immersed in a cold-water tank. The whole manufacturing sequence was thus maintained at a very low temperature, a vital consideration because of the dangerous byproducts that might appear under a high temperature regime.

If the temperature of the manufacturing cycle were to rise very high, a whole new product, dioxin, a highly toxic organic compound, would be created in place of the TCP. In addition to cancer, exposure to dioxin can cause severe reproductive and developmental problems. It can also damage the immune system and interfere with hormonal systems. Dioxin was the carcinogenic chemical that caused many tragic outcomes at Love Canal, New York. The great danger of allowing high temperatures to develop was somehow overlooked when a manager at the factory decided to change the original design. The alternative he chose was to use only water at all stages rather than the chemical that was selected for temperature control. Perhaps this was a lower cost approach. Whatever the reason for the change, it required more time and substantial quantities of water to keep temperatures as low as they had been maintained by the former method.

The accident that led to the formation and then the release of dioxin happened on a Saturday morning when workers went off shift, oblivious to the fact that the hot chemicals needed sufficient water to lower the temperature. The newer method of water control was a slow process and these workers did not want to take the time needed. Furthermore, they were unaware of the terrible consequences of overheating. There was one other unfortunate circumstance. On the vents above the reactor where the two chemicals were mixed there were rupture-discs that would open under pressure and remain open.

Had these rupture-discs been of the spring-loaded kind they would have snapped back once the pressure dropped. Thus less gas would have escaped. As it was, heat and pressure built up steadily in the absence of a water shield and dioxin formed. As the rupture-discs opened, a cloud of gas which carried more than two pounds of the lethal dioxin spread out into the surrounding area. It was not accompanied by the kind of noise that would have alerted people to its presence. All that was visible was a small cloud rising above the factory.

A breeze blew the gas southward over Seveso and several communities bordering Milan. The first people to observe the gas plume from the factory and detect a very unpleasant odor rushed home and shut their doors. They found that the smoke and smell were already in the house when they arrived. Through the night they suffered headaches and nausea. Next morning the children had swollen eyes and skin blisters but doctors were unable to say what the problem was. For more than a week, none of the residents of the affected area knew the cause of the discomforts they were experiencing. Their knowledge of the effects of dioxin was quite limited.

People did quickly note that animals were dying by the thousands and leaves on trees were withering. Doctors and hospitals were swamped with patients who had skin problems. People were being evacuated from the most contaminated area and consumption of all local produce was banned. About one week after the explosion Icmesa's officials urged a mass evacuation from the whole contaminated area. The reality had become clear—there had been a medical catastrophe and the effects were likely to last a long time. One regional health officer declared that Seveso had experienced its own Hiroshima.

The heaviest blow of all came still later, after the gas cloud was gone. A report from the U.S. Food and Drug Administration made it clear that dioxin, even in very small doses, can damage kidneys, livers, and lungs. It is also extremely dangerous for fetuses, much worse than thalidomide, so the fear of having deformed children swept across Italy. Doctors in Seveso warned that if they found deformed fetuses in pregnant women they would recommend abortions. This caused heated debate everywhere because Italy is a Catholic country and the Roman Catholic Church opposes abortions.

To stop the spread of contamination, an army of veterinarians in protective suits destroyed all the surviving animals in the affected areas. This was followed by the destruction of cornfields and vegetable gardens, but no one knew how to ensure a complete cleanup. Reports from other countries were not encouraging. In Britain, eight years earlier, a dioxin spill occurred at a chemical factory. The only solution was to pull down the whole factory building and bury it deep in an abandoned mineshaft. Vietnamese experts who had to deal with the effects of defoliation from their recent war warned that it would be difficult to limit the contamination to the area around Seveso. One of the main components of the defoliation in that war was dioxin.

One valuable consequence of the Seveso disaster was the creation of the European Community's (EC) Seveso Directive, a new system of industrial regulation. Within the EC, each country previously followed its own rules for managing industrial safety. Urgent discussions about a new EC-wide regulatory framework for ensuring the safety of hazardous installations started after the explosion at Flixborough in 1974 and then Seveso. Neither the residents of Seveso nor the local and regional authorities suspected that the Icmesa plant was a source of risk. They did not even know much about the type of production processes and chemical substances that occurred there.

The factory had been in existence for thirty years and the only occasional complaints from nearby residents related to unpleasant smells. Of much greater significance were the changes that had been made at both

Seveso and Flixborough. These were changes in plant or processes which compromised the safety of the facilities but were not communicated to the authorities responsible for public health and safety. In light of these disastrous accidents it was clear that new legislation was needed to improve the safety of industrial sites, to plan for off-site emergencies, and to cope with the broader regional aspects of industrial safety.

The Seveso Directive, adopted by the Council of Ministers of the European Communities in June 1982, is the result of those efforts. A central part of the Directive is a requirement for public information about major industrial hazards and appropriate safety measures in the event of an accident. It is based on the recognition that industrial workers and the general public need to know about hazards that threaten them and about safety procedures. This is the first time that the principle of "need to know" was enshrined in European Community legislation. The "need to know" principle is not as strong as the "right to know" principle that is widely applied in the United States.

Although the Seveso Directive grew out of deficiencies in the existing system of industrial regulation, it is not only intended to provide protection against hazards. It also serves to equalize the burden of regulation on industry. The creation of a single hazardous industry code ensures a "level playing field" for trade within the European Community by depriving unscrupulous industrial operators of competitive advantages they might gain by exploiting differences among individual countries. Adoption of the "need to know" principle increases the political equality of decision making and adds a valuable new tool to the regulatory process.

Twenty-five years after the events of 1976 there is a three hundred acre park, Seveso Oak Forest Park, where once stood the Icmesa Chemical Plant. It is a popular picnic site. Beneath it lie the poisonous remains of the dioxin spill stored in two enormous concrete tanks. They contain the top sixteen inches of soil from all contaminated areas, the bodies of animals that had to be slaughtered, and the factory that caused the tragedy. It was taken apart brick by brick by workers in protective suits and placed below ground in the concrete tanks. Water periodically seeps from the tanks into another container where any dioxin remnants are treated.

One extraordinary finding emerged in the years that followed the dioxin leak. Within the first seven years, those mothers who had experienced some contamination, but not sufficient to require an abortion, brought more female babies to birth than males. The proportions were quite exceptional, forty-six females to twenty-eight males among the whole population of births. This was the first discovery of a molecule that could change the sex ratio.

In 1976, Dr. Mocarelli was put in charge of a lab to test affected people. He decided to take a blood sample from each of the 30,000 most affected and keep these samples in refrigerated storage in the hope that one day a test would be developed to tell levels of dioxin from a person's blood. That discovery was made eleven years later and so, as a result of Dr. Mocarelli's foresight, Seveso is today a world capital of expertise for dioxin's effects on humans. Twenty-five years of patients records coupled with original blood samples are available to researchers.

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Tangshan, China, earthquake

July 28, 1976
China's deadliest earthquake in more than four hundred years struck the city of Tangshan

Information about this earthquake was slow in coming because the Chinese authorities did not want to create widespread fear. The official death toll was 250,000 but many experts think that the total was much greater

Early in the morning of July 28, 1976, China experienced its deadliest earthquake in four hundred years. It was probably the worst earthquake in history if we also take account of the damage to property. The official death toll was 250,000, and three times that number of people were injured. Many experts say that the death toll was far greater than the official number. The earthquake came in two waves, an early morning quake with a strength of 8.2 on the Richter Scale and an aftershock that arrived later in the day with a strength of 7.9. Both waves were individually greater than the San Francisco earthquake of 1906. Because it happened less than 150 miles from Beijing, the nation's authorities, fearing another earthquake, told people to stay out of doors. Six million slept outside in temporary shelters for about two weeks.

The epicenter of the earthquake was directly beneath the city of Tangshan so the destruction was total. Those who were not immediately crushed by collapsing homes were thrown six feet into the air and spun around. Some writers have compared the damage to that caused by the atomic bomb in Hiroshima. There was widespread subsidence and this had far-reaching effects on the complex railway system underground as the ground around the city collapsed on to the open spaces below. The railways that reached

Figure 96 Collapse of a classroom and laboratory building at the College Mining Institute. The school was closed when the earthquake occurred, but more than 2,000 students were killed in their dormitories.

the city through the underground tunnels served the main industrial areas of the country, not just those of Tangshan. As a result, much of the nation's industrial activity was shut down. It took a long time for these railway yards and the dead bodies among them to be cleared and the transportation system restored to normal working conditions.

Thousands of holes appeared in the ground everywhere outside the city limits and the earth had split open for several feet in some places. Surface railway tracks buckled and fences were displaced by as much as five feet. Crops and trees were uprooted and blown over to one side. Traditionally, China is very reluctant to report on events as devastating as this one was, partly because of superstitions that still linger and attribute all kinds of political explanations for what are really natural events. There was another reason too for their reluctance to report the event. Chinese authorities had been making extravagant claims about their ability to predict earthquakes and they did not work for this big event. Such a failure does not necessarily discount their ability to predict. It was well known, especially after the research of a Japanese geologist, that the behavior of animals of all kinds is a good indicator of an approaching quake. They always run away from the earthquake site before the quake occurs. This researcher also discovered that bright lights are a frequent accompaniment of an earthquake and it seems that animals can detect these lights more quickly than humans.

Tangshan is a city of, or was before this event, over one million people. It is a large industrial centre and so during the immediate aftermath of the earthquake huge numbers of people were rushed to the scene, medical and emergency staff included, to try to bring temporary help and protection to the many people affected. There were 252,000 killed and another 164,000 injured in various ways. All together there were 125 aftershocks in this general area, with the strongest of these occurring sixteen hours after the initial earthquake. No information was released to the public because the government of China wondered if the city should be abandoned. Later it was revealed that it took three years for the government to decide to rebuild the city. However, many years passed before adequate accommodation was available for the people of Tangshan. For example, in 1985, nine years after the earthquake, only 100,000 people had been re-housed. One of the first decisions of the new city's administration, and one of the reasons for the slow recovery, was the decision to reassess the building code and environmental care arrangements. The previous standards were totally inadequate for protection against another earthquake of the same magnitude.

The overall damage to the city was one hundred percent destruction of all homes and 80 percent destruction of industrial buildings. The damage to these various buildings included collapsed bridges, bent railway tracks, overturned trains, damaged highways, toppled chimneys, broken pipelines, and the cracking of dams. Fortunately, there were no severe occasions of flooding, but liquefaction occurred and it made it almost impossible to move heavy vehicles across the ground. Tangshan is a centre for coal mining, iron, and steel production, and for the manufacture of cement, so the amount of transportation that is conducted there to and from the city is very great. It is a major railway centre and there were more than twenty of these trains passing through the city at the time of the earthquake. Several were overturned and the rest damaged and derailed. Beneath the city tens of thousands of coal miners were at work on the night shift. Fortunately, all of them returned safely to the surface

China is part of the Eurasian Tectonic Plate and over geological time it was steadily pressured westward by the Pacific Plate, the Philippine Plate and the Australian Plate. All three of these tectonic plates are being subducted underneath the Eurasian Plate. The subduction zone for the Philippine Plate includes a deep ocean trench between Taiwan and Japan and a similar zone for the Pacific Plate includes the Japan and the Kurile trenches. These deep trenches, and the fact that so many plates are pushing against the China mainland and moving underneath, are the reasons for the many earthquake warnings and earthquake events that are part of Chinese life. The main reason for this earthquake being as destructive as it was is simply the poor quality of the buildings. They were not built to withstand an earthquake of the strength of that which occurred in 1976.

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France oil spill

March 17, 1978

Supertanker *Amoco Cadiz* lost its steering ability, ran aground, and spilled its cargo of oil off the west coast of France

The volume of this oil spill was more than six times greater than the Exxon Valdez *spill. Lack of clear authority regarding corrective action resulted in almost all of its sixty-nine million gallons of oil being spilled*

On March 17, 1978, a supertanker, the *Amoco Cadiz*, was stranded off the northwest coast of France when it lost its steering ability in a storm and ran on to rocks. The entire cargo of sixty-nine million gallons of crude oil spilled into the sea, covering neighboring beaches with one-foot-deep oil and causing enormous environmental damage. The oil spill was more than six times the size of the 1989 *Exxon Valdez* spill in Alaska.

In the late 1960s and the 1970s, the average size of oil tankers increased to six times their traditional tonnage as more and more oil was being shipped from the Middle East to Europe and North America. Economies of scale demanded supertankers especially when local conflicts around the Red Sea blocked passage through the Suez Canal and ships had to travel all the way round the Cape of Good Hope. These huge tankers, each able to carry more than 200,000 tons of oil, gave rise to major environmental concerns. Ports were not accustomed to handle them and a single accident could be catastrophic. The first shock of the supertanker age came to Britain in 1967 when the *Torrey Canyon*, with thirty-eight million gallons of oil, went aground in the English Channel and lost most of its cargo, flooding the entire south coast of England with black masses of oil. It was the worst tragedy that the nation had ever experienced apart from war times. After all hopes of salvaging the rest of the ship's oil had to be abandoned the British government bombed the wreck, a move that ignited and so burned up some of the remaining oil.

Four years after the *Torrey Canyon*, two large oil tankers, the *Arizona Standard* and the *Oregon*, collided beneath the Golden Gate Bridge and 840,000 gallons of crude oil was spilled into the bay, spoiling beaches and killing thousands of birds just as had happened with the *Torrey Canyon*. This accident happened in the middle of the night and, though radar equipment was installed and working on both ships, little attention was paid by the ships' captains to their positions relative to each other. The *Arizona Standard* was entering the bay while the *Oregon* was leaving. The shock and the resultant destruction to the bay's wildlife woke up the authorities to the need for proper management of large ship traffic. Before long it became evident to shipping authorities around the world that a new day had dawned and new measures would be needed both to monitor navigation and to prepare for coping with potentially massive oil spills. There was little time to lose. Within twenty years of the bay accident five supertankers were plying the world's oceans, each carrying enormous quantities of crude oil:

Amoco Cadiz	1978	carrying	69	million gallons of crude oil
Gulf of Mexico	1979	carrying	140	million gallons of crude oil
South Africa	1983	carrying	79	million gallons of crude oil
Exxon Valdez	1989	carrying	11	million gallons of crude oil
Gulf Cruises	1991	carrying	240	million gallons of crude oil
Uzbekistan	1992	carrying	88	million gallons of crude oil

Environmentalists' worst fears were realized when the *Amoco Cadiz* ran aground off the northwest coast of France, near Portsall, in 1978. It was the world's worst ever oil spill up to that time. The previous two accidents involved much smaller volumes of oil. While six tankers travel along this coast daily, nothing at this scale had ever been imagined. The ship was a couple of miles off the coast when its steering system failed and the vessel drifted in heavy seas on to rocks. Weather conditions in this part of the Atlantic Ocean are usually stormy and March 17 was no exception. Having lost control, the ship was at the mercy of the waves and before long it broke in two releasing all of its cargo of 230,000 tons of crude oil into the sea.

When the captain sent out a distress signal, a German tugboat that was nearby responded and its captain offered to tow the tanker away from the shore and farther out to sea, but at a price. That offer was made around the middle of the day and a three-way telephone conversation soon followed involving the captains of the tanker and tugboat and an official of Amoco, the ship's owner, in New York. The price was $100,000, on the assumption that the situation was one of assistance, not emergency rescue. If it were the latter, costs do not apply as any neighboring vessel is under obligation to assist a ship in distress. The debate went on for twelve hours with the Amoco representative refusing to agree to any payment, insisting instead that the ship was in distress.

French authorities were justifiably angry as they watched the ship drift closer and closer to the shore. They knew that the argument over costs was quite irrelevant as the price being charged was far less than the value of the cargo, yet they felt they were helpless to do anything. The French government wanted to take the Amoco official to court on charges of criminal negligence but later dropped that plan as a more general legal case on responsibility for the spill entered the courts. Amoco's long-standing claim that it feels responsible for all environmental concerns and the welfare of the local people wherever it operates did not make much sense to French officials as they watched the tragedy unfold. They saw the tanker finally breakup on the shore and discharge its entire cargo of oil into the sea.

Hundreds of thousands of tourists visit this coast annually and the economic impact of losing them weighed heavily on the minds of the local business community. Every effort was made to keep oil away from the shore but there was little experience to deal with such a large volume of oil. Skimmers did not work in the choppy seas, typical of this coast, and oil splashed over the tops of booms. Disillusionment with detergents in other spills persuaded them to avoid that approach. The French government thought of bombing the tanker in order to set it on fire and consume the oil still on-board but that was abandoned because the black fumes would damage crops and farms. The only effective course left was to clean the beaches after the oil washed ashore. In France, that job is always assigned to the army.

All along the two hundred miles of coast soldiers used the only tools that would work—shovels. Oil-soaked sand was bagged and carried away while village fire trucks washed soil from rock surfaces. It was frustrating work as beaches would at times be covered with fresh sand, giving the impression that it had been cleaned while still full of oil underneath. Oil would sometimes accumulate to a depth of four inches in harbors, then suddenly be blown out to sea when the wind changed. Approximately 30,000 seabirds died from the oil and more than 200,000 tons of fish were also lost. Many communities along the coast lost their sources of income for more than the year of cleanup as shellfish habitats had to be rebuilt.

Questions were asked in the wake of the disaster. Why did the French navy not respond to calls for assistance? The navy's tugs were closer to the stricken vessel than the one that did offer to help. Why did the ship sail within six miles of land even though international agencies such as the United Nations recommend a minimum distance of fifteen miles from shore? Was the ship seaworthy? As often happens in shipping, the vessel, *Amoco Cadiz*, was registered in an African country in order to gain tax and insurance advantages for the owner. However, when the claimants finally sought damages from the owner, a U.S. judge decided that the oil company was guilty. The company was considered negligent on several counts including failure to train the crew adequately. The ninety French communities that had suffered most were awarded $85 million, about one-tenth of their claim for $750 million. For the 400,000 people concerned, that amounted to less than $2,000 per person.

In 1999, the French government arranged for divers to go down and examine the wreck of the *Amoco Cadiz*. It had measured two hundred feet longer than the *Titanic* and five times more capacious and divers discovered that much of the frame of the original was still in place. The hull stood 150 feet above the sea floor. The divers found the ship's sides torn in several places, creating underwater sculptures of steel. There was no evidence of the oil spill and the seabed seemed quite clean. Swarms of fish covered the ship and each broken or twisted piece of rusty steel served as a potential breeding site. Flatfish like plaice, shoals of anchovies, and sand eels were common. The main bulk of the ship was far from being stationary. It moved gently under pressure from the ocean swell.

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Love Canal, New York, contamination

August 2, 1978

Major health problems arose from a new subdivision on an old industrial site

No adequate examination of an old waste dump adjoining Niagara Falls, before a new subdivision was developed, led to a large number of homes being declared uninhabitable

In the late 1950s, a former industrial site in New York State near Niagara Falls was taken over by the Niagara Falls School Board and an elementary school was built there. Soon after, hundreds of families took up residence in the area. On August 2, 1978, a succession of health hazards arising from old toxic wastes culminated in the evacuation of the whole neighborhood.

Love Canal, so-named after the site's first developer, William Love, was one of the nation's worst waste sites. Its history goes back to Love's dreams at the end of the nineteenth century to build a model community. He was sure that the location, next to the Niagara River, would be very popular. He began construction on a canal that would bypass the cataracts and the falls, linking the Niagara River in this way with Lake Ontario. Hydroelectricity would be produced locally for his new community and the canal would provide transportation. His dreams never came to fruition and his canal was never finished, mainly because of new developments in the transmission of electricity that enabled factories to be located at a distance from their sources of power. Love's canal remained as a ditch 60 feet wide and 1,300 feet in length.

The site remained a recreational area for many years until it was purchased by the City of Niagara Falls in the 1920s and used as a dump for municipal waste. In the 1940s, the Hooker Electrochemical Company bought the area around the canal, set up a factory on it, and proceeded to add its chemical wastes to the canal. There were few homes in the area at this time and the existence of a bed of impermeable clay five feet below the surface seemed to the Hooker Company to justify its suitability for the dumping of chemical wastes. The company felt that the clay barrier would prevent any toxic materials from reaching the wider water channels. Over the period 1942–1954 about 25,000 tons of chemical wastes, partly in sealed drums, were dumped into the canal. The City of Niagara continued to dump waste there too throughout this period of time.

No one knew at the time but later it was discovered that one component of the Hooker Company's waste was dioxin, one of the world's most carcinogenic chemicals, the one that had caused widespread destruction in Sevesco, Italy, two years earlier. The quantity of dioxin deposited in the Love Canal could have been as high as 120 pounds, a huge amount given its toxic strength. In 1954, the Hooker Company sold the land to the Niagara Falls School Board for the token price of one dollar so that it could build a new school there. Numbers of people had been settling in the area and a school was needed. As part of the agreement of sale, the Hooker Company had the School Board accept responsibility for any chemical wastes deposited on the site, leaving Hooker free from any future liability. The completion of the school provided an incentive for more people to move to the seventy-acre subdivision.

Both school and residences were built on top of the old canal, now a grave for thousands of tons of poisonous wastes. By the early 1970s there were eight hundred single-family homes and 250 apartments there and complaints about toxic wastes that had been surfacing since 1954 caught the attention of both Canadian and New York State governments. Unusually heavy rain and snowfalls in 1975 and 1976 raised groundwater levels and things from the old canal surfaced. Fifty-five-gallon drums appeared and oily substances carrying bad odors began to appear around the homes of residents. Complaints exploded, with fears being expressed by everyone both for their health and the risk that their property values were about to plummet. By late 1977, one member of Congress and the Federal Environmental Protection Agency (EPA) became involved and the latter began to examine the basements of the homes closest to the canal.

Hazardous chemicals were found and the New York Department of Health declared the Love Canal area a threat to human health and ordered the fencing of the old landfill site. The school was closed and evacuation of pregnant women and young children began from many of the homes. Health records collected over the previous two years were brought forward and examined. They suggested alarming trends but the accuracy of their links with such local factors as the wastes from the canal could not be established scientifically. The seriousness of the conditions however demanded action. Many of the children born between 1974 and 1978 had birth defects. Miscarriage rates had increased three hundred percent in the same period. Now, as federal and state agencies began to examine the area minutely, pesticides and traces of dioxin were found in the soil. The result was extreme agitation among all the residents.

The community came together and demanded action to deal with the crisis. They finally secured it from Health Commissioner Whalen in Albany who, on August 2, 1978, declared a health emergency, a great and imminent peril to the general public at Love Canal. Whalen recommended that residents avoid using their basements and not eat food grown in their gardens. The earlier moves, fencing off the landfill site and evacuating children and pregnant women, were immediately extended. About 240 homes bordering the canal were purchased by the state with a view to the permanent relocation of those living in them. At the same time, remedial work to contain the wastes from the canal were launched. All of this, laudable as it was, left large numbers of other homes still bordering the canal. Pressure increased from residents for action to protect all who were endangered.

Two developments increased the pressure for more action. Within three months, additional quantities of dioxin were found, this time at some distance west of the canal. The second surprise was the effects of the remedial measures being undertaken. Instead of containing the wastes and limiting their influence the excavation work became accessible to runoff and unexpected quantities flowed into nearby sewers. More homes were purchased by the state and the occupants removed to a new place. About this time intense political debate surfaced, involving local and state authorities and federal agencies, all in relation to how much of the area could be retained for residence. The state concluded that the residential perimeter of the canal was all that need be evacuated. Residents did not agree. They launched legal action and secured the right of temporary relocation from a wider zone.

Meanwhile, the quality of life for remaining residents deteriorated. Homes that had been abandoned and were now separated from the rest of the area by a chain-link fence became a focus for vandals and thieves. Burglaries and fires were common. A further negative factor was a new study of chromosomes in the blood of Love Canal residents by the EPA indicating significant damage. Public protests broke out. On one occasion, federal officials from the EPA were held captive for several hours. Finally, in May of 1980, almost two years after the dramatic events of August 2, 1978, President Carter declared a federal emergency in the Love Canal area, thus clearing the way for the relocation of families still resident in those districts that were farther away from the canal.

Following the declaration of a federal emergency, New York's Governor Carey created a new agency, the Love Canal Area Revitalization Agency. It was given the task of restoring things to livable status. Federal money was provided for a thorough cleanup of all toxic wastes. Abandoned homes were removed and intense decontamination work began. By May of 1982 the EPA was convinced that the area was habitable and gradually, over the years that followed, plans were advanced for resettlement. The Hooker Company, by that time known as the Occidental Petroleum Company, despite earlier agreements, was persuaded to carry some of the costs involved. In 1996, over two hundred homes beside the old Love Canal were sold to new occupants. The Love Canal was once more a flourishing community. Despite all of this good work, the history of the canal is not likely to be forgotten. It is a silent reminder of the dangers that can lie in the ground beneath our homes and remain undetected for decades.

The tragic story of Bhopal in India, an environmental disaster, shook the world six years after Love Canal and yet again, two years after Bhopal, in a European country, human error led to a disastrous ruination of life in and near the Rhine River. In November of 1986 a fire broke out in a Sandoz storehouse near Basel, Switzerland. The storehouse contained more than a thousand tons of one hundred different chemicals. The majority of these chemicals were destroyed by the fire but twenty tons entered the Rhine River, destroying life for over two hundred miles.

The fire had been spotted by a patrol officer shortly after midnight. He saw flames shooting upward from one warehouse in the Sandoz Chemical Company's factory. Many thousands of gallons of water were used in the five hours it took to extinguish the blaze and all of this water, laced with all kinds of toxic chemicals poured into the Rhine River. Virtually the full length of this major European river lay before this stream of poisoned water, all the way to the sea and to all the places en route.

The Rhine River runs through the most populated and most industrialized part of Europe and over most of the twentieth century its pristine waters were so contaminated that its aquatic organisms almost completely disappeared. There are fifty million people living on or very near the river. Things came to a head during the years of World War II as armies crossed the river, further degrading its waters and life forms. Then in 1950 five countries, France, Germany, Luxembourg, Netherlands, and Switzerland, decided to do something about the problem. They formed the International Commission for the Protection of the Rhine.

For some time it had little success. The money needed to clear up the river was unavailable and neither was there the political pressure to make the problem a high priority. It was not until the 1970s when the sorry state of the river began to make news all over the world, crippling Europe's tourist industry, that billions of dollars began to come in from the nations bordering the Rhine. Pollution controls on industries and cities were tightened and strictly enforced. Industrial and population growth increased concurrently but nevertheless the efforts of the reformers made significant gains and several organisms began to appear.

In summary, it took eight years to restore the Rhine to its former health. The river had been destroyed in one day as the devastating pollution from Basel moved down the river. For three hundred miles the stream of toxic water brought death to the river. Firefighters at the scene of the fire had tried to contain the runoff water but a containment wall collapsed and thirty tons of poisonous chemicals were dumped into the water. There were dyes, herbicides, pesticides, and mercury in the toxic soup. The effects were felt all the way to the sea and they were catastrophic. The Commission felt that everything it had accomplished was destroyed.

Sheep that drank from the river got sick and died. Dead fish were everywhere. Scientists predicted it would take at least twenty years for a recovery. It was the worst case of chemical contamination ever in a European river. The enormity of the tragedy created a sense of urgency among the signatories to the Commission and raised public support to a new height. To take advantage of it a goal was set, the recovery of a salmon population that would thrive all the way from the sea to Basel. This goal was to be achieved by the year 2000 and public relations campaigns were launched all over Europe. First tangible results came as early as 1990. Salmon were found to be spawning in tributaries of the Rhine at points 150 miles upstream.

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Three Mile Island, Pennsylvania, nuclear accident

March 28, 1979

America's worst commercial nuclear power accident ever

Failure of water pumps caused a chain reaction of higher and higher temperatures and some radioactive gas began to escape into the surrounding area

The worst accident in the history of U.S. commercial nuclear power generation occurred at 4:00 A.M. on March 28, 1979. It happened at the Three Mile Island installation near Middleton, Pennsylvania, when the plant experienced a failure in the nonnuclear section. The two main water pumps stopped running and a chain reaction followed. Before long radioactive gas escaped into the surrounding area and the governor of Pennsylvania ordered preschool children and pregnant women to stay away from an area within five miles of the nuclear installation.

There are dozens of nuclear power plants operating in the United States, providing electrical power to more than half of the nation's states. An accident in any one of them sends alarms across the country. Hence, when something went wrong with the installation at Three Mile Island in Pennsylvania in March of 1979 it cast a shadow on every nuclear plant in the rest of the country. The companies that operate these plants knew that these power generators have backup systems to cope with accidents and they also knew that if these systems failed there could be a serious tragedy. The Three Mile Island event was what one expert called a common-mode accident. By that he meant an event that bypasses all the backup systems either because of its rarity or because an operator interferes with the safety systems by disconnecting them.

The basic rule in nuclear generators is to have duplicate safety systems for all the important operations so that failure of one will not cause irreparable damage before repairs can be done. These duplicate systems were installed in the Three Mile Island plant but because nuclear power generators were still relatively new at the time not every eventuality was provided for. The heart of the power generator is the fuel cell that is heated by nuclear fission. This heat is used to generate electricity. However, the heat generated by the fuel cell can rise to uncontrollable levels if it is not kept at a safe level and cooling water is the agent that regulates this temperature. A common-mode accident would be an event that cuts off the supply of cooling water. None of all the other safety systems matter if this were to happen; the power plant would be out of control.

The fundamental weakness that gave rise to the common-mode accident at Three Mile Island was the competence of the plant workers. These maintenance people who looked after the installation day and night were well trained for keeping everything in good order, for conducting routine adjustments and repairs on equipment, and for reporting anything that was abnormal. They had spent a year in a training course. Some of them had previous experience on nuclear-powered submarines. They were not qualified nuclear engineers and they had no training for coping with complex emergencies, nor were they supposed to. The automatic systems were designed for these emergencies but, as it turned out, they could not anticipate every eventuality.

The pipes that provide water to the fuel cells have to be cleaned periodically to remove impurities and the workers had been attending to this for some time when one of the pipes became blocked. While trying to clear the pipe, one man accidentally cut off the main flow of water to the fuel cells and, true to form, the power plant shut down. The workers heard some loud noises that confirmed it. This happened around 4:00 A.M. on March 28, 1979. Within a few seconds of the shutdown emergency, water supplies would normally have gone into operation just as the designers had planned and the plant would be ready to start up again. This was the theory and, indeed, all the systems seemed to work as intended, except that a pressure surge due to the sudden cut-off of water popped open a relief valve. This valve should have returned to normal when operations resumed but instead it got stuck in the open position allowing two hundred gallons of water to escape from the reactor core every minute.

The problem was compounded by an error when the operators cut off the emergency water pumps. They had misunderstood what was happening and thought that the reactor core was receiving too much water. They also opened a drain line and this released still more water from the reactor core. These actions stemmed from a lack of information about how much water was in the core at any time. There was no instrumentation to provide this data. In the absence of this information they had been instructed to check the levels in another water tank and conclude that if it were full then the water around the fuel cells would be adequate. Within a few minutes, temperatures within the core rose sharply, the remaining water turned into steam, and the nuclear core fuel rods overheated and began to disintegrate. Three hours later as the plant manager arrived, a state of emergency was declared. Radioactive material and water continued to escape.

No "meltdown" took place as happened at Chernobyl in the Ukraine. That is, nuclear fuel did not "melt" through the floor beneath the containment or through the steel reactor vessel. However, a substantial amount of fuel did melt. Radioactivity in the reactor coolant increased dramatically. Radioactive gas began to spread through small leaks. It reached all parts of the plant and went out into the surrounding environment. Two days after the accident, Governor Thornburgh of Pennsylvania ordered a precautionary evacuation of preschool children and pregnant women from within a five mile zone around the plant. People living within ten miles were urged to stay inside and keep their windows closed. These measures lasted for about a week until the situation at the plant was completely under control and the danger from radiation was eliminated.

Detailed studies of the consequences of the accident were conducted by a number of government agencies and several independent agencies. The general conclusion was that the average exposure to about two million people in the area was 1 millirem. This corresponds to one-sixth of the amount of radiation one would be exposed to in the course of having a full set of chest x-rays. Besides, the natural levels of radioactivity in and around the Three Mile installation are a little over one hundred millirem per year. Clearly, the average amount of radiation was trivial and the maximum that anyone was likely to experience was one hundred millirem. A

Figure 97 A Pennsylvania State policeman and plant security guards stand outside the closed front gate to the Three Mile Island nuclear plant after the plant was shut down following an accident in the plant that allow radiation to escape into the atmosphere.

consensus gradually emerged over the possible long-term damage. It was a risk of one additional cancer death over a time period of thirty years.

In the months that followed, although questions were raised about possible adverse effects from radiation on human, animal, and plant life in the area, none could be directly related to the accident. Thousands of environmental samples of air, water, milk, vegetation, soil, and foodstuffs were collected and monitored by various groups. Today, the damaged reactor is permanently shut down and the reactor coolant system has been decontaminated. Radioactive liquids have been treated, most components shipped to a licensed low-level waste disposal site, and the whole location carefully monitored. Costs of cleanup have been running at 70,000 dollars annually ever since the accident.

Causes of the Three Mile Island accident continue to be debated to this day. The main factors appear to have been a combination of personnel error, design deficiencies, and component failures. There is no doubt that the accident permanently changed the nuclear industry. Public fear and distrust increased. This was the most serious in U.S. commercial nuclear power plant operating history, even though it led to no deaths or injuries to either plant workers or members of the nearby community. It brought about sweeping changes in emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations. Reactor operator training was high on the list of reforms. All electric utilities expanded their training for personnel who work at and support nuclear plant operations.

The cleanup of the damaged nuclear reactor took nearly twelve years and cost almost a billion dollars. The work was challenging technically and with regard to the handling of radiation. Plant surfaces as well as the water used in the cleanup had to be decontaminated. One hundred tons of damaged uranium fuel was removed from the reactor vessel without any harm being done to the workers involved. Waste nuclear material was sent to Richland, Washington, for storage. After the cleanup, reactor number two in the Three Mile Island Plant was placed on long-term monitored storage. It was kept completely free from number one in that, though unaffected by what had happened, it had also been shut down at the time of the accident. The Three Mile Island number one unit was restarted in 1985 and has been working efficiently and safely ever since.

The National Nuclear Academy was instituted to accredit the training of plant staff for all programs. Utilities purchased simulators for the training of personnel who work in the main control rooms. Training reforms centered on protecting a plant's cooling capacity, whatever the triggering problem might be. In the 1979 accident, operators turned to a book of procedures to pick those that seemed to fit the event. In the new training operators are taken through a set of "yes-no" questions to ensure, first, that the reactor's fuel core remains covered. Then they determine the specific malfunction. This is known as a "symptom-based" approach for responding to plant events. Underlying it is a style of training that gives operators a foundation for understanding both theoretical and practical aspects of nuclear installations.

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Mount St. Helens, Washington, volcanic eruption

May 18, 1980

The eruption of Mount St. Helens was the largest in the history of the contiguous United States

This was the most recent in the long history of volcanic eruptions in the Cascades. It had a VEI of 5, making it the greatest eruption of the twentieth century in the contiguous United States

Mount St. Helens is the youngest of the Cascades' volcanic peaks and the explosion of 1980 is just the most recent of the many intermittent eruptions that took place over the past 40,000 years. Pumice and ash from these past events now cover large areas of the Pacific Northwest. From the 1950s onward, the mountain was intensively monitored, perhaps to a greater degree than any other. Days before the fateful event of Sunday May 18, 1980, there were many signs of impending danger but no one was quite prepared for what finally happened—the largest eruption in the history of the contiguous United States.

It all seemed to take place in seconds. Seattle's air traffic control tower tracked the mass of ash and rocks hurtling out of the mountain and concluded it was traveling at close to three hundred mph. The earthquake that triggered the explosion measured 5.2 on the Richter Scale but the energy released might be more accurately defined as the equivalent of thousands of Hiroshima-size bombs. An avalanche of mud, rock, and ice roared down the mountainside while the ash cloud rose as high as 54,000 feet. What had moments before been a beautiful 9,000-foot-high peak was reduced to a 7,500 foot decapitated mountain. Ash, high in the atmosphere, drifted eastward right across the country, covering the ground ev-

Figure 98 The day Mount St. Helens erupted.

erywhere it went with a layer of ash and blocking out sunlight in several communities near the mountain. Two hundred square miles of forest was flattened. Mudflows rushed westward down river valleys toward the Columbia River, blocking the navigation channel for ships with logs and mud for a distance of ten miles. It was estimated that fifty-seven people lost their lives on that first day.

A Boeing 737 jet flying from Reno, Nevada, to Vancouver, Canada, at 6,000 feet, was forty miles south of Mount St. Helens when the mountain exploded. The pilot saw the explosion and swung away from his course, a path that would have taken him directly over the eruption, escaping in so doing a dirty gray cloud that was rising quickly to meet him. His 737 rocked in the air from the shock of the explosion as if it were a ship at sea. Fortunately, his flight had been delayed for thirty minutes at Reno or all 122 passengers plus crew would have been added to the list of deaths for May 18. The explosion that triggered the eruption was an earthquake of magnitude 5.2, not an unusual event in a region that experiences frequent earthquakes of this strength and stronger ones, but the scale of the eruption was a very different matter. It was a rare event even in historical time. Volcanic eruptions are identified by a volcanic eruption index number (VEI) based on the volume and speed of the rock and ash that is ejected. The index is numbered similarly to the Richter Scale, each number representing ten times the volume of the one immediately below it and one tenth that of the next number above it.

For Mount St. Helens the VEI is 5, a volume of eruption greater than that from any other within the contiguous U.S. since 1900. One has to go back into earlier times to find a meaningful comparison. Vesuvius in the year 79 or Krakatau in 1883 each had VEIs of 6; that is, they were ten times more powerful than Mount St. Helens. Volcanoes in the Cascade Range are fairly new in geological time. A few date back several million years. Mount St. Helens is one of the youngest. Much of its visible cone was formed within the last thousand years. It was frequently active during that time and because of that geologists were convinced that a major eruption would occur sometime in the twentieth century. Further evidence in support of that expectation came more recently when it was found that the mountain had been more active and more violent over the past few thousand years than any other volcanic mountain in the contiguous United States. From the evidence in ash deposits across the western Cordillera it is clear that some of these older eruptions must have had VEIs of 6.

The most recent well-documented eruption, prior to 1980, occurred in 1842. Eyewitness accounts from that time described seeing vast columns of lurid smoke and fire. Ash from that time was subsequently located at The Dalles in Oregon, about sixty-five miles away. Fireworks continued intermittently over a fifteen-year period. Then came a three-year lull followed by a lot of activity in the year of 1857. After that date the volcano seemed to have slept for the 123 years before 1980. The moment of eruption on May 18 of that year was indelibly etched on news reporters' memories. David Johnston, the expert geologist from the United States Geological Service, who was monitoring the mountain on the morning of the explosion, talked to news reporters early on that day. He described Mount St. Helens as a keg of dynamite with a lit fuse whose length you do not know. He was well aware of the risks of being so close to the summit but he stayed on there right up to the moment of the eruption. He told the reporters that it was extremely dangerous to stand where they were at that time. "If the mountain explodes," he told them before they left, "we would all die." Soon afterward they heard his final words as he yelled into his radio, "Vancouver, Vancouver, this is it!"

A family watched their $100,000 dream home smashed and washed down the chocolate-brown Toutle River. A couple was on a camping and fishing trip on the same river when they heard the explosion. They tried to grab their camping gear but quickly saw there was no time to escape in their car. They were thrown into the water and carried along in a mass of mud, logs, and rocks, grimly clinging to one log. They were lucky. The log was shunted sideways out of the main stream and some time later, a helicopter picked them up. A television cameraman was aporoximately one mile from the base of the mountain filming the event. He saw the mass of mud and debris heading for him so he dropped everything, got into his car and drove madly to keep ahead of destruction. He was able to stay ahead.

Farther east, travelers were stranded in numerous small communities, altogether 10,000 of them in three states. One couple driving west from Spokane saw the black oncoming cloud. Soon they could only inch along the highway at a speed of about 5 mph. They abandoned their car and joined the other stranded ones. Everywhere around, trains, buses, airplanes, and cars came to a stop. Walking was the only mode of transportation that worked. Digging out from under the ash was yet another hazard. It proved to be as hard as getting around it. For some time people wore masks of whatever material they could find for fear of toxic fumes.

As is common in volcanic eruptions, the magma that had risen and caused the explosion of May 18 left the inner chamber empty for a time until new magma moved up from below. The interior dome then began to grow until pressure rose to a level that caused another eruption. Several of these subsequent eruptions came in May, June, July, August, and October of 1980. By 1983, the dome had grown to six hundred feet and the crater in which it sat was two miles in diameter, waiting for the moment of the next event and meanwhile continuing to grow.

Figure 99 Mount St. Helens in eruption on May 18, 1980. Mount Adams in background. Skamania County, Washington.

Figure 100 The May 18, 1980 eruption of Mount St. Helens caused flooding and sedimentation along the Cowlitz River, Cowlitz County, Washington. 1980.

How can volcanic eruptions and earthquakes be predicted? The answer remains elusive but experience at Mount St. Helens shows us some of the things that can be done. As mentioned earlier in this chapter, this mountain received more monitoring since the 1950s than almost any other and the small number of people who were killed is largely due to this as well as the actions that were taken in the months before May 18, 1980. The first earthquake in Mount St. Helens struck on March 20, 1980, and immediately seismologists met with local authorities to warn of the danger ahead and make some preliminary plans.

One week later, steam and ash exploded from the summit of the volcano and this was followed by several minor eruptions over the following weeks. As these eruptions became more frequent public authorities closed off the area around the mountain, causing heated opposition from the general public. Later they lowered the water level in the Swift Dam reservoir to minimize damage from mudflows. Still closer to the eruption, the state governor issued a state of emergency in order to use the National Guard to staff the roadways. So angry were some over the closure that they found ways of circumventing the law by using little known roads and footpaths to gain access. Many of these people were too close to the volcano when it exploded and died. Some like Harry Truman, a veteran resident of the mountain, refused to leave his home on the north side and died.

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Canada, sinking of oil platform

February 15, 1982
An oil-drilling rig, The Ocean Ranger, was sunk by a one hundred mph storm

The Ocean Ranger *was stationed at sea 170 miles east of Newfoundland. Because of inadequate preparations for windstorms 84 lives were lost*

The *Ocean Ranger*, an oil-drilling rig stationed in the North Atlantic 170 miles east of Newfoundland, Canada, encountered a one hundred mph storm on 15 February 1982. Storm waves swept over the uppermost deck and the rig began to list. A few hours later, in darkness, it sank and eighty-four lives were lost. All rescue efforts failed. It weighed 16,500 tons and was the largest self-propelled, semi-submersible, offshore drilling unit in the world at the time. It was launched in 1976 and spent its first three years off the Alaskan coast in the Bering Sea, then was moved to a position off the coast of New Jersey in 1979 where it spent a year before moving again, this time to Ireland. In 1980 it was moved once more, to the Grand Banks, a relatively shallow area near Newfoundland, Canada.

The *Ocean Ranger* carried a crew of eighty-four and drew oil from the seabed in 250 feet of water. Sixty-nine members of the crew were Canadians. This part of the Atlantic Ocean has large reserves of oil but they are hard to recover because of bad weather. The main supports for flotation and stability were two large pontoons that floated well below the level of the waves. Each was four hundred feet in length, sixty feet wide, and twenty feet in height. They carried most of the everyday needs of the oil-drilling rig, ballast water tanks and water for the oil drills, fuel oil tanks, and various pumps, motors, and control valves. Rising from the pontoons to the lower and upper decks were eight watertight tubular cylinders, some forty feet in diameter and others twenty-five feet. Some of these contained the hundreds of feet of chain for the twelve anchors, each weighing twenty-three tons. In one of them, quite close to the waterline, was the control room, often referred to as the brain of the rig. It was here that damage was experienced on the night of the accident.

The top deck of the rig was seventy feet above the surface of the ocean and measured two hundred by one hundred and eighty feet. Beneath it was the lower deck on which stood the oil drilling equipment. Balance and buoyancy of the whole vessel were maintained from the control room. Water allowed into a pontoon or removed from it was all that was needed to cope with a list in any direction. An operator was always on duty in the control room. A foreboding of things to come was experienced on one occasion. Captain Clarence Hauss, who had taken charge of the rig only eight days earlier, took responsibility for the control room for a short time in place of the regular operator. A slight list occurred and Hauss tried to make the proper correction. He pressed the wrong button and things began to get worse for a few scary moments until someone made the necessary correction.

This experience was typical of the nonpreparedness for emergencies among all the crew. The correct action for Captain Hauss was clearly marked on the control panels. However, he had no way of knowing that there had been earlier problems with the operation of the valves on the pontoons. They were accustomed to behave erratically and brass rods had been installed to make the valves work the way the operator wanted whenever an error was noted in their response to the controls. This was not all that was wrong. Representatives of the oil company had little contact with the daily operations of the rig. They failed to notice that the routine inspection of safety equipment and procedures had not been carried out and the vessel therefore did not have a valid certificate of inspection at the time of the accident. There were no survival suits available on board, essential equipment for anyone operating in the freezing waters of the North Atlantic.

Men were hired to work on the rig but were given almost no training and never had the kind of regular boat drill for emergencies that are standard in other vessels. One man who had been on board when Captain Hauss made the mistake told how the crew was immediately called to emergency stations. Everyone was awakened at six in the morning by an announcement telling him to get warm clothing, put his lifejacket on and go at once to the lifeboat station. Two hours went by before the rest of the men responded and finally sixty-five people arrived at this man's lifeboat that was only capable of carrying fifty-five. This approach on the only occasion when he had to cope with an emergency made him wonder how anyone could escape if a crisis occurred in the middle of the night in the midst of a violent storm.

Late on the evening of February 14, 1982, a violent storm reached the *Ocean Ranger*. Winds built up to one hundred miles an hour and the crew on the lower deck removed the drilling pipe as a precaution. Waves rose to forty feet. By removing the drilling pipe the vessel was free to move and would present less resistance to the wind. One wave broke a porthole in the control room and some water came in. Three hours later, the operator reported to shore that all had been repaired and there was no more water on board. However, damage had been done to the electrical system and two hours after that report lights went out and electricity failed in the control room. The ballast pontoons could no longer be controlled. Standby ships are supposed to be within two or three miles of an oil-drilling rig at all times in order to assist in case of an emergency. Because of the storm, the ship that was supposed to be on hand for the *Ocean Ranger* drifted eight miles away. When a call for help came from the rig about an hour after midnight this ship was unable to give immediate help.

The *Ocean Ranger* listed ten degrees and an emergency was declared. When the standby ship did arrive an hour later and tried to make contact with one of the lifeboats that had been launched, the boat collapsed and the men were thrown into the sea. The reality of the situation was that neither the *Ocean Ranger* nor the assisting vessel had any competence for the crisis that arose. An hour later the oil rig capsized and sank taking the rest of the crew down with it. It took two years for their family members to receive some sort of financial settlement for their loss. Ultimately, they did not receive a large amount of money, and legal fees absorbed 30 percent of it, but on the whole it provided for the needs of their children until they were through school.

The *Ocean Ranger* disaster was a great loss to the growing offshore oil industry. The Royal Commission that considered the disaster reported that the engineering design was inadequate and unreliable, especially in relation to the control room. That heart of the vessel should have been able to resist the wave strength it encountered and should not have had its electricity system knocked out. The Commission also criticized operations generally, stressing that management arrangements were very weak. Finally, the absence of any system of inspection by either Canadian or U.S. government agencies was listed as a glaring error.

A good example of the way things should have been done can be seen in the Hibernia, a new high tech offshore drilling rig that was built subsequently and placed where the *Ocean Ranger* had been. The Hibernia was fitted with eight lifeboats, each able to carry seventy-two. Each lifeboat was equipped with launching systems and three life raft systems, thus providing an evacuation capacity for three times the number of personnel on the rig at any one time. Beyond all of this redundancy it was also possible to evacuate personnel directly from the rig to a standby vessel without resorting to launching lifeboats or life rafts into the sea. Today there are three oil-drilling rigs at work off the east coast of Canada, Hibernia, Terra Nova, and White Rose but the new reality, made all the more urgent in the wake of the tragedy of Sikh terrorism in 1985, is more about external dangers than about coping with the weather.

New regulations were introduced in 2007 to ensure that no potential terrorist, whether by submarine, surface vessel, or airplane, could approach one of these rigs without being thoroughly checked. These regulations had to be able to override the various local security provisions of the different provinces on Canada's east coast. Information on potential terrorism, for security, has to be limited to a small number of people. Thus the people with knowledge of threats had to be free to act on preventive action with or without the agreement of local authorities. Rules of this kind were already in place on oil-drilling rigs off the coasts of the United States and Australia but it took some time for Canada to make similar arrangements. The long history of inter-provincial battles over rights led to delays before the new rules were put in place.

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Coalinga, California, earthquake

May 2, 1983

Coalinga, about one hundred miles northwest of Bakersfield, CA, experienced a surprise quake

Since no known faults had been identified in this area, no one expected this earthquake

On May 2, 1983, an earthquake of magnitude 6.5 occurred about eight miles northeast of the town of Coalinga. It was a surprise quake since no known active faults had been identified within historical time anywhere near the epicenter. Subsequent investigations revealed that the quake was associated with a deep concealed fault that was twenty miles northeast of the San Andreas Fault. The area as a whole had recorded only low levels of seismicity within historical times. This earthquake caused an estimated $10 million in property damage and injured ninety-four people. Damage was greatest in Coalinga where the eight-block downtown commercial district was almost completely destroyed. Nonreinforced brick walls did not stand up at all but newer buildings such as the Bank of America and the Guarantee Savings and Loan buildings were only slightly damaged.

Outside of Coalinga the worst damage was at Avenal, twenty miles southeast of the epicenter. Altogether 309 single-family homes and thirty-three apartment buildings were destroyed and 558 single-family homes, ninety-four mobile homes, and thirty-nine apartment buildings suffered major damage. There was minor damage to 811 single-family homes, twenty-two mobile homes, and seventy apartment buildings. All public utilities were damaged to some degree, delaying service for different lengths of time for all of them. There were thousands of rock falls and rockslides outwards from the epicenter as far as twenty miles northward, ten miles

Figure 101 Coalinga, California, earthquake, May 2, 1983. House displaced from its foundation, as shown by movement of its columns. The house was in the restricted area of heavily damaged downtown Coalinga. May 7, 1983.

south, and fifteen miles to the southwest. The quake was felt from Los Angeles to north of Sacramento and from the coast to Nevada. Numerous aftershocks were recorded.

The town of Coalinga is almost completely surrounded by oil fields. The history of oil in this area dates from the late 1800s. By the 1990s, production was running at a rate of 14,000 barrels per day. Drilling continued to spread more widely in the Coalinga oil field as a whole despite the fact that oil prices in that far off time of 1905 was only fifteen cents a barrel. By 1920, production reached sixteen million barrels per day and almost immediately afterward a protracted strike by oil workers stopped production for most of the following years until World War II. Beginning in the early 1950s a new venture was launched in Coalinga, the injection of steam pressure into shallow tar sands, the same method that is today in use in Alberta, Canada, on a vast scale. For Coalinga the method proved to be economically viable and this approach along with others added up to a billion barrels of oil being produced before the earthquake of 1983 brought everything to a stop.

Damage to individual wells was seen in the representative case of Shell Oil. There, only twenty-six out of their more than nine hundred active wells were severely damaged. All electric power to the oilfields was cut when the earthquake struck. Several days were needed to repair downed lines and repair damaged transformers. Although no pumping units were heavily damaged, a large number were knocked out of alignment by as much as four inches. Most of Shell Oil's pumping units were displaced. Oil tanks were damaged in various ways while pipelines fared quite well.

The numerous leaks that developed were easily repaired. Buckling and cracking were common on roads and slumping frequently appeared on cut-and-fill slopes and on berms.

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Bhopal, India, gas poisoning

December 3, 1984
Thousands killed by an escape of poisonous gas
from Union Carbide's factory

Union Carbide's factory was built to provide insecticide for India's farmers so they would not lose crops. When demand for insecticide dropped Union Carbide began to cut costs wherever it could and, in the process, created circumstances that led to the disaster

In the early hours of December 3, 1984, tons of poisonous gas escaped from Union Carbide's factory at Bhopal, India. Methyl isocyanate, a highly toxic substance, was being processed here to produce insecticide for farmers. The nighttime gas leak caught people still in their beds. Eight thousand were killed and another quarter million injured, some very seriously. The problem began late on the evening of December 2 when water entered one of the big storage tanks containing methyl isocyanate at some stage of conversion. A chemical reaction was triggered and both temperature and pressure rose quickly. Officials at the plant knew what was happening and could also see that pressure was going to build up until something gave way but they were unsure about what to do.

A warning siren was available to warn local residents of any danger but workers were slow in turning it on. Shortly after midnight, the storage tank was breached and gas shot outward. Even then, no siren was sounded for an hour. By that time an area of more than fifteen square miles was contaminated and thousands were dying. Bhopal was a city of 800,000 people, mostly Moslems, which had tripled in size over the previous twelve years, largely due to the arrival of Union Carbide's pesticide plant in 1969. The first ten years of the plant were highly successful and adequate safety precautions were in place. Indian chemical engineers were

Figure 102 This photo shows some of the thousands of people stricken by a poisonous gas leak from a Union Carbide pesticide factory in Bhopal, India, on December 4, 1984. Poisonous chemicals leaked from the plant during the night, killing more than 2,000 people and affecting 200,000 others.

taken to the United States for training and then brought back to their own country to oversee operations and train new staff. By the beginning of the 1980s it was a different story. Huge losses had overtaken the company, partly due to lack of demand for pesticides. The green revolution, the use of new and better grains for seed, was yielding a surplus of food and there was less need to buy expensive pesticides in order to reduce losses from insects.

As profits slumped, cost cutting measures appeared. Instead of sending their chemical engineers to the United States for training, men who had taken some university science were given a four-month crash course locally and then handed major responsibilities within the plant. These people were not qualified chemical engineers so they could be paid less, thus reducing the budget for staff. For people at this level of responsibility it was usually $30 a month. The level of training steadily deteriorated with each group of new workers. Additional workers were frequently needed because the best-trained chemical engineers often left for better pay and greater security elsewhere. Men were hired to work in the very sensitive and highly toxic Methyl Isocyanate (MIC) Unit with limited training and little practical experience. This was the unit that had been a highly controversial addition to the plant. It was added in 1980 for the same reason that lay behind other decisions of that time—it was cheaper. Bhopal was the only Indian plant to use this chemical and the company's U.S. plant in West Virginia was the only other one using it. In addition to the risks associated with MIC, instead of the safer yet more expensive chemicals used at all the other Indian plants there was the challenge of adding one more building to the Bhopal installation to store MIC.

Local government leaders knew that Union Carbide's factory should never have been built where it was. It was too close to areas of concentrated settlement and, since it first opened, more and more people moved to places close to the plant. The local officials were faced with a big addition because Union Carbide decided it would save a lot of money if large quantities of MIC were stored at the site instead of frequent additions of small amounts being added from time to time. The city administrator was insistent. He asked the company to set it up farther out, away from the populated areas in order to avoid tragedies like the one that hit Mexico City only a few weeks earlier and killed large numbers of workers whose homes were close to the plant. In the debate that ensued, the company won out and the city administrator lost his job. He said it was not due to the position he took over the MIC unit but others wondered if that was really true.

Symptoms of the victims who were exposed to the poisonous gas took different forms depending on distance from the factory. They included immediate irritation, chest pain, breathlessness, and if no help was at hand the problem developed into asthma, pneumonia, and finally cardiac arrest. Almost nothing was known by those affected as to what to do in a tragedy of this kind. Had they known, simple protective measures were possible. If, for example, a wet cloth is placed over nose and mouth until help arrives, many lives can be saved.

The accident shocked the world and Union Carbide, the United States parent company, was particularly concerned because it operated a facility of the same kind in West Virginia. Some months later on, in August of 1985, that same plant experienced a leak like the Bhopal one but fortunately safety measures were in place to prevent widespread damage. For the people of Bhopal, similar safety measures were almost nonexistent. The failure to anticipate the developing leak was only the beginning. An analysis conducted in January of 1985 revealed that safety measures were totally inadequate. A refrigerator designed to prevent dangerous chemical reactions in storage tanks had been shut down, ostensibly as a cost-cutting move. Had this been in place the build up of pressure and the resultant leak would never have happened. A mechanical vent scrubber to detoxify escaping gas with caustic soda was not working. A network of waterspouts for neutralizing toxic gas was also inoperative, and so was another safety installation, a high-flare tower that would burn off dangerous gases high in the air. These conditions together with evidence of unreliable instruments throughout the plant confirmed the investigators' findings. Bhopal's security was totally inadequate.

Bhopal had experienced as many as six smaller accidents in the previous three years, all of them related to gas leaks, most frequently chlorine, a part of the methyl isocyanate manufacturing process. This particular gas is best known because of its use as poison gas in World War I. Chlorine comes from simple salt. Once broken away from its partner sodium, chlorine becomes a heavier-than-air gas, and an unstable chemical. It will recombine easily with carbon, and with material in the bodies of living things. But the chemical combinations formed by chlorine are known to cause cancer and other diseases. A single accident at a chlorine plant has the potential to kill hundreds of thousands of people. The accident at Bhopal killed 8,000 and injured a quarter million more. Fallout from the accident was felt across the chemical industry. Safety audits and new regulatory standards became a primary focus of government and industry. Nongovernmental agencies increased their public awareness campaigns to ensure there would never again be another Bhopal. Concerns about technology transfers, the relations between economic and environmental issues, and the interests of labor all led to intense debate over public policy. In India, The Disaster Management Institute was formed to provide long-term planning in order to prevent future industrial accidents. The chemical industry responded with the formation of The Center for Chemical Process Safety to develop management strategies for the industry.

Poisonous gas spilled from a Union Carbide plant at Institute, West Virginia, in August of 1985, sending 130 people to hospital. The cause of the accident was almost identical to the one that was caused by the same company on a much bigger scale in India. New equipment had just been installed to make the plant safer but something went wrong. The lessons from Bhopal had not yet been learned. The plant at Institute produced the pesticide Temik from MIC just like Union Carbide's operation in India. Before the Bhopal tragedy the company transported MIC to other plants across the United States. After Bhopal, public concern forced the company to convert MIC to a less toxic chemical, aldicarb, before shipping it to other locations. This concern was heightened when the cause of the accident was known. The very same thing that went wrong in India was repeated when a valve failed and aldicarb heated up, bursting the container and escaping outside.

Within twenty minutes of the accident Union Carbide notified local emergency services. Fifteen minutes later the gas reached the town of Institute. People were warned to stay indoors but many were caught outside. These suffered from irritations to eyes, nose, throat, and lungs. It appeared that aldicarb had broken down into more volatile irritants in the course of being heated up before it escaped. The runaway reaction was identical to what happened in India. Fortunately, in West Virginia, action to correct the problem was quick and effective. Some concern remained after the accident, particularly since its cause had been directly related to the installation of a new warning system designed to prevent the kind of thing that happened at Bhopal. The new system, known as "Safer," analyzed wind speed and weather conditions on a continuing basis in order to predict the movement of escaping gas in case of a leak. Unfortunately, once again, even at the headquarters of the chemical company's operation, the new safer system failed to work.

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Air terrorism

June 23, 1985
Sikh terrorists who had moved to Canada blew up
an Air India airplane

These terrorists had been fighting for an independent state within their home country of India but they decided it would be easier to carry out terrorist acts in Canada

Sikh terrorists who had moved to Canada and were now Canadian citizens were inflamed by the actions of the Indian government in their homeland where, in 1984, Indian soldiers, acting against local militants, destroyed the Golden Temple in Amritsar, a sacred site for the Sikh religion. The Canadian Sikhs, in revenge, on June 23, 1985, placed bombs on two Air India flights out of Vancouver. It was Canada's first experience of terrorism and it led to the involvement of five nations and the deaths of 331 innocent people before it was all over. The worst features of all were the incompetence of Canada's security services and the successful cover up latterly by the perpetrators of the crimes. In spite of warnings from the government of India, Canadian security services failed to maintain a close watch on those members of the Sikh community who had already engaged in violent action against India's offices in Vancouver and who went on to plan their terrorism. After the tragedy, those same Sikhs made sure that they would not be caught by carrying out assassinations of two known witnesses and ensuring that other potential witnesses would not testify against them by using threats and assaults, behaviors that were more akin to the tactics of criminal gangs than to anything in everyday Canadian life.

The whole disaster became a wake-up call to Canada. Terrorism was no longer an event somewhere else. The nation's security service was well aware of all the violent acts that had occurred around the world since the murder of Israeli athletes at Munich in 1972, but somehow it assumed that similar violence would not happen in Canada. Even the actions of Quebec terrorists in 1971 failed to alert the nation. For example, early in 1985 Prime Minister Rajiv Gandhi was due to visit New York and a Sikh friend in Germany used an ordinary telephone line to call one of the Vancouver terrorists, offering to go to New York and assassinate the Indian prime minister. Canadian security services monitored that call but took no action to alert the New York Police for a whole month. Finally, they did send a warning to New York two days before Gandhi arrived but no action was taken to monitor the movements of the person who had received the message from Germany. Thus, it was very easy for one particular Sikh to book seats by telephone on two Air India flights that were due to leave Vancouver on June 23, 1985, then to arrive on the day of the flights with cash to pay for the flights and to check two pieces of advance luggage. At that time the rule of passengers having to accompany their luggage was not in effect. You could check baggage and later fail to turn up for the flight as happened with this man.

One flight was to Lester Pearson Airport, Toronto, and from Mirabel Airport, Montreal, on Air India 182, for ongoing travel via London to India. The other flight went to Narita Airport, Tokyo, on a Canadian Airlines flight and L. Singh's luggage was to be transferred at Narita to an Air India flight. M. Singh was booked on the Toronto flight and L. Singh on the flight headed to Tokyo. Their suitcases went on to Toronto and Tokyo, each carrying a bomb that was timed to go off on the Air India flights somewhere over the ocean. M. Singh who was going to Toronto was on a wait list for the Air India flight but he asked that his luggage be sent on to India even though he did not have a ticket for that flight at the time. The agent at the airport refused to do this. After many protests from M. Singh, and with a long line-up of passengers waiting, the clerk relented and allowed his baggage to be checked through to India. It was quite a different story on the flight to Tokyo. Something went wrong for the terrorists. The bomb went off at Narita Airport during transfers from Canadian to Air India planes. Two workers were killed. Had this not happened, the terrorist plot would have been an even greater tragedy. Many more lives would have been lost.

There are large numbers of Sikhs living in Canada, many of them recent immigrants. They come from the Punjab in Northwest India, part of which is in Pakistan and part in India. Ever since these two countries were freed from British rule in 1947, Sikhs have been clamoring for an independent state of their own. Because of their religion they did not want to join either Moslem Pakistan or Hindu India. Over the years many hundreds died in the fighting that ensued. In 1984, Indian soldiers went to this part of the country to quell local violence. The Golden Temple of Amritsar, a place sacred to all Sikhs, was destroyed and some Sikh leaders killed. As one result of this action, Prime Minister Indira Gandhi was assassinated later in 1984 by two of her Sikh bodyguards. In retaliation, Hindus killed thousands of Sikhs. This was the violent background of many Sikh immigrants who came to Canada and it is not surprising that some of them brought with them a hatred of India. The freedom they enjoyed in Canada made it easier than would be the case in India for them to engage in acts of terrorism. Sikh revolutionaries who live in India feel that their opportunities to hurt the state government there are limited so they encouraged their friends in Canada to act for them.

Indian government authorities repeatedly warned their Canadian counterparts of this danger but sadly the warnings were not taken very seriously. From time to time local newspapers reported acts of violence from the suburban area where large numbers of Sikhs live. Some related to disputes over religious rituals, fundamentalists against modernists, but on occasion there was violence. Once, Ujjal Dosanjh, a Sikh lawyer, was seriously injured when fellow Sikhs assaulted him because he advocated nonviolence as the proper way to settle quarrels. Even after the Air India flight reached Toronto normal precautionary procedures failed, including one that might well have saved the flight from destruction had it been followed. While loading baggage on to Flight 182 at Toronto, a scanning machine broke down, leaving a quarter of the luggage, including M. Singh's, unchecked. A hand-held detector was used on this section of luggage but it could not detect explosives. On the next leg of the flight, at Mirabel, three bags gave rise to suspicion among handlers so they were put to one side for further examination. Later they were considered to be harmless. Nothing further was done and Flight 182 was allowed to take off despite an official regulation that in all such circumstances every bit of luggage on a plane must be taken off and thoroughly examined.

Air India 182 flew on through the night and as it approached the Irish coast around 8:00 A.M. next day began the descent from 31,000 feet in anticipation of a landing at London's Heathrow Airport. The air controller at Ireland's Shannon Airport established contact with the plane and talked with the pilot for a short time. Suddenly voice communication stopped and a few moments later, as he looked at his radar screen, the controller was startled by the sudden disappearance of the plane. There had not been any emergency signal or any other indication of trouble, just silence. Later when the black box was recovered from the ocean depths, there was evidence that the pilot tried to send out a distress call before all power failed and the aircraft plunged helplessly into the sea. The only other signals captured by the black box were a thud, a muffled bang, and a faint shriek before loss of power cut off the recording. The plane's position at the moment of disappearance was recorded at Shannon's Airport and this was used in locating bodies and debris when recovery work began. From these two bits of information the plane's speed as it hit the water was calculated, nine hundred miles an hour. Had there not been two hours delay leaving Canada the explosion would have occurred over London and casualties and destruction might have been even worse.

Within minutes of the plane vanishing, the Irish Marine Rescue Coordination Center was notified and all available planes and ships were sent to the crash site. By 9:00 A.M. it was known that 182 had crashed. An emergency message was picked up from an Air India locator, the kind that operates automatically as soon as it hits salt water. First hopes were that the plane had been forced to ditch and that survivors would be found. That expectation faded when the first rescue ship reached the scene at 11:00 A.M. and found a vast floating mass of debris, broken airplane parts, and more than a hundred bodies. The rescuers had to work fast. They knew that bodies float for only a short time and that wreckage drifts farther and farther away as they work. Fortunately, the morning of the twenty-third was calm and sunny. By sunset eighty-eight bodies had been taken from the sea. More were taken from the sea later. The process was slow at first: a helicopter hovers over a spot in the sea while a man is winched down to the water where he puts a sling on the water-logged body so that both can be winched back up. Around 3:00 P.M. rescuers heard the dreaded news that sharks, six-foot blues, were racing toward them. Three-man inflatable lifeboats were introduced to speed up the recovery. Men had to jump into the water among the sharks and sometimes fight for possession of the bodies. When they came back to the site next day all they could find were dead sharks, victims of the feeding frenzy.

The total salvage effort to recover bodies and plane parts was the most extensive ever attempted. In all, 131 bodies were recovered and their postmortems conducted at Cork Regional Hospital to establish cause of death and help with identification. The damage done to bodies was extensive, consistent with decompression at the higher elevations when pressure was lost, and the swinging and turning from the long free fall. Some survived the crash although unconscious but then drowned. Of the 329 who were lost most were Hindus, many of them Canadian citizens. On the southwestern shore of Ireland a monument was erected by representatives of the three nations affected—India, Canada, and Ireland. An Irish artist designed the monument which looked like a compass pointing out to sea in the direction of the crash. The time, date, and location of the tragedy are marked on it along with the words "Time Flies. Suns Rise and Shadows Fall. Let it Pass By. Love Reigns Forever Over All." The names of the 329 who lost their lives are inscribed in three languages—English, French, and Hindi.

Air terrorism had become a new social problem for Canada, challenging all the norms of civilized behavior. Many of today's procedures at airports were initiated after the 1985 disaster. Criminal investigations on the perpetrators of Air India 182 were immediately launched but the long and difficult process of securing convictions took years and involved investigations in five countries. Finally, sixteen years after the Air India tragedy, only one or two were charged. One of them is serving time in prison in British Columbia for the deaths at Narita Airport. Overall, at the end, there was consensus among Canadian security experts that the main causes of the tragedy were poor surveillance by authorities over individuals who were known to be dangerous and persistent insensitivity to the warnings that had come from India. Immediate corrective measures were taken after the event, upgrading all procedures and installing new security measures.

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Mexico earthquake

September 19, 1985

Mexico City suffered severe damage from an earthquake with an epicenter thousands of miles away on Mexico's west coast

This was one of the most destructive and deadly in Mexico's history

On September 19, 1985, Mexico was hit with an earthquake of magnitude 8. Its epicenter was in a subduction zone in the western part of the country, in Baja California near Michoacan. At least 9,500 people were killed, about 30,000 were injured, more than 100,000 people were left homeless, and severe damage was caused in parts of Mexico City and in several states of central Mexico. It is estimated that the quake seriously affected an area of approximately 300,000 square miles, caused over three billion U.S. dollars of damage, and was felt by almost twenty million people.

This was one of the most devastating earthquakes in the history of the Americas and it was followed by major aftershocks. In Mexico City, on the opposite side of the country, shaking from the quake lasted three to four minutes. The most damaged zones were those in the bed of the historic Lake Texcoco, where the prevailing silt and volcanic clay sediments amplified the shaking. Building damage was worsened by occurrences of soil liquefaction, causing loss of foundation support and settlement of large buildings. Altogether four hundred buildings collapsed and another 3,000 were seriously damaged. Extensive damage also occurred all across the country.

The earthquake generated a small tsunami and the first aftershock that had a magnitude of 7.5 produced a small second tsunami. Both tsunamis spread across the Pacific and were recorded by several tide stations in Central America, Colombia, Ecuador, French Polynesia, Samoa, and Hawaii. No reports of damage were received from any of these stations and the only minor damage due to the first tsunami came from the source region. Seiches were observed in East Galveston Bay, Texas and in swimming pools in Texas, New Mexico, Colorado, and Idaho. Water well fluctuations were recorded at Ingleside, Texas, Santa Fe, New Mexico; Rolla, Missouri, Hillsborough County, Florida, and Smithsburg, Maryland.

Compared with California which, in the course of the twentieth century, experienced five earthquakes of magnitudes greater than 7, Mexico had forty-two, most of them leading to a high death toll of human lives. The September 1985 quake happened in a seismicity gap that had been identified by geologists as a risk area for the previous ten years. Fortunately, the earthquake struck early in the morning of September 19 before schools and offices in Mexico City were occupied because it was there that the greatest death toll occurred when buildings collapsed. The length of the intervening distance between the earthquake's source and Mexico City greatly reduced the amplitude of the seismic waves so that very few structures that were built on firm soil and rock suffered damage.

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Nevado del Ruiz, Colombia volcanic eruption

November 13, 1985
Colombia's town of Armero was completely devastated by a landslide

Colombia's Nevado del Ruiz erupted and mudflows swept down from a height of 17,500 feet

On November 13, 1985, Colombia's Nevado del Ruiz, South America's most northerly active volcano, erupted close to midnight. Pyroclastic flows melted ice and snow at the 17,500-foot summit, forming mudflows that rushed down several river valleys. These mudflows, known locally as lahars, were as thick as 150 feet and they traveled at more than 65 mph, devastating houses and towns in their paths. The town of Armero, fifty miles from Colombia's capital, Bogota, was completely covered by them, killing 21,000 of its population of 28,700. In all there were 23,000 deaths, 5,000 injuries, and the destruction of more than 5,000 homes.

There were hundreds of instances where people that were only a few feet apart were either killed or survived the massive mudflows. Among the terrible consequences for some survivors was that the high temperature of the mudflows had made them collectors of all kinds of pathogenic fungi and bacteria. Some survivors who had minor cuts were killed by the infections because they could not be treated with known antibiotics. The villagers had been warned of the impending disaster but, because of false information that had been circulating about it for some time, these warnings were ignored. The first sign of activity occurred in the afternoon of November 13 and local officials immediately ordered a general evacuation but then cancelled it within a couple of hours when the mountain became quiescent.

Figure 103 More than 22,000 Colombians were killed on November 13, 1985, by the eruption of Nevado del Ruiz, the northernmost active volcano in the Andes. This is history's fourth largest single-eruption death toll. The photo shows a steam eruption in September of 1985 prior to the major eruption on November 13, 1985.

Nevado del Ruiz is an active volcano with a history of generating deadly volcanic mudflows from relatively small-volume eruptions. In 1595, a lahar swept down the valleys of the River Guali and the River Lagunillas, killing 636 people. In 1845, an immense lahar flooded the upper valley of the River Lagunillas, killing over 1,000 people. It continued for forty-five miles downstream before spreading across a plain in the lower valley floor. The young village of Armero was built directly on top of the 1845 mudflow deposit. Over the ensuing years, Armero grew into a vibrant town with over 27,000 residents. On November 13, 1985, history repeated itself for the third time in four hundred years, with another eruption and another deadly lahar racing down the River Lagunillas.

Survivors who fled to other towns in the area were gradually housed in new government schemes, but problems for the displaced population occurred for many years after. Several years later, the scarred sides of the creeks along which the lahar flowed were clearly visible from commercial aircraft. Even in the mid-1990s the town was covered with up to twenty feet of ash and debris. Local villagers harvested stones for building work. A few small trees were trying to grow, protected from wandering animals by makeshift fences. The eruption cost Colombia 7.7 billion dollars; about 20 percent of the country's GNP for the year in question. Following the 1985 eruption, Nevado del Ruiz remained active for several more years, culminating in smaller eruptions in 1991 and 1992, well below the VEI of 3 that defined the 1985 eruption.

Ultimately, this was a tragedy that could have been averted. Nevado del Ruiz had served up a steady menu of minor earthquakes and steam eruptions for fifty-one weeks prior to the November 13 eruption. The ongoing activity was just enough to keep people nervous, but not enough to convince authorities that the volcano provided a real threat to the communities surrounding the volcano. Since Colombia had no equipment to monitor the volcano, or geologists skilled in using such equipment, expertise could only come from other countries. A scientific commission and some journalists visited the crater in late February and soon after a report of the volcanic activity first appeared in the newspaper *La Patria* in early March. By July, seismographs were obtained from several countries that would help in plotting the movement of rising magma beneath the volcano. Money was obtained from the Unified Nations to help map the areas that were thought to be at the greatest risk. The resulting report and volcanic hazards map were finished on October 7, but only ten copies were distributed. Based on the report, the National Bureau of Geology and Mines declared that a moderate eruption would produce a percent hundred percent probability of mudflows with the greatest danger for Armero.

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Challenger (space shuttle), Florida, fire/explosion

January 28, 1986

Within one minute of launch the space shuttle *Challenger* caught fire and exploded

All seven astronauts were killed and the accident gave rise to new, stringent, regulations about decisions on launching

Shortly before noon on January 28, 1986 the space shuttle Challenger lifted off from the Kennedy Space Center at Cape Canaveral. Seven people were on board, five of them astronauts and two civilians. In less than one minute into the flight a fire broke out and the shuttle tore away from the flaming booster rockets to plummet ten miles in free fall into the ocean. All seven died instantly on impact if not before.

By 1986, space travel had become almost routine. Americans had flown beyond the bounds of gravity more than fifty times and their safe return from every mission was now taken for granted. The *Challenger* shuttle had already been in space on a number of missions and was about to take off on one more in January of 1986. This time two civilians were going to accompany five astronauts. Christa McAuliffe, a teacher, was one of the two and a great deal of attention had been focused on her because of the role she was to play.

Classrooms around the nation were getting ready to receive signals from space. McAuliffe was to conduct two fifteen-minute lessons, describing the spacecraft and the duties of each of the seven on board. She called the first lesson the ultimate field trip. Her second lesson would go into more details of the experiments being conducted, pointing out at the same time the future scientific, commercial, and industrial benefits that would come from these activities. Behind the educational values were the hopes that this kind of activity would build broader public support for NASA's shuttle programs.

Challenger was to have lifted off on January 20 but all kinds of delays cropped up over the following week. Again and again flight plans had to be canceled, sometimes just a few hours before takeoff. There were various reasons for the cancellations. Additional training for the astronauts was one unexpected stall. A second was a desert storm in Africa that made an emergency landing site unusable so the launch had to wait until that location was back to normal. Ships at stand by to pick up the booster rockets after they are jettisoned were grounded by high winds on one occasion. Once, an hour before launch, a sticky bolt prevented the removal of an exterior-hatch handle. All seven were in the shuttle at this time and the delay forced another cancellation.

Finally, on January 28, everything was in place for liftoff; everything, that is, except that temperatures had dropped below freezing on the previous night. There were serious concerns among the engineers who designed the o-rings, the seals that prevent leaks between sections of the rocket boosters. They were unanimous in their decision to stop the launch. These o-rings are sensitive to very cold weather because low temperatures might make them shrink and cause a leak of the highly flammable fuel. NASA's management team, distressed by the week's delay, pressured the o-ring manufacturer to let the *Challenger* go. They succeeded. NASA was anxious to get the shuttle aloft in order to measure the ultra-violet spectrum of Halley's Comet before it moved too far away from the earth.

The liftoff sequence is always an impressive sight. Thousands come to Cape Canaveral to watch from a safe distance every time a new mission is about to be launched. The huge volume of fuel expended in getting the spacecraft into orbit leaves no room for mistakes. Once ignited the two booster rockets burn uncontrollably until all their fuel is gone. They then separate from the shuttle and plunge into the sea where they are picked up by NASA's recovery ships. At T minus three minutes *Columbia* was ready to go. Its internal electrical system was operating independently. Captain Dick Scobee had completed his examination of all systems on board and given the green light to mission control. Two and a half minutes later powerful jets of water were directed at the launch pad to dampen the roar of takeoff and so prevent sound waves damaging the underside of the spacecraft.

America's twenty-fifth space shuttle mission was a perfect launch, but almost immediately a tiny puff of smoke was caught on NASA's cameras. At T plus forty-five seconds the puffs of smoke were more than just noticeable. The shuttle crew felt their craft being jostled and wondering what was wrong switched immediately to their emergency air. Thirty seconds later the shuttle was enveloped in a fireball and all control was lost. The boosters flew away from it in opposite directions. The crew cabin was now a free moving object with the seven astronauts inside. With the momentum of the trajectory it sped upward several thousand feet then plunged downward toward the ocean. Three minutes later it hit the water at two hundred miles an hour, killing all seven instantly. The crew cabin disintegrated and sank.

About an hour later, a lone parachute was observed coming down with a booster nose cap rather than the whole booster attached to it. Over the weeks following the tragedy no identifiable remains of the astronauts' bodies were recovered from the sea but substantial pieces of wreckage did turn up. Recovery vessels found a twenty-five-foot-long section of the shuttle's fuselage, parts of the shuttle's wings, and a door from a cargo hold. One or two voice recorders from Columbia were recovered from the sea. They contained only trivial amounts of data. After their initial shock and reactions the astronauts were unaware of events until flames exploded around them, destroying all power and communications.

The impact across the nation and around the world was instant and

Figure 104 At about seventy-six seconds after launch, fragments of the space shuttle can be seen tumbling against a background of fire, smoke and vaporized propellants from the external tank. All seven crew members perished.

massive. Classrooms in many states waited for their lessons from space so when the tragic news arrived whole communities were in shock. President Reagan was due to present the annual state of the nation address to Congress on the evening of the twenty-eighth and undoubtedly he planned to speak about the teacher in space. It was he who suggested to NASA that a teacher be the first civilian to go aloft. Christa McAuliffe's comment about her career, "I touch the future. I am a teacher," fitted perfectly into his state of the union speech. That speech was delayed for a week. Messages of sympathy arrived from nation after nation. One from Soviet Party Chief Mikhail Gorbachev was particularly significant because of the fierce competition existing between the United States and the Soviet Union in space exploration.

A final ceremony to honor the seven astronauts was held at the Johnson Space Center in Texas where the seven had lived and trained. It was attended by six thousand NASA employees, ninety Senators and Congressmen, and about two hundred relatives of those who died. President Reagan and his wife met family members and then the president spoke about the human cost, not the errors. His comments included the following: "The future is not free. Human progress is a struggle. America was built on heroism and noble sacrifice like our seven-star voyagers." In addition to the ceremony in Texas, a Space Shuttle *Challenger* Memorial was placed in Arlington National Ceremony on March 21, 1987. It marked the common grave of the astronauts' remains which were recovered but could not be identified.

The *Challenger* disaster could have been prevented. Engineers from the company that manufactured the o-rings tried to convince NASA to delay the launch and wait for better weather. Future designs, future methods, and future procedures were affected. A new ethic was reestablished at NASA. There would never again be a rejection of majority engineering advice and the final decision in cases of doubt would be taken by an astronaut.

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Chernobyl, Ukraine, nuclear accident

April 26, 1986

An accident at the Chernobyl nuclear power station caused a massive environmental disaster

The reactor in one of the units lost its cooling water, heat built up, and radioactive gas burst out and spread all over Europe and parts of the USSR

On the April 26, 1986, a nuclear power station at Chernobyl in the Ukraine, then part of the USSR, caused the world's worst nuclear accident. The tragedy followed a routine maintenance operation when something terrible went wrong and radioactive gas drifted all over Europe. The disaster continued to claim more victims long after the accident disappeared from the public eye.

The Chernobyl nuclear power plant near Kiev in the Ukraine, formerly a state of the Soviet Union, was the pride of the country's nuclear power program. It was the biggest installation of this kind with four generators, each producing one thousand megawatts of electricity, and two more of the same kind under construction. Construction of the first unit began in 1971 and by early in 1986, with four units operating, the Soviet government was about to launch a five-year program in which several new Chernobyl-style plants were to be built. The decision to go ahead was made in February of 1986 and the Communist Party Congress was to approve it in June of the same year. Between the two dates came the explosion of Chernobyl's number four reactor.

The initial events were similar to accidents at other nuclear facilities. The reactor lost its cooling water and the nuclear fuel elements began to heat up. Action can be taken at this stage to bring in emergency supplies of water. Time is thus gained to locate the trouble and fix it. In the case of the Chernobyl accident, nothing was done to counter the build up of heat and soon dangerous levels of radiation were being released into the atmosphere. The reactor did not have a protective building around it to prevent the escape of these radioactive gases. Finally, the heat level rose so high that graphite in the reactor core caught fire and a burst of radioactive material swept over the surrounding countryside devastating everything.

At the time of the accident the reactor was undergoing routine maintenance and that required a shutdown. The manager of the plant decided to conduct an experiment during this time, a test that could only be conducted during a shutdown. The manager wanted to know how he would deal with a reactor problem if power were unavailable from the main electrical grid. Even when a reactor is shut down it still requires power to maintain the cooling circuit. His experiment was to use diesel generators in such an emergency and he hoped that the fifty seconds or so that these engines required to come up to full speed would not jeopardize the operation.

No one knows exactly what went wrong with the experiment. We only know that the reactor heated up and then burst into flames. It happened in the middle of the night. A plume of radioactive material and radiation shot upward into the sky and then wind blew this cloud northwards across Poland and Scandinavia. A day later, Swedish technicians at a nuclear facility in that country picked up high levels of radioactivity. It was the remnants of a much thicker cloud that did most damage in the area immediately around the Chernobyl plant and second greatest damage as it passed over Belarus.

Nothing was said about the event at that time, nor was much revealed for days afterwards. Characteristic Soviet secrecy surrounded the event. Some reports were lost or destroyed. The Soviet Union was anxious to maintain a positive approach to nuclear sources of energy because there were plans to expand them. They did not want to arouse public fears. All this secrecy took place in the face of accurate information that was available to Soviet authorities telling them exactly how much radiation had reached any part of eastern or northern Europe. The Test Ban Treaty with the United States demanded that each side possessed the ability and the equipment to do this. In full knowledge of the terrible consequences of exposure to radiation, the Soviet Union refused to release what it knew until compelled by external evidence.

The staff at the plant attempted to assess the extent of the damage to unit four and to limit the spread of fire to the other reactor units. In doing so, many of these people averted what may have been a far greater catastrophe but also lost their lives as a result of lethal doses of radiation. Fire fighters risked their lives pouring water into the burning unit four reactor. Over a period of two weeks the Soviet Air Force dropped more than 10,000 tons of material into the reactor core to try and smother the fire. The pilots who flew on these missions died from the massive radiation doses they received and a dozen giant helicopters became so radioactive that they had to be dumped along with trucks, cars and other things around Chernobyl.

In a reactor core, when heat rises sufficiently high, hydrogen explosions occur. In unit four, explosions of this kind hurled burning lumps of graphite and reactor fuel into the air that then landed on neighboring buildings and set them on fire. Most of the buildings had tar roofs and this fueled the fires. Once the fires were extinguished there was the question of what to do with all the radioactive debris that had escaped from the reactor core. It was decided to gather as much as possible and push it back into the reactor. This dangerous task was at first undertaken by robots but these were soon found to be unable to cope with the terrain. They kept getting stuck so a fateful decision was made to use humans.

Choosing to use people for this task was tantamount to killing them. Everyone involved with nuclear installations knew by this time the deadly effects of radiation. The men, mostly from the army, were only able to work for a maximum of one minute even with heavy lead protective clothing on. Radiation levels were dangerously high. The one minute of work proved to be too much for some. They later succumbed to serious illness from their exposure to radiation. In total, almost one million men worked on the cleanup and the construction of a sarcophagus that would seal up unit four and stop the spread of radiation.

The sarcophagus consisted of a massive concrete container that would encircle the damaged reactor and form a roof on top. It took seven months to complete, was two hundred feet in height, and stretched for two hundred feet along each side of the reactor building. Construction was speedy and the quality of work correspondingly poor. Everyone wanted to minimize the workers' exposure to radiation. The container was intended to last for thirty years but within a decade cracks and weaknesses appeared and repairs were needed. In addition, the concrete was gradually weakened by irradiation from within and tension from the huge temperature difference between inside and outside.

Scattered around the Chernobyl nuclear power plant were hundreds of dumps of radioactive waste. These usually consisted of open pits with linings of clay, containing anything from soil, timber, and vehicles to domestic items such as refrigerators and clothing. Some of the pits contained the remnants of the forest which surrounded the power station and absorbed so much radiation that the trees had to be destroyed and treated as radioactive waste. These pits became a big environmental hazard because they posed a threat to the main water table.

This water table is linked to the Dnieper River which supplied the water needs of thirty-five million people, including the residents of Kiev. Police and military personnel guarded the area around Chernobyl, ensuring that no one ventured close to lethal radiation. In spite of that, a few people, mostly the elderly, were allowed back into their old homes. They insisted that they could not see, taste, smell or touch the deadly radiation so it did not bother them. While they might not be concerned, future generations must. The long-term effects of radiation have yet to be understood. Such effects modify the genetic structures of animals, food, and humans.

The Chernobyl accident led to huge health problems in the Ukraine and elsewhere. Plant personnel, fire fighters, medical staff, and cleanup workers suffered the most. Reports from Belarus indicate a 50 percent drop in birth rates and a steady rise in miscarriages and birth defects. Other estimates claim that over three million Russians suffered radiation exposure with 370,000 likely to develop a radiation-linked illness. By 2001, estimates of total deaths from the Chernobyl accident totaled 15,000. On the wider scale of Europe other kinds of evidence mounted.

Researchers were able to counter the Soviet claim that no other country was affected by radiation from the accident. It was all propaganda, claimed the Soviets, when the countries of Western Europe refused to accept agricultural produce from Eastern Europe. Within a year, the evidence of widespread devastation was overwhelming and the USSR was forced to accept it. Scandinavia, Britain, West Germany, Italy, and all the countries in between had been hit with damaging radiation. A very large area had been contaminated.

Sweden was one of the hardest hit with much of the damage being carried in rain. An area of 4,040 square miles, 175 miles north of Stockholm, was so badly contaminated that all the grass had to be harvested and burned. Thousands of gallons of milk from this same area was poured away daily for some time. In the far north of Sweden, where the Lapp people live, levels of radiation was twelve times the permissible limit. These people were totally dependent on reindeer for almost everything they needed. The Swedish government helped pay the costs of destroying about 50,000 reindeer. To make matters worse, the vegetation of northern latitudes has a very slow rate of decay for radiation contamination. In 1987 it was estimated that much of the vegetation and soils of the Lapps will remain contaminated until the year 2030.

In December 2000, the last of Chernobyl's four reactors was shut down permanently, the final act in a financial deal struck between western nations and the Ukraine. The nuclear power plant and an area extending outwards for nineteen miles in all directions became a wasteland as badly polluted as was Bikini (see Bikini Atoll, Marshall Islands, nuclear tests). Like Bikini it will remain a useless desert far beyond the lifetime of those who witnessed the original catastrophe.

The stone coffin erected around the plant at the time of the accident was still in disrepair in 2000. It had been built over the plant to prevent more radiation escaping and the work at that time was done at high speed and at enormous risk to all involved. To minimize the health hazard work shifts were limited to fifteen minute stints. Even fourteen years later, as the reactors were being closed down, repair men with special clothing to protect them from radiation could not stay on the roof longer than five minutes at a time. Radiation levels around cracks were seven times higher than the amounts regarded as unacceptably high.

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Armenia earthquake

December 7, 1988
Almost half of the territory of Armenia was hit
with a powerful earthquake

Armenia at the time was part of the USSR and at war with a neighboring country, Azerbaijan, over territory. Hence the destruction was greater than the small country of eleven million could absorb

On December 7, 1988, an earthquake of magnitude 6.9 suddenly struck over 40 percent of the territory of Armenia while it was still part of the USSR, three years before it became an independent republic. In 1988, Armenia had a population of eleven million, including 400,000 children, and it was still involved in a war with Azerbaijan over the ownership of territory. Four principal towns of the affected territory and fifty-eight villages were severely damaged. Nearly 70 percent of all buildings were knocked down and the entire town of Spitak was almost totally destroyed. Soviet officials estimated the death toll as being 25,000. More than half a million people were left homeless.

The children suffered more than adults because they were in school at the time of the quake. According to the Armenian National Mental Health Research Center, children and adolescents constituted almost two-thirds of the total number of deaths. School and kindergarten buildings were inadequately designed and could not withstand an earthquake. For example, there was a school with 302 children 285 of which were killed by the quake. In all, 380 children's and youth institutions were seriously damaged or totally destroyed. After the quake, 32,000 children were temporarily evacuated into different parts of the Soviet Union and 6,000 of these

Figure 105 This is the five-story communications building in Spitak. It is a pre-cast, concrete-frame composite structure. Many of these structures collapsed contributing to the high death toll.

were lost in the post-disaster chaos. Some were discovered later and brought back to their families.

Spitak, a town of 25,000, was completely destroyed and could not be rebuilt. A new city had to be rebuilt over the wreckage. The city of Leninakan, with 290,000 inhabitants, and the towns of Stepanavan and Kirovakan in the northern area of Armenia, were also severely damaged by the earthquake. The main environmental problem that led to so many deaths was the concentration of so many people in high-rise buildings, closely spaced in many places. These homes had not been built to standards that could ensure survival in an earthquake. The Soviet Union, in recognition of past failures, promised to build a new Spitak with much better materials. In addition, contrary to much of its past practice, the Soviet Union appealed to America, Asia, and Europe for help and help of all kinds poured in. Mikhail Gorbachev, Soviet president at that time, was in the United States when the earthquake struck. He cut his trip short and went directly to Armenia to visit the quake-affected areas.

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Alaska oil spill

March 24, 1989

The tanker *Exxon Valdez*, fully laded with oil, ran aground on a small island as it was leaving Alaska via Prince William Sound

From the moment an oil tanker arrived at the port of Valdez to load oil, every aspect of the operation had to be carefully watched to ensure a safe exit for the fully loaded ship. In this case several necessary procedures were ignored

On March 24, 1989, the tanker *Exxon Valdez* ran aground on a small island in Prince William Sound. In the days that followed, the ship spilled almost eleven million gallons of Alaskan crude oil into the water. The oil coated shorelines along the sound, and killed hundreds of harbor seals and otters, and thousands of seabirds.

At Prudhoe Bay on the north coast of Alaska large deposits of oil and gas began to be intensively exploited in the late 1960s. By 1977 a nine hundred-mile long pipeline was completed, bringing oil to ports on the south coast where the milder climate permitted all year round operations. From the moment the first big tanker arrived at Valdez, a principal terminal for loading oil, there were environmental concerns. The ship channels along this coast are narrow and rocky and weather conditions are often bad. To make matters worse the tankers in service since 1977 were almost all old, with single hulls, not the double hulls that would be prudent in such stormy seas. The *Exxon Valdez* had a single hull.

Oil is shipped from Valdez to refineries in Washington state and other places along the west coast as well as to Hawaii. The volume transported is huge. Alaska is the second biggest U.S. producer of oil, after Texas, and accounts for one quarter of the nation's supplies. It is not surprising therefore that people were greatly concerned when Alaska's oil first came on stream. Some spills occurred in the years between 1977 and 1989 but the

Exxon Valdez accident became the villain that focused the anger of merchants and environmentalists alike. Fishing is a major industry all along the southern coast of Alaska and the amount of destruction to that resource was immense.

The actual volume of oil that was spilled, though very large, was not nearly as big as other spills. The *Amoco Cadiz* accident in France, a little over a year before the *Exxon Valdez*, was more than six times bigger. The Gulf spill, two years after the Alaskan spill, was the world's worst and was far bigger than *Amoco Cadiz* and *Exxon Valdez* combined. The unique problem surrounding the *Exxon Valdez* spill is the location. In the colder northern waters of Alaska, contamination lingers. The ocean takes a long time to absorb oil and every day or delay means death to many forms of marine life. The damage from the spill took years to eradicate and even after twelve years persistent problems remained to be tackled.

The *Exxon Valdez* arrived at Valdez in the evening of March 22 1989. It was a big ship, longer than three football fields, able to carry more than fifty million gallons of oil. The tough work began early the next morning when the crew had to haul the delivery hoses from the oil terminal and start loading the cargo tanks. Water in the ballast tanks had to be released in matched quantities simultaneously in order to maintain the right stress levels within the ship. All the essential work was finished by eight o'clock in the evening and the crew was very tired. Federal regulations require that every member of a crew be given at least six hours of off-duty time within the twelve hours that precede departure. This rule was ignored because the company wanted to get the oil to market as quickly as possible. It was the first of several errors.

By nine o'clock, only one hour after the ship was loaded, the *Exxon Valdez* was underway, guided by a pilot for the first few miles. Captain Hazelwood and his Chief Mate Kunkel were on the bridge with the pilot. Half an hour later the second of a series of errors occurred. In spite of standard guidelines requiring two officers to be on the bridge, Captain Hazelwood retired to his cabin for an hour and a half and shortly afterward his Chief Mate left to get some sleep. He was awakened two and a half hours later by the noise of the ship hitting the rocks. All this time, from nine o'clock to just after midnight, various people took turns on the bridge to let others catch some sleep. Shortly after eleven o'clock, in view of the arrival of large quantities of ice from the Columbia Glacier on the west side of Valdez Arm, Hazelwood requested and was given permission to alter his normal course to avoid the ice.

What happened next is not clear. Hazelwood went back to his cabin again after giving orders to make course changes to avoid the ice. Several people were involved in carrying out these changes. Someone must have made a wrong turn because at one point a lookout shouted that the ship was on the wrong side of a navigation buoy. A radar station that normally monitors all departing ships until they are clear of the narrowest part of Valdez Arm had recently been downgraded as a cost-saving measure. It was unable to see the *Exxon Valdez* in those critical moments when it took the wrong turn and ran into an island. It may be that Hazelwood was unaware that the radar station did not see him and was counting on it to alert him to possible danger.

Early in the morning of March 24 the *Exxon Valdez* hit the island and almost at once oil was seen oozing out from the ship's side. Engines were stopped and not long afterward oil was seen spouting into the air from tanks. For twelve days oil leaks continued, then on April 5 special efforts were made to remove as much oil as possible from the ship before trying to do anything about the damage that was caused. Approximately 80 percent of the cargo was recovered, leaving eleven million gallons scattered along shorelines for one hundred and fifty miles. In the weeks that followed another three hundred miles of beaches, past Kodiak Island, were smothered in black oil.

First concerns centered on the marine and shore life populations. The number of species affected was enormous. One reporter listed 120 different forms of life, some of them vital to the economic life of Alaska. They included salmon, otter, herring, halibut, whale, shrimp, sea lion, Arctic fox, Arctic loon, and bald eagle. Everywhere the oil came ashore one could see the dead or the dying among the myriad forms of life, from the tiny plankton to the big sea lions. A cleanup series of activities was soon launched, involving thousands of workers, more than 10,000 vessels, and a hundred miles of boom which was found in haste from all over the world.

Larger birds were treated with tubes that were pushed down via their beaks into their stomachs to give them special food, often at the expense of severe bites on the faces of rescuers. Otters that were not too seriously hurt and abandoned otter pups were taken to shelters. Booms were mounted in numerous places to stop the flow of oil on to the shore and so protect salmon hatcheries and oyster beds. On top of all this activity there was a different kind of concern regarding migrating birds and mammals. Prince William Sound at the center of the oil spill is the world's single largest stopping place for waterfowl. In summer this area is also visited by large numbers of humpback and killer whales.

One year after the spill only a quarter of the normal volume of birds and whales appeared. Ten years later estimates of loss included 3,000 otters and 300,000 birds. Only two of twenty-nine species examined in detail, bald eagles and river otters, seemed to have made a complete recovery. The cost to the oil company was immense and some environmentalists argued that the inevitable costs of cleanup may be the best way of ensuring that another *Exxon Valdez* spill will never occur. The ship was barred from ever returning to Alaska. Two billion dollars were paid out for the cleanup, most of it providing needed income for those deprived of their normal livelihood. Civil and criminal charges claimed another billion. Some of the legal ramifications were far from being settled by the year 2001.

Alaska passed a bill requiring the oil industry to stockpile enough supplies to deal with a twelve million gallon spill. There were other bills dealing with reimbursement of people victimized by spills, monitoring of tankers, pipelines, and vessel traffic, and penalties for violation of the rules governing tankers. The U.S. Congress took action by raising the liability tonnage level for shippers to eight times its previous amount. Congress added a new five-cent-a-barrel fee to provide a billion dollar oil spill response and cleanup fund, and it also dealt with the problem of single-hull tankers. Beginning in 1990, all new U.S. tankers must have double hulls and all those without them must be taken out of service over a period of time depending on their ages.

Fortunately, not every oil spill in U.S. waters ended up as a major disaster. Lessons were learned from the *Exxon Valdez* experience and used subsequently in the Rhode Island spill. On January 19, 1996, an intense winter storm off the southern coast of Rhode Island drove the barge *North Cape* ashore adjacent to Rhone Island's Ninigret National Wildlife Refuge. Damaged from the grounding, the barge spilled at least 828,000 gallons of heating oil, which rapidly spread to the coastal ocean. Within hours of the spill, dead marine organisms and sea birds began washing up on the beach. It quickly became the largest oil spill in the history of Rhode Island.

North Cape, a barge loaded with oil, reached the southern shores of Rhode Island when it ran into a storm. The bad weather was not a surprise as it had been forecast, but the seaworthiness of the tug was much less certain. Shortly after leaving New York, while in the protected waters of Long Island Sound, it ran into engine trouble but was able to continue. As it entered the more open waters of Block Island Sound and encountered 60 mph winds with seas running as high as twenty feet, the tug seemed to stall. A fire broke out in its engine room as it approached Point Judith and the crew, after sending a distress signal, abandoned ship. Within minutes the tug was engulfed in flames. The Coast Guard picked up the men from the water.

Barge and tug drifted toward the coast under pressure from the wind. Two men went aboard the barge and attempted to stop the drift by throwing out an anchor. That effort failed because the anchor could not be released. Within a few hours both tug and barge were aground on a barrier beach just west of Point Judith on Rhode Island's southern shore and next door to the Ninigret National Wildlife Refuge. The next morning oil was visible on the water and there were the first marine casualties of the spill. In the following days, the magnitude of the event was evident. About 828,000 gallons of oil had spilled from the barge. As the oil spread from Block Island Sound toward Rhode Island Sound and Narragansett Bay, it forced a closure for fishing for an area of 250 square miles of ocean.

This was Rhode Island's worst ever oil spill. The stretch of water along Rhode Island's southern coast is the regular path for all coastwise traffic to and from New York and the probability of an accident of this kind was always high. At any given time huge volumes of oil are passing nearby. Closure of fishing in a large area around Narragansett Bay was followed by other closures. Within a week ponds with lobsters, starfish, clams were all closed down and a general slump set in for all segments of the fishing industry. The barge and tug were finally removed but the damage had been done and little was to change for a long time. Heating oil is lighter than crude, the kind that formed the spills in Alaska and France, and its long-lasting effects are accordingly less. In the short-term, however, it is much more toxic and so damage to Rhode Island was extensive and deep.

The coastal environment impacted by this spill lies at the heart of the recreational and commercial fishing industries of Rhode Island. These industries are vital to the economy and lifestyle of the state, and the natural resources of the coast are a key draw for summer visitors. Residents are dependent on these renewable natural resources for fishing, boating, and hiking, as well as for a wide range of economic pursuits. When the livelihood of a whole community is tied to a particular natural thing as is the case here, the effects are felt throughout the state. One indication of this can be seen in the seasonal movements of people from farther north to southern coastal areas. Coastal areas are highly valued by these people and the felt sense of loss is great when a disaster of this kind occurs.

The causes of this oil spill were twofold—poor maintenance of tugs and lack of care when dangerous cargoes are being transported in bad weather. Two years before this accident, a bill had been before Congress providing for the inspection, training, and ongoing supervision of tugboat operators. That bill was never passed. It may yet be revived in the light of this accident. Whether or not that will happen, the experiences in Alaska with the *Exxon Valdez* and in France with the *Amoco Cadiz* have already caused major changes in the rules governing oil spills and the resultant cleanup. In the aftermath of this spill, even though it was much smaller than the other two just mentioned, the new regulations and a new awareness of the seriousness of any spill made it much easier to rehabilitate a damaged environment and to do it in less time.

Less than four years after the January 19, 1996, spill, much sooner than anyone expected, a full settlement was reached between federal authorities and the government of Rhode Island in July of 2000. It provided, among many other things, for the replenishment of the lobster populations. Costs of sixteen million dollars were awarded, most of it to be paid by the owners of the tugboat that caused the accident. The spill had killed nine million lobsters and more than 2,000 marine birds and was responsible for the lobster industry being shut down for five months. The habitat of the piping plover was endangered and about one million pounds of clams, oysters and other crustaceans were killed. To ensure a restoration of the Piping Plover's habitat predator barriers were installed and a public education program launched to gain public support for the renovated habitat.

As part of the same overall agreement with the state of Rhode Island, over a million female lobsters were to be added to Block Island Sound before the year 2005. These would gradually be purchased and introduced over time and all of them would have their tails notched with a "v." It is illegal to harvest lobsters so marked. As a result, the number of adult females and the overall number of offspring will increase rapidly over the five year development period. For the recovery of the shellfish industry ten million clams were added to specific habitats in Narragansett Bay and some coastal salt ponds. For the restoration of loons, habitats were restored and arrangements made to monitor nesting sites. In addition, a conservation site was purchased in nearby Maine where loons are known to nest. To improve fish runs obstructions on rivers or streams were removed to ensure easy access to salt ponds.

On the day before the U.S. Department of Justice announced the multimillion dollar settlement, a damaged barge spilled 14,000 gallons of oil into Rhode Island's Narragansett Bay, stirring memories of the far larger spill in 1996 into the Ninigret National Wildlife Refuge. Five swans had to be euthanized after becoming coated with oil. Another fifty Canada geese were spotted with oily feathers. Sixteen of these birds were captured and loaded on to a boat that has been converted into an animal rescue hospital. There the birds were washed clean of oil and given intravenous fluids to prevent dehydration. Government authorities assured everyone that the coincidence of the two events was purely accidental. Nevertheless it was a timely and vital reminder of the ubiquitous threat from oil spills.

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Tiananmen Square, China, massacre

June 4, 1989

A nonviolent student protest is crushed by Communist authorities

Thousands were killed and thousands of others wounded

Tiananmen Square, meaning "Gate of Heavenly Peace" refers to a cluster of ancient buildings plus a massive square in the heart of Beijing. The former is a museum dealing with events from China's past, the latter is an important site ever since 1949 when communist revolutionaries became the government of China. Official celebrations and national day rallies are held here. For some time, in the months leading up to June 4, 1989, large numbers of students had been protesting corruption in government circles and authoritarian responses to their complaints. These protests kept increasing in intensity and finally the government ordered its army to crush the protesters. Thousands were killed and thousands more were injured in the military action that followed on June 4.

When Hong Kong was transferred from Britain to China in 1997 the celebrations for the event were held in Tiananmen Square. Protests also occured in the square and the reason that the 1989 protest was so well internationally publicized on television relates to the fact that President Mikhail Gorbachev of the Soviet Union was visiting China at that time. Cameras from many countries were in place for Gorbachev's visit and they switched to the massacre in the square when it happened. The student protests that developed in the summer of 1989 began as mourning ceremonies for Hu Yaobang, a senior member of the Communist government, who died suddenly in April of 1989. Before his death he was disgraced and removed from office because he was a long-time friend of students, supporting them in their demands for political reform. Thousands gathered around the residences of top Chinese officials near Beijing's Forbidden City to talk about democracy with Prime Minister Li Peng. They wanted to know why Hu Yaobang had been disgraced and dismissed from office.

The numbers grew when they learned that some of the students who were protesting had been arrested. Students took up temporary residence on Tiananmen Square and pressed their requests, including asking high-ranking officials to publish lists of their personal property. In support of their demands, students from Beijing University, the most prestigious in China, organized a strike. Half of the student body boycotted classes and students from other universities joined them. Together, aided by workers from other walks of life, 80,000 people marched to the square where they presented a seven-point demand to the government. It included the rehabilitation of Hu, press freedom, and more money for education. These students were not opposed to their communist form of government, they just wanted their leaders and the party as a whole to live up to their own ideals.

When the memorial service for Hu Yaobang was held in the Great Hall of the People in Tiananmen Square, students won their first victory. They were permitted to remain in the square during the memorial service. About 200,000 came to pay their respects to Hu but, at the end, Li Ping refused to meet with the students to discuss their concerns. Instead he

Figure 106 The bodies of dead civilians lie among mangled bicycles near Beijing's Tiananmen Square early June 4, 1989. Tanks and soldiers stormed the area overnight, bringing a violent end to student demonstrations for democratic reform in China.

issued a statement criticizing the student movement for reckless behavior and for inciting strikes. The student response to Li Ping was a carefully organized march of students from Beijing University and forty other universities together with people from the community, as many as half a million in all. They went to the square and held up a large copy of the country's constitution with a focus on the guarantee of the right of demonstration. The protest activities continued for some days, aided by three hundred journalists who had been demanding greater freedom of the press. Sympathy protests were held at other universities across the country. On May 13, 1989, several hundred students began a hunger strike in the square.

The influence of the protests expanded greatly on May 14. Soviet President Mikhail Gorbachev was about to arrive and the students planned to welcome him because of the political reforms he instituted in the Soviet Union. This was to be the first Sino-Soviet summit conference in thirty years. For China, however, the visit became a huge embarrassment. Gorbachev was far too popular with the students. Furthermore, the official procession could not come through Tiananmen Square, the traditional route for all such occasions. The Russian delegation therefore had to come through a back street where no welcoming crowd could see them.

The tense situation was by now the main topic of conversation at the top levels of government. Some wanted to deal sympathetically with the students and give consideration to their demands. Zhao Ziyang, the Communist Party secretary and a well-known reformist was the foremost proponent of this approach. Li Ping was on the opposite side. Students were naive, convinced that the army would never shoot Chinese citizens. There were divisions in the army too. Some units were unwilling to open fire on the protestors so the government officers issued statements saying that the army was there to protect people, not harm them. They added that guns would only be used as a last resort. All of these things heightened tension.

The only person who could settle the dispute among government leaders was Deng Xiaoping, the leader who had transformed China's economy by adopting western ideas. Although retired, his opinion still carried more weight than any other. His decision, on June 3, 1989, was to bring in the troops and clear the square within twelve hours. The square by this time was full of students and a ten-meter-high goddess of democracy statue had recently been added to their demonstration. Troops began to make their way into the center of Beijing, encountering taunting and public opposition. Students had erected road blocks all around the square.

In the early morning of June 4, the crack of rifle fire and the occasional thud-thud of heavy machine guns told everyone what had happened. There was no warning. As the gunfire came nearer, the crowd became frantic and started to push several buses across the road to block the path against any incoming troops. There were clear signs of the terror to come. Behind the Great Hall of the People in the square 1,000 troops stood, for a moment surrounded by a jeering crowd. Suddenly, eight hundred riot police stormed out of the compound where government leaders lived, firing tear gas and laying about them with clubs.

They were supported by a large contingent of troops accompanied by trucks, tanks, and armored personnel carriers that poured into the square from the east side. The road was soon littered with broken glass and bricks, partly the result of student action against the soldiers, partly due to the destructive activity of the troops. More and more wounded were being taken to the nearest hospital. In the eyes of an onlooker, one of the hospitals looked like a war zone of dead and broken bodies. There were some on benches and beds or on blood-soaked mattresses on the floor, and many had bullet wounds on chest, legs, or head. Students had been bayoneted to death. Students in tents were crushed to death by oncoming tanks. The shock among students was palpable. Again and again voices cried out in words like the following: How could the Communist Party do this? How could they shoot children? Many could not find words to express their horror. Next day the world knew what had happened. It had been documented on film. The Chinese Red Cross estimated that close to 3,000 had been killed.

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Loma Prieta, California, earthquake

October 18, 1989
Thousands of destructive landslides were triggered by the Loma Prieta earthquake

Damage was extensive and large as twenty-five miles of the San Andreas Fault slipped

On October 18, 1989, an earthquake of magnitude 6.9 struck a branch fault of the San Andreas near the city of Santa Cruz in the southern Santa Cruz Mountains. It came to be known as the Loma Prieta earthquake after the name of a 3,000-foot mountain in the Santa Cruz area that was close to the epicenter. A series of thousands of destructive landslides was triggered all along a stretch of coast and in the central valley from north of San Francisco to points forty-five miles south of Santa Cruz. This earthquake took sixty-three lives, cost $10 billion, and damaged 27,000 structures. The source of the quake was a slip along a twenty-five-mile segment of the San Andreas Fault where it crosses the Santa Cruz Mountains sixty miles south of San Francisco. It was the most powerful earthquake to strike this part of California since the 1906 San Francisco quake.

Extensive studies were made in the wake of this quake to ensure adequate preparation for any future similar event. For the most part, places that were damaged by landslides were checked out and where necessary, as in some coastal locations, homes were removed or other remedial action taken. One particularly weak area was the Marina District of San Francisco. Despite the experience of 1906 when this part suffered severe damage, city officials went on to fill the area with sand and rubble from the

Figure 107 Loma Prieta, California, earthquake, October 17, 1989. Roadbed collapse near the interface of the cantilever and truss sections of the San Francisco–Oakland Bay Bridge.

quake, in order to use it as a site for the 1912 Panama–Pacific International Exhibition. In later years it became a very popular section of the city. The lurking danger, which was ignored, was liquefaction in the event of an earthquake. When Loma Prieta struck, the Marina area immediately sunk five inches. This was followed by widespread liquefaction as water-saturated sand turned into a liquid. Buildings shifted off their foundations and many collapsed.

Thousands of landslides generated by the quake were found all over an area half the size of the one hit in 1906. Loma Prieta thus provided the first opportunity to study the effects of a major earthquake on landslides. Previous landslide-producing earthquakes, apart from the 1906 quake, were either too small or too poorly documented for this purpose. Techniques for identifying slopes susceptible to failure that had been developed over the previous ten years were proved correct in the studies that followed the Loma Prieta earthquake. At the same time there was recognition of new types of landslide hazards not fully appreciated in the past. The most severe property damage occurred in San Francisco and Oakland. The earthquake was felt over most of central California and in part of western Nevada.

It was fortunate that the epicenter was in a sparsely populated area because the amount of shaking was very strong. In homes furniture was

Figure 108 Loma Prieta, California, earthquake, October 17, 1989. Structures damaged in the Marina District of San Francisco. The first story of this three-story building was damaged because of liquefaction; the second story collapsed. What is seen is the third story.

moved several feet and in one case a built-in oven was ejected from its cabinet. The city of Watsonville was badly damaged as were older buildings in downtown Santa Cruz. Around the margins of San Francisco Bay the shaking that was experienced in 1906 was much stronger than in 1989. Most publicity was focused on the collapse of a section of the freeway that connects downtown Oakland to the Bay Bridge. The freeway's bridge was built in 1936 and was intended to withstand moderate earthquakes. Such designs were common at that time before people were acquainted with the damaging influence of earthquake motions.

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Persian Gulf oil inferno

March 1, 1991
A flood of oil was deliberately released
into the Gulf by Iraq's defeated army

This new form of terrorism brought a wave of toxic gases over Kuwait and its surrounding area. At the same time, large areas of ocean life in the Gulf were destroyed

At the beginning of August 1990, Iraqi troops invaded Kuwait in order to gain control of its oilfields and make it a province of Iraq. The United Nations immediately condemned this action and, when diplomatic efforts to solve the crisis failed, a coalition of many countries was assembled to reclaim Kuwait by force. Air attacks on Iraq were launched early in January of 1991 and later ground forces crossed into Kuwait. The ground war was brief and by the end of February 1991 Iraqi military units had been completely defeated. There were many Iraqi deaths, perhaps as many as 100,000. Among the armies of the coalition between two and three hundred were killed.

This might have been the end of the story but Iraq decided to launch a series of environmental acts of terrorism as it withdrew from Kuwait. A flood of oil was released into the Gulf destroying most forms of life there. At the same time, hundreds of oil wells were set on fire within Kuwait, creating a massive blanket of air pollution. From the air the fires from the oil wells made the country look like a huge black blanket through which oil flares shot upward from time to time. It was a double terrorist catastrophe with great implications for the future of the surrounding environment, comparable in its destructiveness to the Chernobyl nuclear disaster and greater in its extent than any other oil spill in history.

Animals and people alike were having trouble breathing. There was a

Figure 109 Oil well fires rage outside Kuwait City in the aftermath of Operation Desert Storm. The wells were set on fire by Iraqi forces before they were ousted from the region by coalition.

stinging unpleasant smell everywhere that irritated lungs, clothing, and skin. On the ground there were pools of oil that caught fire occasionally as some nearby flame reached them. Trees, buildings, cars, anything on the land surface, all were covered with tar. Specialists in fire control were brought in at an early stage from all over the world. So challenging did the task seem to them that their first estimate for getting rid of all the fires was five years. Logistical problems faced them on every hand. The airport was not accessible so they had to wait for the smoke and fires around it to be cleared before they could bring in personnel and materials.

During their short period of occupation, the Iraqis had stripped the country of everything movable. Roads had to be created from fire site to fire site because the soldiers had cut defensive trenches across highways. In addition, the retreating army had left stores of ammunition and discarded vehicles everywhere. Minefields had to be cleared but no one knew where they were. Frequently the fire crews used huge bulldozers to pile up heaps of sand to fill in the trenches. At the same time they were able to use these mountains of sand to absorb the impact of exploding mines and thus get rid of them.

The scale of destruction by the Iraqis was so great that every innovative method possible was welcomed. Every day, about 15 percent of the world's consumption of oil was going up in smoke or forming rivers of oil. That amounted to six million barrels, roughly the quantity consumed daily by all the gas-powered vehicles in the United States. This went on for almost two months before the first fires were extinguished. Two months supply of oil is often the amount of emergency reserves stored in western countries. Furthermore, Kuwait was not the only casualty of Iraqi's environmental terrorism. All the surrounding countries, covering an area twice that of the area of Alaska, were smothered with poisonous black air, creating all kinds of health problems.

Most of Kuwait's oil wells are operated by underground pressure. There is no need for the kind of surface derricks so common in North America where oil has to be pumped up. Each Kuwaiti well is, therefore, a small inconspicuous structure carrying the usual "Christmas tree" of control pipes and surrounded by a chain-link fence. Where Iraqi damage was minimal, it was possible to stop the fire just by using an ordinary wrench. These opportunities were few. For the most part explosives had been used to destroy the control equipment. A critical part of the controls was the blow out preventer, a valve that adjusts pressure to cope with sudden increases from below. The loss of this control as fires were being extinguished led to sudden ignition in a few places, killing workers. Five men lost their lives in this way.

For the bigger fires a remote-operated crane was used to place a huge wide-diameter pipe over the well. Water and dry chemicals were then poured into the pipe to smother the flames. Both the heat and the noise made it impossible to talk to one another when close to the well so hand signals were used. Large supplies of liquid nitrogen happened to be on hand in Saudi Arabia and this was found to be an excellent chemical for putting out a fire. Its minus 320 degrees Fahrenheit temperature was an ideal cooling agent. Where flames shot out of a well horizontally as well as vertically it was too dangerous to use the wide-diameter pipes. Explosives became the only answer. They quickly put out the flames and, though they caused additional damage, they made it possible to reach the well and rebuild it.

As each team from the various countries coped with one fire after another the effect on the work as a whole was quite dramatic. Visibility gradually opened up. Teams could see better what was going on and were able to tackle those that seemed to be doing most damage. Instead of the original five-year prospect, the end of their work began to look more like one year. The final landscape looked like the moon. Swamps were everywhere, mainly filled with a mixture of oil and mud, and the ground had become saturated into a thick black mass. It would be a long time before any plants took root in that kind of soil. The end came in November of 1991. The last well was put out eight months after the first foray.

The other half of the environmental catastrophe, the oil flooding into the Gulf, was receiving the same intensive attention as the flaming oil wells and over the same period of time. For some places there was nothing that could be done. Salt marshes, mangrove plants, and coral habitats of rare turtles were destroyed. Estimates of seabird deaths reached 30,000. Fishing is a major industry all along the shores of the Gulf. After oil it is the main source of income for thousands of people on both sides of the

Gulf. All their fish stocks, including shrimp, barracuda, and mackerel were wiped out.

Forty times the amount of oil spilled by the *Exxon Valdez* in Alaska was released into the Gulf, adding to an earlier spill. In the 1980s, when Iraq and Iran were at war, Iraqi missiles hit offshore Iranian platforms and spilled two million barrels of oil into the ocean. Now, a decade later, the new flood of oil was being attacked with booms and skimmers, recovering one million barrels of oil from the ocean's surface. That was a record for any spill and it was urged on by the unique demands of Saudi Arabia's desalination plants.

Three of these plants are on the Gulf side of the country and they provide 40 percent of the nation's drinking water. It was the top priority of the government of Saudi Arabia to prevent any oil reaching the intake pipes of these installations. One plant alone produces 220 million gallons of fresh water a day, meeting three-quarters of the water needed by the country's capital, Riyadh. That same installation is also the source of water for a range of industrial enterprises in and around Riyadh. All the intake sites to these desalination plants were immediately surrounded with several lengths of boom as soon as news of the oil flood reached Riyadh. The booms were arranged in an inverted "V" formation to deflect oil away from the plants and to minimize the risk of oil splashing over the booms.

The final cost of all the cleanups was more than twelve billion dollars, including the value of lost oil, but unlike other spills there was little prospect of collecting these costs from the people responsible. Any national leader who could do what Iraqi's president did in and around the Gulf Region is beyond all rules of law. Several international conventions exist for dealing with the Kuwaiti catastrophe. They extend from the Hague Convention of 1907, condemning warring nations for environmental destruction, to similar agreements in 1949 and 1977. Economic sanctions against Iraq were the only possible response by the international community in relation to these conventions and agreements, and they were imposed at once. Ten years later they were still in place with little likelihood of being lifted.

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Mount Pinatubo, Philippines, volcanic eruption

June 15, 1991

The eruption that cooled the planet

This was the second largest volcanic eruption worldwide in the twentieth century. The biggest was Mount Katmai in Alaska in 1912

On June 15, 1991, and persisting for eight hours, the second largest volcanic eruption of the twentieth century, that of Mount Pinatubo, took place on the island of Luzon in the Philippines. The largest eruption was Katmai in Alaska in 1912. Pinatubo is only fifty-five miles from the capital city, Manila. As many as eight hundred people were killed and 100,000 became homeless following the eruption. Millions of tons of sulfur dioxide were discharged into the atmosphere, causing a decrease in the surface temperature of the entire globe over the next few years.

Mount Pinatubo is part of a chain of volcanoes along the Luzon arc on the west coast of the main island of the Philippines, Luzon, created by subduction action of tectonic plates similar to the way the volcanic mountains of Cascadia develop, such as Mount St. Helens. The events of the 1991 eruption began back in July 1990, when a magnitude 7.8 earthquake occurred sixty-two miles northeast of the Pinatubo region, a result of the reawakening of Mount Pinatubo. In mid-March 1991, villagers around Mount Pinatubo began feeling earthquakes and vulcanologists began to study the mountain. About 30,000 people lived in villages on the flanks of the volcano prior to the disaster. On April 2, 1991, small explosions from the mountain led to eruptions of ash that was deposited on local villages. The first evacuations of 5,000 people were ordered later that month.

Figure 110 Aerial view of the north side of Pinatubo crater with a small explosion in progress on June 22, 1991.

Before the catastrophic eruption of 1991, Pinatubo was not a dominant landmark, unknown to most people in the surrounding areas. Its summit was 5,725 feet above sea level, but only about 1,800 feet above nearby plains, and only about six hundred feet higher than surrounding peaks, which largely obscured it from view. An indigenous people, the Aeta, had lived on its slopes and in surrounding areas for several centuries, having fled the lowlands to escape persecution by the Spanish. They were a hunter-gatherer people who were extremely successful in surviving in the dense jungles of the area. The dense jungle that covered most of the mountain and surrounding peaks supported the hunter-gathering Aeta, while on the surrounding lowlying areas the abundant rainfall provided by the monsoon climate and the fertile volcanic soils provided excellent conditions for agriculture. Many people grew rice and other staple foods. Many of the Aeta who lived on the slopes of the volcano left their villages of their own volition when the first explosions began in April, gathering in a village about eight miles from the summit. They moved to increasingly distant villages as the eruptions escalated, some moving as much as nine times in the two months preceding the eruption.

Earthquakes and explosions continued to occur. On June 5, a level 3 alert was issued for two weeks due to the possibility of a major eruption. The extrusion of a lava dome on June 7, led to the issuance of a level 5 alert on June 9, indicating an eruption in progress. An evacuation area twelve miles away from the volcano was established and 25,000 people were evacuated. On June 10, Clark Air Base, a U.S. military installation near the volcano, was evacuated. The 18,000 personnel and their families were transported to Subic Bay Naval Station and most were returned to the United States. On June 12, the danger radius was extended to eighteen miles from the volcano and this involved increasing the total numbers evacuated to 58,000. Unfortunately, at the time of the eruption, Tropical Storm Yunya was passing forty-seven miles to the northeast of Mount Pinatubo, causing a large amount of rainfall in the region. The ash that was ejected from the volcano mixed with the water vapor in the air to cause deposits of rock and ash to fall across the whole of the island of Luzon. Many of the eight hundred people who died during the eruption were killed by the weight of the ash collapsing roofs and killing occupants. Had Tropical Storm Yunya not been nearby, the death toll from the volcano would have been much lower.

The volcano had experienced major eruptions in the past, the last being about five hundred years ago. Pinatubo stood about 5,725 feet above sea level before the June 1991 eruption. On June 15, the climactic eruption of Mount Pinatubo began in the early afternoon and lasted for nine hours, causing numerous earthquakes due to the collapse of the summit of Mount Pinatubo and the creation of a caldera. The caldera reduced the peak from 5,725 feet to 4,872 feet. In addition to the ash, Mount Pinatubo ejected between fifteen and thirty million tons of sulfur dioxide gas. Sulfur dioxide in the atmosphere mixes with water and oxygen in the atmosphere to become sulfuric acid, which in turn triggers ozone depletion. Over 90 percent of the material released from the volcano was ejected during the nine hour eruption of June 15. The human impacts of the disaster are staggering. In addition to the up to eight hundred people who lost their lives, there was almost one half of a billion dollars in property and economic damage. The economy of central Luzon was completely disrupted, the volcano having destroyed 4,979 homes and damaged another 70,257. One year after the eruption thousands of additional homes were destroyed and 3,137 were damaged, usually as a result of rain-induced torrents of volcanic debris.

The eruption plume of Mount Pinatubo's various gasses and ash reached high into the atmosphere within two hours of the eruption, reaching an altitude of twenty-one miles and covering an area 250 miles wide. This eruption was the largest disturbance of the stratosphere since the eruption of Krakatau in 1883. It had a Volcanic Explosivity Index (VEI) of 6, making it equivalent to some of the most violent eruptions in all of human history. Mount Vesuvius, Krakatau, and Thera of ancient Greece all had VEI of 6. The aerosol cloud spread around the earth in two weeks and covered the planet within a year. During 1992 and 1993, as a result of this aerosol cloud, the ozone hole over Antarctica reached an unprecedented size, creating a heightened risk of skin cancer all over the world. The cloud over the earth reduced global temperatures. In 1992 and 1993, the average temperature in the Northern Hemisphere was greatly reduced and the entire planet experienced its minimum temperature in August 1992.

Overall, the cooling effects of Mount Pinatubo's eruption were greater than those of the El Nino climatic event that coincided with the aftermath of the eruption. Pinatubo's cooling effects were also much greater in the years 1992 and 1993 than the increases that were accumulating due to human actions via greenhouse gases. The United States military never returned to Clark Air Base. The damaged base was turned over to the Philippine government on November 26, 1991. In all, the eruption ejected about two and a half cubic miles of material into the atmosphere. Damage to health care facilities, and the spread of illnesses in relocation facilities, led to soaring death rates in the months following the eruption. Education for thousands of children was seriously disrupted by the destruction of schools in the eruption.

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Hurricane Andrew

August 24, 1992
Florida was hit with the most destructive hurricane of the twentieth century

The peak gusts of 164 mph led to huge destruction of homes in the built-up area of southern Florida. Total damage costs were $26.5 billion

Hurricane Andrew was the most destructive twentieth century U.S. hurricane. It reached Florida as a category 4 storm where it made landfall at Homestead at 5 A.M. on August 24 with a peak gust of 164 mph. It caused twenty-three deaths in the United States, three more in the Bahamas, and ended up with a damage total of $26.5 billion, of which $1 billion occurred in Louisiana. The vast majority of the damage in Florida was due to the winds.

This most destructive hurricane started modestly as a tropical wave that emerged from the west coast of Africa on August 14. The wave spawned a tropical depression on August 16, which became Tropical Storm Andrew the next day. Further development was slow, as the west-northwestward moving Andrew encountered an unfavorable upper-level trough. Indeed, the storm almost dissipated on August 20 due to vertical wind shear. By August 21, Andrew was midway between Bermuda and Puerto Rico and turning westward into a more favorable environment. Rapid strengthening occurred, with Andrew reaching hurricane strength on August 22 and category 4 status on August 24 when it made landfall in Florida.

Florida is no stranger to hurricanes and throughout the twentieth century, again and again, the frequency and strength of the storms that arrived led to the waxing and waning of its attractiveness to northerners who wanted to enjoy its warmer temperatures. In the forty years from 1926 to 1966, Miami was hit with hurricanes about thirteen times but from the

Figure 111 Hurricane Andrew. Boat damage at Black Point Marina. Wind and surge from this category four storm tossed boats about like toys.

Figure 112 Hurricane Andrew, FL, August 24, 1992. Many houses, businesses and personal effects suffered extensive damage from one of the most destructive hurricanes ever recorded in America. One million people were evacuated and fifty-four died in this hurricane.

quarter century 1966 to 1992 there were none and during that period of time people flocked to Miami, doubling its population. New subdivisions sprung up but supervision of building codes and other regulations was lax. There were fewer than twenty building inspectors for a population of one million. The sudden arrival of Andrew was a great shock. Its fierce winds caused most of the damage. Houses were torn apart, cars lifted off the streets, and trees uprooted. Boarding up their windows proved useless as a protection in the face of the wind and very few homes had basements where people could shelter. It was an almost total destruction of whole subdivisions.

Reports from private barometers helped establish that Andrew's central pressure at landfall in Homestead, Florida, was 27.23 inches, which makes it the third most intense hurricane of record to hit the United States. Andrew's peak winds in south Florida were not directly measured due to the official measuring instruments having been destroyed. A storm surge of seventeen feet was recorded at Homestead. Thereafter the hurricane con-

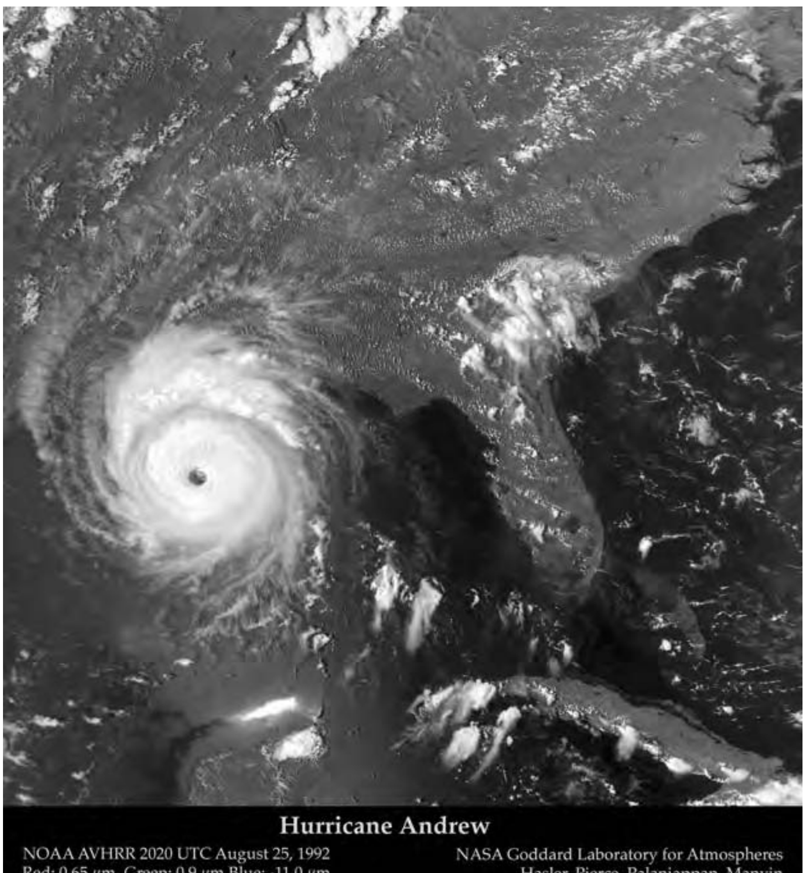

Figure 113 Satellite image of Hurricane Andrew on August 25, 1992.

tinued westward into the Gulf of Mexico where it gradually turned northward. This motion brought Andrew to the central Louisiana coast on August 26 as a category 3 hurricane where the storm surge of eight feet inundated much of the Louisiana coast. It also triggered a killer tornado in southeastern Louisiana. The storm then turned northeastward, eventually merging with a frontal system over the mid-Atlantic on August 28.

In all, 63,000 of the residences in Dale County, where Miami is located, were destroyed and another 110,000 damaged. Nine out of every ten mobile homes were also destroyed. Hospitals, fire stations, and other emergency stations had been put out of action by the storm and relief was slow to arrive from other places because there were no telephones or other communications to contact them. Andrew remained the most devastating natural disaster in U.S. history until the arrival of Hurricane Katrina in 2005. The name Andrew was retired in the spring of 1993 and will never again be used for an Atlantic hurricane. It was replaced with Alex in the 1998 season.

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New York City, New York, terrorism

February 26, 1993
A powerful bomb exploded in the parking area beneath the World Trade Center towers

This was the first and failed attempt by terrorists to take down the twin towers

Just before noon on the morning of February 26, 1993, a bomb went off beneath one of the towers of the World Trade Center, New York. It was so powerful that a steel reinforced concrete floor collapsed, tons of debris came down, a fire was started, and power for the entire complex was cut off. Fifty thousand people were soon without lights, heat, or elevators, and smoke was rising into the towers.

The World Trade Center (WTC) consisted of twin towers with 110 floors in each, located on a sixteen-acre site near the southern tip of Manhattan Island. They rose to more than 1,350 feet above street level and in 1970, when they were first occupied, they were the world's tallest buildings. The elevator system was a combination of express and local elevators and this arrangement increased the amount of floor space given to occupancy. In conventional systems only half the area on each floor is available for offices. In the WTC it was 75 percent. Economy of space was obtained by having three vertical zones, ground to forty-first, then to seventy-fourth, and from that point to the top. Express elevators served the three zones and four banks of local ones operate within each vertical zone.

The explosion occurred in an underground garage beneath the WTC, powerful enough to rock the towers and demolish the steel-and-concrete ceiling of the underground train station, a major transportation point for New Jersey commuters. A huge hole was ripped in the station wall and

Figure 114 The crater in an underground parking garage from the World Trade Center explosion is shown in this Saturday, February 27, 1993 photo. The blast left at least five people dead and several hundred injured.

an even bigger cavity was created beneath. Thick black smoke from the smoldering fire created by the blast swept upward to the top of both buildings where as many as 100,000 people work or visit daily. On February 26, there were 50,000 people in the buildings, including two hundred kindergarten and elementary school children who were visitors. They had to be left for hours on the observation deck until injured people were attended to. Six had been killed by the blast and a thousand injured, mostly from smoke inhalation. To the thousands who were in the building it was a terrifying experience. There was darkness, no heat or light, no elevators working, and smoke everywhere.

Hundreds of people poured out of the towers into the streets, their faces black with soot, some of them having managed to find their way down from as high as the hundredth floor. Many others stayed on their floors waiting for assistance to arrive. They packed cloths against doors and vents where smoke was entering or used moistened cloths on their faces. The blast just so happened to be located at the point where it could do the most damage. It knocked out the power plant for the entire complex, plunging everyone in the Twin Towers into darkness. One newscaster, unfortunately, went on the air and advised people in the towers that if they were having trouble breathing, they should break out the glass window. This was the worst thing he could have said and his call was quickly refuted by others. There were over five hundred emergency personnel on the ground who could be hit with flying glass and, furthermore, the open window would allow smoke to enter the area.

Charles Maikish was the director of the whole WTC and as he felt the tower sway a little beyond the normal he knew that a major accident had taken place. He was on the thirty-fifth floor at the time so his first move was to check the elevators. They, in accordance with emergency procedures, had already moved back down to their starter floors. He made his way as best he could to the lobby and began to organize a command center there. Smoke was everywhere. A policeman on duty in the building made a hole with his bare hands at the top of an elevator and consoled a group of five-year olds who were stranded in it. A fireman broke down an elevator door and found it was full of partly conscious people lying on the floor. Down below in the parking area, those who were arriving at the time of the blast witnessed the smoke and fire and heard the screams of those who were closest to the bomb.

New York's television stations are located on the top of the first tower and all but one were cut off. The one that remained was not dependent on the towers for its power so, where battery power and various radio outlets were available, the station provided information for people on their different floors. Everyone was urged to stay calm and to wait. The scale of the rescue effort must have been disheartening, having to reach and help people on 110 floors in each of the two towers, not knowing how many were stuck in elevators. It was impossible to say how long it would take to get everyone to safety and meanwhile anxious relatives and friends waited below. For two hours the fire and smoke persisted. A number of disabled people had to be rescued by helicopter from the roof. Close to midnight on the twenty-sixth the last elevator was reached. Several had been stuck in it for eleven hours. The terrorists had planned to send up a cloud of cyanide gas amid the smoke of the fire but the cyanide was burnt up in the heat of the explosion and did not vaporize.

The chief of NewYork's fire department provided a summary of the events of February 26,1993. He pointed out that there had been numerous trips to the WTC since 1970 when it was first occupied. These related to minor fires, fire alarms, and one or two major fires but nothing in these experiences prepared the department for the events of February 26. It was the largest incident ever handled in the city's one hundred and twenty-eight-year history. In fact, it was the equivalent of several major multi-alarm fires combined into one. Many fire department units from other parts of the city had to be called in to help. The statistics tell the story well. Six people died and more than a thousand were injured, fifteen of the latter having received traumatic damage directly from the blast. Eighty-eight firefighters and thirty-five police officers were injured.

Approximately 25,000 people were evacuated from each tower. Most of the victims were trapped on the upper floors and hence the large amount of time needed to rescue them. Search and rescue work was finally completed shortly before midnight on the same day. The bomb weighed more than a thousand pounds and did comprehensive damage on seven floors, six of them below street level. The crater it made measured

130 by 150 feet and was located beneath the Vista Hotel. While the emergency work was concentrated in one day the Fire Department staff maintained a presence at the WTC for a further month. The bomb was located where it could do the most damage. Later it was discovered that the total destruction of the entire World Trade Center's two towers was planned. Fortunately, the terrorists underestimated the strength of the buildings.

Arrests of four of the six terrorists, those who were still in the United States, came quickly because the FBI had an informant who taped conversations with them two months after the bombing. Their trials were held in New York and they obviously had no trouble finding enough money to hire the best and probably the most expensive lawyers they could find. William Kunsler, the well-known defense attorney, represented at least one of them. For six months the trial proceeded. The jury had to be together all of that time with protective security throughout. All of the rights of the accused were safeguarded as fully as they would be for any American.

The judge handling the court cases knew that he was dealing with extremists for whom neither justice nor life had much value. They had their own view of Islam and felt that to die in the name of Allah was a holy act. They certainly had no respect for the American rule of law so the courthouse had to be made secure for the entire period of the six-month trial. The jury found all four guilty—Mohammed Salameh, Nidal Ayyad, Mahmond Abouhalima, and Ahmad Ajaj. Pandemonium broke out as soon as the verdicts were given with Allah's name being shouted and anger vented at what they called injustice. Salameh, who for some unknown reason thought he had won the case against him, lunged at the members of the jury and had to be restrained by marshals. There was screaming and abusive language before they were handcuffed and dragged away to serve their 240 years.

Before the leader of the terrorist unit, Ramzi Yousef, was finally caught and imprisoned he had worked out plans for additional attacks. He came to the United States prior to the events of February 26, 1993, on an Iraqi passport and left very soon after the bombing. Then in Manila, Philippines, in January of 1995, while mixing some bomb material, a fire broke out and he was forced to run away to avoid detection. He knew that U.S. authorities were on his trail. When investigators examined the place that had caught fire they found evidence that led to his arrest in Pakistan a month later. They also found details of a plan to blow up eleven U.S. commercial planes on one day. He hoped to use a new liquid explosive that could pass metal detectors at airports. Most sinister of all was a note among his belongings saying he could use chemicals and poison gas against whole populations.

Ramzi Yousef's plots were the most ambitious terrorist conspiracies ever attempted against the United States, that is, until the devastating events of nine eleven, all bearing a frightening resemblance to the plans found in the Philippines. Now the whole nation knows that terrorism demands eternal vigilance. The last of Yousef's five, Eyad Ismail, a twenty-six-year-old Palestinian, the youngest of the six, was the one who drove the lethal truck to the WTC, then escaped after lighting the fuse and fled to Jordan where he was captured in 1995. No one among the six is ever likely to be released. They each received 240 years imprisonment. In the event that any one tries to make money by publishing a book on the bombing, the judge levied a fine of ten million dollars on each to pay for restitution. Yousef was levied a bit more, 250 million damages for restitution. Actual cost of the damage to the WTC was half a billion dollars.

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Northridge, California, earthquake

January 17, 1994

The costliest earthquake in U.S. history

The damage caused was enormous and concentrated because this earthquake occurred within a densely-populated area

An earthquake of magnitude 6.7 hit an area of high population density twenty-five miles northwest of Los Angeles at 4:30 A.M. on January 17, 1994. About ten million people in the Greater Los Angeles region felt the impact of the quake. This earthquake, named for its epicenter in the town of Northridge, proved to be the most costly in U.S. history. Communities throughout the San Fernando Valley and in its surrounding mountains north and west of Los Angeles were affected, causing losses of 20 billion dollars. Fifty-seven people died, more than 9,000 were injured, and more than 20,000 were displaced from their homes.

Because the earthquake was centered beneath a built-up urban area, the impact on buildings of all kinds was immense. Thousands of buildings were significantly damaged, and more than 1,600 became unsafe to enter. The shaking lasted for less than thirty seconds but in that time buildings came down, freeway interchanges collapsed, and fires broke out as gas lines were broken. Fortunately, the early morning timing of the earthquake spared many lives that otherwise might have been lost in collapsed parking buildings and on failed freeways. Freeway bridges built or designed before the mid-1970s and had not been retrofitted to meet new standards failed. Telephone systems broke down, not because of equipment failure but due to overload and they were inadequate for an emergency of this scale.

The earthquake began as a rupture on a hidden fault at a depth of ten

Figure 115 Road collapse caused by Northridge earthquake.

Figure 116 Landslide caused by Northridge earthquake.

miles beneath the San Fernando Valley. For eight seconds following the initial break, the rupture continued to extend upward and northwestward along the fault plane at a rate of two miles per second. The rupture front spread out across as well as along the fault plane, so that the eventual size of the rupture covered an area of ten by twelve miles. The rupture stopped at a depth of three miles. Maximum intensities from the quake were felt in and near Northridge and in Sherman Oaks. Lesser, but still significant intensities were felt in Fillmore, Glendale, Santa Clarita, Santa Monica, Simi Valley, and in western and central Los Angeles. A rise in ground level of six inches occurred in the Santa Susana Mountains and there were many rockslides in mountain areas that blocked roads. Some ground cracks were observed at Granada Hills and liquefaction occurred at a number of locations in the Simi Valley.

In summary, all the lifeline systems in the areas affected by the quake were damaged in various ways, including freeways, communications, gas, water, power, and sewage. Additionally, the delivery of water from the Colorado River and northern California was disrupted so that some areas were without water for weeks. This earthquake measured 6.7 on the Richter Scale and there is a tendency to assume that an event of this strength will do less damage than one of magnitude 8 or higher. However, everything changes when an earthquake occurs in the middle of a major urban area. In Japan in 1995, when the city of Kobe was hit with a quake of magnitude 6.9, the destruction that followed was far more costly than anything the country had previously experienced. Costs in that event were seven times the total for the Northridge quake.

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Rwanda genocide

April 6, 1994
An entire tribe close to a million in number
were massacred by another tribe

A long-standing hatred of Tutsis by the Hutus exploded in extreme violence, killing more than half of the Tutsis

When a radical group took power on April 6, 1994, the Hutu-controlled government of Rwanda launched an extermination campaign against the Tutsis, the other tribal group in the country. Within the short time span of three months close to one million Tutsis were murdered, urged on by national radio broadcasts that kept shouting slogans such as "Kill them all," or "Who will help us fill the half-empty graves?"

It is hard for people in North America's multicultural society to understand how one cultural group can hate another so much that it is willing to completely exterminate it. The reason is that in Africa group rights and group loyalty are frequently the primary concern, not the individual and his or her rights and loyalties. In Rwanda, over the course of the thirty years since it secured independence from Belgium, there were recurring conflicts between the two main tribal groups. The events of 1994 were by far the worst. They were also the most barbaric actions seen anywhere in Africa in modern times.

Genocide, the deliberate destruction of an identifiable cultural group, is the name for the murders committed in Rwanda in 1994. These acts of genocide were not unique. Similar campaigns of violence against particular groups happened in many parts of the world in the course of the twentieth century. In Cambodia genocide took the form of a wholesale killing of the middle classes, in the area east of Turkey it was seen in the slaughter of Armenian citizens, and in the former Soviet Union millions of Ukrainian farmers were starved to death (see Ukraine catastrophe). Perhaps the best-known genocide of all was Hitler's gassing of millions of Jews.

The Rwandan problem dates back to the time when the country was a colony of Belgium. The colonial administrators decided to favor the Tutsis as the better of the two tribal groups for administering the country's affairs. The Tutsis were tall and good-looking, but they were a minority tribe and this angered the Hutus. Then, to make matters worse, the Belgians introduced identity cards in the 1930s on which the name and tribal identity was entered. Thus, differences between the two cultural groups were further emphasized with the Hutus feeling that they were permanently relegated to second class status in their own country.

This technique of creating tensions between different ethnic groups was a common ploy among the European colonial powers. They all did it as the results of such tensions made administration easier for them because the different groups became so busy fighting one another that they did not unite to fight the intruder from Europe. It was not fully realized at the time that this approach would lead to warfare when the colonial empires became independent nations. In the case of Rwanda the problem was worse than in most places. When the Belgians finally gave the country independence in the early 1960s they decided to switch and hand over power to the majority Hutu. The stage was set for terrible retribution.

Immediately after they took over the government, the Hutus launched attacks on the Tutsis, calling them foreigners who had invaded the state at an earlier time and now had no citizenship rights. This was a more extreme form of dictatorship than anything imposed by the Tutsis when they were in power and before long mass persecutions began. Within six months 10,000 Tutsis were dead at the hands of government troops. A majority of the rest, approximately 350,000 in all, fled into the neighboring countries of Burundi and Uganda. For the ensuing twelve years there was an ongoing civil war as the Tutsi diaspora which gave itself the name Rwanda Patriotic Front (RPF) launched armed incursions into their homeland from Uganda or Burundi.

Their efforts soon stopped, however, when they discovered that thousands of the Tutsis who had stayed at home when the mass exodus occurred were now being blamed for these attacks from without. In 1963, about 6,500 were murdered on this account and later another 10,000 met the same fate. Although the incursions stopped, their determination to return continued to grow even as the Tutsis became involved in the affairs of the countries to which they had fled. In 1979, a moderate group of Hutus took over the government and persecution of the Tutsis stopped but a general repatriation from Uganda and Burundi was not part of this new development. These Tutsis were still treated as foreigners.

Many individual Tutsis returned from exile. Others, in spite of the better conditions at home, stayed away. It was another fourteen years before the RPF in Uganda and Burundi felt able to launch a raid into Rwanda. They succeeded in driving the government troops back to within fifteen miles of Kigali, the capital of the country. Their success forced General Habyarimana the extremist head of the Hutu government to agree to peace with Paul Kagame, RPF leader. The Arusha Accord was the result and it defined the new structure of government. It provided for power sharing, the rule of law, and a transition process leading to democracy. A United Nations peacekeeping force under the command of the Canadian General Dallaire was sent to Kigali to give support to the new political system.

Substantial evidence exists to prove that, in spite of the Arusha Accord which he signed; General Habyarimana and his friends in government had been planning mass killings for some time in a desperate attempt to prevent any sharing of power. A United Nations report in 1993 described the murders that had occurred as a prelude to genocide. Perhaps if that document had been circulated, to those who arranged the peacekeeping contingent, the outcome might have been very different. The event that provided an excuse for a wholesale slaughter was the death of Habyarimana when his plane was shot down on April 6, 1994. There was no evidence that Tutsis had anything to do with this but that did not seem to matter. The attack made their planned genocide look plausible. Within hours of the plane crash the killings began. All the moderates in government were the first victims.

The campaign was urged on by government radio which declared day by day that it was the sacred duty of every Hutu to kill the Tutsis. Slogans such as "spare none, fill the empty graves" and "kill their babies or they will grow up and kill us" were typical broadcasts. Threats were even extended to Hutus who might hesitate to join in, telling them that they too would be killed if they failed to cooperate. Bullets were either too expensive to use or were just not available in sufficient quantities so machetes and farm implements became the instruments of slaughter. Raping, mutilating, burning, and hacking to death were the sights and sounds throughout the country for about three months. Acts of torture were commonplace.

Escape routes were blocked to prevent anyone escaping. Murderous bands hunted Tutsis day and night for more than three months while the Security Council and the Secretary-General of the United Nations (UN) conveniently ignored the problem, describing it as "Tutsis fighting Hutus and Hutus fighting Tutsis in some ancient blood feud." It was no surprise therefore that the international community did not intervene at the time and that General Dallaire's small contingent of troops was powerless to stop the violence. Added to these comments by leaders at the UN were the institutional weaknesses of that international body. The Rwandan ambassador remained in New York throughout the three months of genocide, insisting all the time that Hutu actions were in self-defense against the violent Tutsis.

Even though the scale of the massacre was becoming well known at the UN, protocol required that Rwanda's ambassador be accorded the same respect given to representatives of other countries. Furthermore, at this time, Rwanda was a nonpermanent member of the Security Council so unanimous decisions against Rwanda could not be secured there at the heart of the UN. France added to the general confusion at the UN by insisting that the Hutus were the larger of the two tribal groups and they therefore, in the interests of democracy, should be given preferential treatment. France went further and supplied arms, through Zaire, to the Hutu militia in the middle of the genocide.

All this time, death squads rounded up large numbers of men, women, and children and forced them into churches and stadiums so they could be killed more easily. Grenades were thrown into these buildings, followed by tear gas. Those still alive could then be killed as they choked on the gas. Some Tutsis begged the peacekeepers to kill them so that they would escape the Hutu torturers. Hutu recruits were trained to use machetes, called pangas, for their bloody genocide. Rwanda is in a hot climate, close to the equator, even though it is mostly 3,000 feet above sea level, and the terrible work of slicing heads, hands, or legs was exhausting. Hutus decided that if they just severed the Achilles tendons, which connect the heel to the calf muscles, their victims would be helpless, unable to run away. They could then rest for a time before returning to the butchery. RPF soldiers, though a small minority, fought for their own survival and succeeded in killing or driving out of the country many of the Hutu death squads.

Rwandan women were subjected to sexual violence on a massive scale, perpetrated by both the infamous Hutu militia known as the Interahamwe and soldiers of the Rwandan Armed Forces. Political leaders at the national and local levels directed or encouraged both killings and sexual violence to further their political goal of destroying the Tutsis as an identifiable group. This goes far beyond the historic ravages of war and links up these atrocities with similar events in the Bosnian war (see Srebrenica, Bosnia-Herzegovina, genocide). As will be seen later, it was the diabolical nature of sexual violence in these two places that led to recognizing them as crimes against humanity.

Testimonies from survivors confirm that rape was widespread with thousands individually raped, gang-raped, raped with objects such as sharpened sticks or gun barrels, held in sexual slavery, or sexually mutilated. Often these crimes occurred after their family members were tortured and killed and their homes destroyed. The Tutsi women were the almost exclusive targets in these attacks which were intended to dehumanize and subjugate the whole tribal group. Some Hutu women were also raped because they were married to Tutsi men or because they protected members of that tribe. The legacy of all they experienced is now compounded by the fact that they will be the key administrators in post-massacre Rwanda. There will be few men.

On July 4, 1994, the RPF, aided by widespread disorder everywhere, achieved a total military victory and become the new government of Rwanda. Over the following few weeks close to two million Hutus fled the country and set up camps across the border in Zaire. For a time these camps in a place called Goma became the center of interest as various agencies tried to cope with outbreaks of disease, hunger, and armed conflict. The Hutus tried to reorganize for a return to Rwanda in the hope of regaining power but that hope was foiled by the actions of the government of Zaire that forced them out of its territory. Some did manage to get back to Rwanda but most were caught and they ended up in prisons that were already overcrowded.

International responses were slow in coming. When the world finally knew the extent of the killing a tide of sympathy and support turned toward the victims. The new Tutsi government was faced with the enormous task of resettling hundreds of thousands of refugees, reconstructing a devastated economy, and coping with the Hutus who had fled and were now coming back from Zaire. Out of a total population of eight million, more than a third had been either murdered or driven out of the country. Many of those remaining were dislocated within the country and innumerable lives were traumatized. Subsistence farming, the basis of the nation's economy, was in disrepair and the only means of survival in the short term was foreign aid. Fortunately this was provided. Buildings and infrastructure generally were destroyed and financial and legal services were not available.

Within a few months of the new Tutsi-based government taking power, about 200,000 additional Tutsis returned from other countries and began to reclaim the homes they left thirty years earlier. These people had to be fed and housed until they could look after themselves and aid for this was forthcoming from western countries who were at last fully aware of the horror that had taken place. Hutus also had to be accepted back because they were not welcome as permanent residents of Zaire. There were tensions everywhere arising from the presence of the two tribal groups. From the Hutus about 130,000 had been arrested and were now imprisoned, awaiting trial, in cramped, often rat-infested prisons. In one of these places, sixty people were forced into a room designed for a few and the door locked. Next morning authorities found that twenty-four had died. They had suffocated in their fetid, hot, overcrowded room.

The United Nations Security Council created the International Criminal Court (or Tribunal) for Rwanda (ICTR) later in 1994 and set up its offices in Arusha, Tanzania. The chief prosecutor for this tribunal had his office at The Hague in Holland, from which place he made occasional visits to Arusha. The Appeals Court for ICTR was also set up at The Hague. These two logistic problems made it difficult for the tribunal to work quickly. A backlog of cases mounted and there was only a small budget available for hiring additional staff. Delays led to criticisms. Western governments made invidious comparisons between a similar United Nations Court on Yugoslavia (ICTY) without acknowledging the factor of distance from The Hague and the larger budget that ICTY enjoyed.

The early problems of the ICTR were matched by others as the work of the tribunal began. The enormity of the crime, unprecedented even in recent African history, created an atmosphere of fear in the course of the trials. Many witnesses were killed before they reached the trial location and some who were about to testify were threatened. An inadequate security system enabled the public to discover the names of those who were witnesses. One person who was called to testify lived in a small town where he owned a shop. A large car clearly marked with the United Nations' black and while license plates was visible outside his home. Everyone in the village knew what was happening.

His wife was terrified and refused to give any information to the visitor from Arusha. She knew that other witnesses had been killed to prevent them testifying. Her husband was willing to talk though he too knew the danger of doing so. He asked for protection and was told that if he called the United Nations office he would receive protection. Unfortunately for him, the nearest telephone was twenty miles away. Even if the phone had been in his store it would not have made any difference. Two weeks before he was to travel to Arusha armed men forced their way into his home and killed him, along with his daughter, brother, and nephew. The tribunal now uses unmarked cars when they visit potential witnesses.

The United Nations terms of reference for the tribunal included strict procedures for the protection of witnesses and these were usually followed carefully during trials. Everything was done in camera and people were identified by a letter code rather than a name. Laudable as these rules were, they could not ensure secrecy for witnesses. Rwanda is the least urbanized country on earth. Virtually everyone lives in small rural communities where there are no secrets. When a person left home in a car from any one of these places, particularly when no reason for the trip was given, and traveled to another country, it was easy to find out who had been a witness. Two years after the tribunal's work began, in the course of the calendar year 1996, over two hundred witnesses were murdered.

One of the biggest challenges to justice lay in the physical conditions of the prisons where suspects were held. In the weeks following the establishment of the new Tutsi government and the mass escape of Hutus into Zaire, almost any Hutu found in Rwanda was suspect. About 130,000 of them had been arrested—many of them on the basis of ethnic identity alone—and the prisons were overcrowded, unhealthy, and filthy. The temptation for prisoners to offer false but ostensibly valuable testimony was strong. If they were selected for the trials they gained access to the spacious and clean prison facilities at the United Nations compound in Arusha. There they would be fed well, given two complete outfits of clothing, and allowed access to a gymnasium, computers, and a library. The contrast with their hot, unhealthy holding cells could hardly be greater.

Quite apart from operational difficulties there were fundamental issues of justice in the rules governing the ICTR. No United Nations agency could sentence anyone to death. In addition, the tribunal had power to make plea agreements. The accused, provided they confessed before they came to trial, could receive lesser sentences. The Rwanda government did have the death penalty so, given its strong feelings, it wanted the maximum sentences for convicted killers. There was an immediate conflict between national and international jurisdictions. The Rwanda government tried by all means in its power to take charge of some trials rather than leaving them to the ICTR. Some neighboring countries, such as Ethiopia, which had arrested Hutu criminals, were persuaded to hand them over to Rwanda instead of the ICTR.

The familiar western pattern of justice where defense attorneys are allowed to question witnesses intensively created outbursts of angry opposition. Once a shouting match broke out as both a defense attorney and a witness called each other stupid. Members of the Tutsi-dominated government also criticized the actions of the defense, leaving the impression that they were more interested in revenge than in justice. A further occasion of tension between the ICTR and Rwanda's government was the time limitations on the former. It was permitted to examine the events of 1994 only, but the government insisted that plans for the genocide go back several years.

Rwanda, as has been said, is now a country of women. About 70 percent of the population is female. These women face social stigmatization, poor health that often includes the AIDS disease, unwanted pregnancy, and poverty. They dare not reveal their experiences publicly, fearing that they will never be able to marry. Others, like the Tribunal's witnesses, fear retribution from their attackers if they speak out. Furthermore, they suffer guilt for having survived and been held for rape, rather than being executed. An estimated 5,000 unwanted babies created their own series of crises. Some babies were abandoned by their mothers and others were killed.

As they tackle the problems of rebuilding the country, Rwandan women have to contend with laws that discriminate against them. They are second-class citizens in the legal structure of their country despite constitutional guarantees of full equality. Inheritance rights are not documented rights. That is, they are governed by custom. For example, women cannot inherit property unless so designated by some male who has the right to transfer it. Such a situation is meaningless in the wake of the massacre. Widows and daughters have no legal claim on the properties or possessions of their dead husbands or relatives. Neither can they receive pensions due to their male relatives.

There were some success stories that stood in sharp contrast to all the negative experiences at ICTR and in the Rwanda community generally. A former Rwanda mayor was successfully convicted of crimes against humanity on the basis of rape charges. Later the same level of conviction was accorded some of the soldiers involved in the Bosnian war. Four others Hutus were convicted of genocide and this carried a maximum sentence of life in prison. In Belgium, Rwanda's former colonial master, two nuns and two others were found guilty in 2001 for helping the Hutu militias kill thousands of Tutsis in the 1994 massacre. One nun, a former Benedictine Mother Superior, was given fifteen years in prison and the second twelve years. The other two received comparable sentences.

This case made legal history because it was the first time a civilian jury convicted war criminals from another country. Belgium has a special law that permits this. During the three months of killings in 1994, around seven hundred Tutsi men, women, and children hid in a building at the convent's health clinic. The nuns wanted to get rid of them so they brought cans of gasoline to the militias who had chained the doors to make sure that no one would escape. The militias then threw grenades through holes in the walls and set the building on fire.

The agonies of the genocide were still very much alive in the year 2001. In spite of all the worldwide recognition of what had happened, leaders of the genocide who had succeeded in hiding out in the former Zaire, began to send trained groups of young men back into Rwanda. The plan was to capture territory in local areas so that these locations could be used as staging points for larger ventures. Their numbers are steadily decreasing but probably as many as 30,000 still survive in the former Zaire, a country that wants to get rid of them but is too weak to do anything about it. In June of 2001 soldiers from the Tutsi-controlled government surprised and killed a band of 1,500 youths which had been trained by leaders of the genocide, and had infiltrated the northwest areas of the country intending to establish a base there. Tutsis now increasingly feel that their survival depends on themselves alone, not on the UN.

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Kobe, Japan, earthquake

January 17, 1995
Kobe experienced the nation's most destructive earthquake in fifty years

Like the Northridge earthquake that also occurred in a densely populated area, Kobe suffered very extensive damage and many casualties

Early in the morning of January 17, 1995, Kobe, Japan, experienced the nation's most destructive earthquake since 1946. Its epicenter was at Awaji, offshore from Kobe, and ten miles below the surface. Damage was extensive and there were many casualties. Over 5,400 were killed, another 26,800 injured, and over 300,000 made homeless. Additionally, around 105,000 buildings were damaged beyond repair and numerous others suffered lesser forms of damage. The financial costs of the earthquake were in excess of 150 billion U.S. dollars.

The Kobe area is dominated by the Philippine Tectonic Plate's subducting action as it moves beneath the Eurasian Plate at a rate of about two inches a year. Great subduction earthquakes arise from this action at average recurrence rates of one hundred years. This part of Japan has the most dense number of faults of anywhere in the country and they, like the main subducting action, also on average have an annual slippage rate, one much smaller than that of the main tectonic plate. As a result of these lesser fault movements, the Kyoto-Osaka corridor has experienced more intraplate earthquakes throughout history than any other region of Japan.

The quake devastated central Kobe, crushing buildings and homes and filling the narrow streets with debris. Train services, so vital to Japan's transportation system, came to a sudden stop and all electricity and water provisions were cut off. So complete was the destruction of everything

Figure 117 An office building with a partially destroyed first floor. The majority of partial or complete collapses were in the older, reinforced concrete buildings built before 1975.

Figure 118 The first and second stories of a metal frame office building collapsed. This photo demonstrates the lateral force of the quake and the structural damage caused by the sine wave effect of the force. Note the unbroken windows.

that the term "Great Hanshin Disaster" was born to indicate an event similar to the "Great Kanto Disaster" of 1923. The word "Hanshin" is another term for the Kobe Region. With the loss of all water supplies it became impossible to cope with all the fires that broke out as electrical sparks and flammable materials were thrown together. Thus a firestorm, like the one that engulfed San Francisco in 1906 for the same reason, and lack of water supplies, swept across Kobe. By late on January 17, there were 234 fires and, before the middle of the next day, five hundred conflagrations were consuming the large amounts of flammable materials that lay around.

The destruction that took place along Kobe's waterfront was another mirror image of the 1906 earthquake, that of liquefaction. All along the waterfront zone of Kobe extensive reclamation work had gone on for decades to provide space for shipping activities and warehouses. The widespread liquefaction that took place destroyed the roads leading to the waterfront installations, collapsed both housing and warehouses, and lowered the ground level across the whole area by several feet. A few buildings that had been erected on deeper geological formations remained intact. Liquefaction extended downward in the reclaimed areas as deep as thirty feet in the wake of the thousands of aftershocks that followed the main quake and the wave movements in these deeper zones of liquefaction damaged several areas farther inland.

Minimum amounts of restoration took several months to complete. Gas and electrical supply lines had been so badly disrupted that even Japan's extremely efficient system of records was incapable of deciding what line belongs where. Officials had to interview individual family survivors, mass media reports, and a variety of telephone and printed records before reconnecting trunk lines. For water lines, the available pressure was initially inadequate for identifying breaks in the system and when officials tried to reach locations to examine conditions directly they were held up by a total absence of roads. Within the downtown part of Kobe all the main streets were impassable. Removing liquefied sand from damaged pipes was yet another hurdle to overcome before the pipes could be reconnected.

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Oklahoma City, Oklahoma, terrorism

April 19, 1995

A powerful bomb destroyed a Federal building in Oklahoma City

The P. Murrah Federal building was targeted by one or two U.S. terrorists who had a grudge against the Federal government

On the morning of April 19, 1995, a gigantic bomb went off at the entrance to the Alfred P. Murrah Federal Building in Oklahoma City. A red and orange fireball shot upward, a deep crater appeared beneath the entrance, and all over the building slabs of glass and concrete crashed down. Ten buildings within a three-block radius almost collapsed and hundreds of others were damaged. The blast was felt forty miles away. One hundred and sixty-eight were killed and five hundred injured.

On the April 17, 1993, a man who had earlier booked a truck by telephone, picked up the Ryder truck that could carry five thousand pounds. He made a $150 deposit on the car, gave a false name, provided a wrong home address, and gave another person's driver's license, then left with the truck. The bomb materials were assembled and placed on the truck next day. Early on the morning of the nineteenth, the same day of the same month as the Waco conflagration, he drove the truck into Oklahoma. He had previously left his Mercury car a short distance from the scene of the crime. He lit the fuse before parking outside the Murrah Building and then, having locked the truck door, ran to his Mercury.

The explosion hurled everything nearby into the air. In the Murrah Building there was double destruction, floors being thrust upward by the force of the blast and higher floors collapsing as the building's foundations

Figure 119 Oklahoma City, Oklahoma, April 26, 1995. Search and rescue crews work to save those trapped beneath the debris, following the Oklahoma City bombing.

were cut away. On the seventh floor, fifty people were instantly crushed to death while another twenty met a similar fate on the fourth floor. It was a comparable story on all the other floors. Saddest of all was the instant destruction of a day-care center on the second floor where there were fifteen children and three teachers. That floor took the full force of the bomb. Human remains from it were found a block away.

Twenty-four bystanders near the building were killed instantly. Survivors staggered from the ruins of the Murrah Building, some half-naked because shoes and clothing had been ripped off. Their wounds were evident and they were bleeding either because of cuts or through walking over broken glass. Blood, dust, plaster, and concrete littered the ground and filled the cavity below ground created by the bomb. Hundreds of people were running around outside, screaming as they burned to death or tried to cope with the pieces of glass embedded in their faces and hands.

Relief efforts came together in large numbers. Everyone who could get near the scene of destruction helped. More than five hundred had been injured and the number dead would not be known for a few days because of the amount and weight of rubble. Family members brought dental and other records to help with identification. Often the shattered state of their children's bodies made visual recognition impossible. Every doctor in Oklahoma City was on hand to do whatever could be done. Blood was in short supply because so many had been pierced with glass and were bleeding badly. One man had more than a hundred deep cuts from glass.

Cranes and bulldozers were busy moving concrete slabs out of the way in order to rescue whoever might still be alive below. Sophisticated listening devices also assisted in finding people. There were dogs specially trained to sniff out victims, some of them specially trained to sniff out babies who have a scent that is different from that of adults. This special dog resource had a poignant appeal here because of the large number of infants and young children who had been in the building. The search went on through the night and on into the next day. When a final death count was reached it was 168 and it included 19 very young children. Five hundred others were injured.

Suspicion universally focused on Islamic extremists. The World Trade Center bombing of 1993 was still fresh in people's minds (see New York City, New York, terrorism) as well as earlier acts of violence by the same people. Every media outlet and all comments from political leaders declared that the criminals must have come from abroad. Violence at this scale in heartland America could not happen, it was said, unless it was inspired by the same mindset that blew Pam Am 103 out of the sky in 1988 (see Munich, Germany, terrorism). One congressman went so far as to say that there was clear evidence that fundamentalist Islamic terrorists were involved. People from the Middle East who happened to be in the United States or who had come from there but were now U.S. citizens were under suspicion and some were taken in for questioning. In spite of vehement denials from Muslim groups all over the world, there persisted the sad spectacle of a whole ethnic group being held suspect without a single bit of supporting evidence.

Some reflection on recent events, even the date of the disaster, might have alerted authorities to another possibility. Several had been disturbed by the tragedies at Ruby Ridge in 1992 and Waco in 1993 and felt they should avenge what they considered to be indefensible violence on the part of the U.S. government. These were people who do not subscribe to the democratic ethic of majority rule. They are few in number but in an age that gives enormous power to the individual they can be very dangerous. The terrorist and mass murderer who was responsible for this worst terrorist act in American history was one of them. He was an American and his name was Timothy McVeigh.

The media usually take note of people like McVeigh only when something bad happens. There are people like him who are violently opposed to the law of the land because it gives rights to homosexuals and permits abortions. Others have racist views, hating blacks and Jews, while yet another group feels justified in taking violent action against established authority on the basis of some kind of Christian faith, or just because they disagree with a particular action. Warnings about the dangers posed by these extremist groups and individuals have largely been ignored, partly because the victims were few and partly because their terrorist actions had not caused extensive damage.

The bombing of the Murrah Building changed all that. If one individual could do this much damage then the potential for major destruction lay within the reach of a small number of extremists. For many years federal authorities were fully aware of the existence of these outlaws, but they only made contact with them when they had to. For their part, these extremists were largely inactive. They lived away from the main centers of population and trained their people in the use of firearms.

In searching for the perpetrators of major disasters, FBI officials know that their acts usually leave a trail. Everyone and everything at the scene of the bombing was scrutinized. Within a day these officials had identified the identification number and place of origin of the truck that carried the more than 1,000 gallons of ammonium nitrate and diesel fuel. They went to the place where the truck had been rented. Other details followed quickly. In small-town Oklahoma, outside the main cities, everyone knows everyone else and unusual behaviors or new visitors are noted. One of the first discoveries came at an army and navy store where the clerk, recognizing the police sketch that was by now being circulated, told about selling the book, *Improvised Munitions Handbook*, to a young man who looked just like the one in the police sketch.

As already noted, Timothy McVeigh quickly left the Murrah Building after lighting the fuse and drove away in his car. Racing northwards in his Mercury, McVeigh was stopped by a highway patrolman who noticed that a license plate was missing. This had nothing to do with the bomb because no news of the tragedy had yet been circulated but, as the patrolman examined the inside of the car, he saw several guns and a knife. He checked via his cell phone and found that the statements he was given about car ownership were false. McVeigh was booked into jail at Perry, about fifty miles north of Oklahoma City, awaiting the hearing of his case. By the time he came before a judge the FBI had tracked him down and found out where he was.

Timothy McVeigh was born in Lockport, New York, in 1968 and spent his early years, including graduation from high school, in or near that city. After he left school friends noticed that he was becoming more and more of a loner. He dropped out of a business college where he had been taking a course on computers, he seemed unable to befriend girls, and he was upset over his parents' divorce. An interest in guns developed and this interest remained strong as McVeigh grew older. At the age of twenty, on the spur of the moment, he decided to join the U.S. Army. He drove to Buffalo and signed up for a three-year stint.

At Fort Benning, Georgia, during basic training, McVeigh met Terry Nichols, a man who was ten years older and was, like McVeigh a loner who had joined the army because he had nothing else to do. They became very good friends and both moved to Fort Riley, Kansas, after training, to await their next assignment. McVeigh was ecstatic about army life. He was now part of a mechanized infantry unit which had Bradley armored tanks. He signed on for another three years and was promoted to sergeant shortly afterward. In the six months of basic training and then at Fort Riley, McVeigh also acquired through Nichols, a copy of a book, *The Turner Diaries*, which carried a strong condemnation of the Federal government for advocating gun control.

December of 1990 saw McVeigh off to Operation Desert Storm with his unit. Two months later McVeigh was sitting in the gunner's seat of his Bradley tank as the unit made one of the first drives into Kuwait. The attack involved rolling over trenches in which thousands of Iraqis had taken up positions, suffocating the soldiers in the process and shooting up the artillery bunkers behind them. McVeigh's accuracy was already well known and he excelled in this environment. He destroyed an Iraqi vehicle a hundred yards away, killed individual soldiers at half a mile range and, with one blast, smashed an Iraqi gun nest that was more than a mile away from him. For that action he was later awarded a Bronze Star for valor. He also received other decorations.

As he returned home with all the others after the brief war, McVeigh was surprised to find his name listed as a candidate for the army's elite Special Forces, the Green Berets. He had dreamed of this for years but was afraid his physical condition was too poor for him to go into training right away. He was right. He failed the course within a couple of days and was once more back with the other losers at Fort Riley. A post-war hangover set in, not unlike that experienced by other soldiers. In McVeigh's case, his memories of the *Turner Diaries* and other publications hardened into a paranoia about guns. He attacked the National Rifle Association for softening its stand against gun control and copied on to a sweatshirt some words from a magazine: "Freedom's Last Stand—Are you willing to fight for your guns."

At the end of 1991 McVeigh left the army and went back to Lockport where he got a job with a security company. He wrote letters to his hometown paper, all with the common theme of national evil. The following three sentences were typical of his letters: America is in serious decline. Do we have to shed blood to reform the current system? I hope it doesn't come to that but it might. McVeigh became increasingly reclusive and his letters eventually stopped. In the succeeding two years there were two events that dominated the news and focused his thinking about what he should do. These were the events at Ruby Ridge and David Koresh's compound in Waco. For the second time in his life McVeigh had found something to which he felt he could completely give himself.

The conflict at Ruby Ridge on August 22,1992, on a remote site in northern Idaho was a week-long standoff between white supremacist Randy Weaver and federal agents. It ended in a shootout in which an FBI sniper shot and killed Weaver's wife, Vicky. Earlier, when federal marshals tried to arrest Weaver for failing to appear in court on weapons charges a gun battle erupted between marshals and Weaver's fourteen-year-old son, resulting in two deaths—Weaver's son and a marshal. There followed some severe criticism by the Attorney-General's Department of the way the marshals behaved, concluding that they had overreacted to the threat of violence. The Department felt that the four deaths need not have happened.

The fiery ending to David Koresh's complex in Waco on April 19, 1993, was the other event. McVeigh was convinced that injustice had been done and he was determined to do something about it. He knew that there had been criticism of government action in both events and he conveniently magnified the criticism into outright condemnation. The ending of the complex at Waco happened on April 19, 1993. The Oklahoma City devastation took place on April 19, 1995. That was no coincidence.

For the two years following the Waco event, McVeigh's mind was focused on one thing only, finding a suitable target to bomb and planning its destruction. He traveled a lot hoping to find support for his plan but, as was the case during his army stint, he was too much of a loner to develop strong friendships. Terry Nichols was the only contact he retained from the days of the Gulf War. One old newspaper article from an extremist group came into his hands. It recommended bombing the Alfred P. Murrah Federal Building and this idea stuck with him. Another old extremist publication clinched the idea when it outlined the value, for public impact, of careful timing any reprisal. It suggested choosing a date exactly two years after the tragedy you want to revenge. The issues of what to do and when to act were now crystal clear in McVeigh's twisted mind.

Activity speeded up on April 14, 1995. McVeigh rented a motel some distance north of Oklahoma City and pressured Terry Nichols, who lived nearby, to allow the bomb materials to be stored in his basement, threatening to harm his family if he did not cooperate. Over the following two or three days, McVeigh purchased large quantities of diesel fuel and ammonium nitrate from different locations. He had purchased a large quantity of these same materials on a previous occasion and left them in a nearby storage locker. These were now brought to the Nichols home. Then, on the seventeenth, eighteenth, and nineteenth of April, as already recounted, the bomb-loaded truck was taken to Oklahoma City and detonated.

McVeigh was found guilty and executed on June 11, 2001. Before his death he gave an extensive interview to two news reporters from *The Buffalo News* who subsequently wrote a book on the crime, *American Terror-*

ist: Timothy McVeigh and the Oklahoma City Bombing. In the interview he expressed no regrets for what he had done. He felt no sympathy for the people of Oklahoma City and his only disappointment over the deaths of children was that they became a public relations nightmare which undercut his cause. The huge loss of life and many injuries were to him just collateral damage. He spoke at length about his anger over the events at Ruby Ridge and Waco. Terry Nichols was later imprisoned as an accomplice but was not given the death penalty.

The bombing of the Murrah Building goes beyond just remembering and reflecting on the past. It is an illustration of the enormous power for harm that is now available to individuals and of the different ways in which they can use this power to paralyze a society. No longer can the few extremists within our society be ignored. Not everyone agrees that McVeigh was a terrorist. Gore Vidal and others, while not condoning what was done, insist that we must give more thought to individual rights. The rest of the Murrah Building was demolished after the bombing and national services were held to commemorate the tragedy. Today a huge memorial stands where the building once stood, a silent reminder of the nation's worst ever domestic terrorist attack. People from all over the country visit the site daily.

On February 28, 1993, heavily-armed agents of the Bureau of Alcohol Tobacco and Firearms (ATF) tried to serve a search-and-arrest warrant on David Koresh's Branch Davidian headquarters in Waco, Texas. A serious gunfight erupted, several were killed, and the agents had to withdraw. A siege ensued which went on for fifty-one days and ended in a conflagration which killed eighty.

David Koresh was the leader of the Branch Davidians, a religious sect that had broken away from the main Seventh Day Adventists organization. There had been three other leaders of this sect before him and they too had exhibited apocalyptic views like those of Koresh, in one case expecting the world to come to an end in 1959. These views were in keeping with some aspects of the parent church, the Seventh Day Adventists, which was embedded in Old Testament ideas. Their name, for example, was derived from the Old Testament Jewish Sabbath, present-day Saturday, which this sect felt was the correct day of rest and not Sunday, the one commonly accepted by most Christian churches.

Koresh's birth name was Vernon Howell and at the age of twenty-five he joined the Branch Davidian sect. Before long he found himself engaged in a power struggle with Benjamin Roden, the then leader, a conflict that ended with Howell and some of his friends killing the leader in a shoot out. They were convicted of murder but later acquitted. As he took control, Howell changed his name to David Koresh, again because of some significance in Jewish history. From that moment on there was a big change. The religious sect became a cult; that is, a group of people totally controlled by one person. He traveled to different countries, recruiting members as he went, and expanding the size of the compound at Waco, Texas.

At the same time he built up through constant teaching his apocalyptic views that there would inevitably be a colossal confrontation between the true people, his followers, and all the rest, the outside unbelievers. According to Koresh, he alone knew the truth. He was the one prophet appointed by God to teach the truth and prepare his followers for the end catastrophe and to this end he stocked the compound with guns and food reserves. Cult leaders like Koresh usually have attractive personalities with the ability to persuade others that they have unique knowledge and status. They succeed in securing absolute control over the lives of their followers, making them do things that most people would immediately recognize as absurd. The following examples will illustrate the nature of Koresh's power over the hundred or more of his followers in Waco.

Each member willingly gave up all personal wealth and possessions and these resources supported the place. All decisions of any consequence were made by Koresh alone and these included rationing food for all from time to time either as a tool of control or of discipline. Food was vegetarian except for the leader who was entitled to meat and some other things. No one, again except the leader, had access to television, and no birthdays were ever celebrated. Perhaps the most bizarre of all the community's mores were the sexual rules. Only Koresh could father children because he alone had the pure line of descent. He freely engaged sexually with any and all of the women and girls in the compound, fathering numerous children. Some of the girls with whom he had intercourse were as young as eleven. He had the sexual rights of women who were married while their husbands along with all the other males lived a life of celibacy.

As long as the Waco compound carried on its religious activities without offending the laws of the land, the government did not interfere. Early in February of 1993 reports reached the federal government that Koresh's people were in possession of illegal firearms and that they were modifying automatic rifles, turning them into machine guns. Koresh was now thirty-four years old. A search and arrest warrant was issued and on February 28 members of the ATF attempted to serve it. What happened next is not clear. Gunfire broke out as the ATF men approached the building. Four were killed and fourteen others wounded and the whole event ended in a standoff.

It was clear that, whoever was responsible for the shooting, Koresh's followers were quite prepared to use deadly force to oppose uninvited intruders. The FBI was brought in and a siege was initiated. For the following fifty-one days the siege went on but with little progress on the business of the search warrant. Throughout this time there was no gunfire of any kind from the FBI side and only occasional shots from inside the compound. A team of negotiators was brought in and discussions began with representatives of Koresh. Initially, the negotiations seemed to be very promising.

Within the first few days a plan was agreed upon. If the FBI would arrange to have one of Koresh's sermons broadcast on a particular radio station he would release two children on the following day. The tape was duly broadcast and two children were released on the following day. Their mother brought them out, then she retreated back into the compound. The same routine was repeated on the following day and again two children were released. This was repeated about ten times in all, ensuring freedom for some twenty children. There followed a pause in these cycles of broadcast and release.

All through this initial period of time it was clear to the negotiators that Koresh's interest was the conversion of those he dealt with. Those who spoke with his representatives were often subjected to long harangues on his theory of religion. Perhaps he felt he was having some success because on one day he offered to surrender if one more of his tapes were broadcast. The day following, instead of surrendering, he told those outside that he had to wait before making a decision. The surrender offer was never repeated. Instead, he showed intense interest in news of a very bright star that had been seen, but afterward concluded that it was not the right sign.

Specialists who examined the letters he sent out from time to time concluded that he was a religious fanatic with delusions of grandeur, imaging himself as the third person of the trinity along with Jesus and God, he being the prophet through whom God speaks. Koresh was charismatic and manipulative, able to hold people within the compound even if they had opportunity to leave. His statements contradicted what was heard from many in the compound, namely that a suicide pact was in place. If violence came from outside and they were unable to repel it, they would blow everything up as a demonstration of Koresh's apocalyptic theology, the inevitable clash between the good ones within and the devils without.

The compound was stocked with a year's supply of food and any requests for additional things like milk were met. The problem confronting the federal authorities was how to end the standoff. After fifty days of recurring episodes of cat and mouse operations, concessions followed by withdrawals, the basic situation was unchanged. Koresh was defying a federal arrest warrant and he had to be taken into custody. How could it be done without causing a repeat of the deaths that accompanied the visit of the ATF men? An indefinite siege was just not realistic. It would make a mockery of law and order and it would give Koresh exactly what he wanted, extended national publicity.

It was decided to pump tear gas into the building and force people out whether or not they felt free to leave. At the same time, bulldozers were to approach the building and create escape holes in several places. Immediately after the federal action began, fires erupted in a few places within the building, leading quickly to a massive conflagration. A few were able to run out. Most of the people remained inside. When the premises were searched next day a substantial number of bodies were found to have bullet wounds. Many of them were children. Koresh had been shot through his forehead. The FBI concluded that the fires that destroyed the building had been set by persons within the compound.

Not everyone was satisfied with the federal conclusions about the conflagration. There were claims that the high level of military force present intimidated those in the compound and inhibited negotiations. Later, in 1993, some of the survivors sued the federal government for $700 million but lost. The case was held in a Texas court near Waco and the jury found the U.S. government not liable for the deaths. Criticism persisted in spite of that verdict and Senator Danforth of the U.S. Senate was asked to conduct a thorough review of all the actions taken. In his report he concurred with the Texas court.

As is now well known the government actions at Waco were not quickly forgotten. Terrorist behavior in Oklahoma City two years later to the day was one of the tragic outcomes. It seems there is common ground between the radical right, the armed militia who claim that their freedom is being destroyed by the requirements of the law, and the religious fanatics. These latter are the ones who claim that they do not have to obey the law because they have an alternative law in the one they call God. The answer to this kind of social unrest demands a continuing assessment both of these extremists and the government responses to their behavior.

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Srebrenica, Bosnia-Herzegovina, genocide

July 15, 1995

7,500 Muslim men were massacred by Serbian soldiers just because they were Muslims

Srebrenica was placed under UN protection but the number of soldiers guarding the city was small and the Serbian Army easily captured it and arrested the 7,500 Muslim men

During the war in Bosnia-Herzegovina in the 1990s, the community of Srebrenica was named a safe haven by the United Nations (UN). That is, men and women could take refuge there under UN protection. Serbian soldiers, seeing that there was only a small number of armed UN soldiers, took possession of this area by force and murdered the more than 7,500 unarmed Muslim men and boys who had been sheltering there.

Bosnia-Herzegovina is a province of the former Yugoslavia, a country that was formed after World War I, and stayed united for about sixty years. President Tito was able to hold it together for all of this time. He had dictatorial power under a communist type of government, similar to but independent of the Soviet Union. When he died in 1980, the different provinces began to express their desires for freedom. The differences between them were not ethnic. As Croats, Muslims, and Serbs they represented different religions, but they had a long history of living together. Bosnia-Herzegovina was mainly Muslim and Serbian, similar in size to West Virginia.

Croatia and Slovenia, in the north, were the first two provinces to declare independence in 1991. The Serbs, the largest group of the largest province, Serbia, resisted these declarations of independence. They were convinced that the country should remain united under their leadership and they took up arms to restore the previous order. Fighting went on for some months between Serbia and the two independent regions but finally, aided by 12,000 United Nations peacekeepers, a cease-fire was established. Bosnia-Herzegovina's move to independence came next in 1992. This was a much greater challenge to Serbia as it was next door and about one-third of the people in Bosnia-Herzegovina were ethic Serbs. The Bosnian Serbs argued that an independent Bosnia would be dominated by Muslims because their numbers were slightly larger than the Serbs.

Religious elements surfaced for the first time. In the long history of Southeastern Europe some people had become Catholic under the Holy Roman Empire. They were the Croats. In the East, those influenced by the Byzantine Empire converted to Orthodox Christianity. They were the Serbs. Under the dominance of the Ottoman Turks when they occupied this region many became Muslims. These differences of religions had not been a problem in previous times, but the Serbs argued that it would be impossible to share Bosnia with Muslims because of their religion and their numbers. That was the beginning of what came to be known as ethnic cleansing.

Serbs immediately began forcing Muslims out of their part of Bosnia. This was not genocide of the kind seen in Rwanda; rather, it was a case of compelling people to leave their homes and live permanently in another part of the country. Naturally this was resisted and intense fighting ensued, but the violence that erupted was much worse than traditional warfare. Where resistance was strong, mass executions were employed as a terror tactic. Srebrenica, an industrial and prosperous Bosnian town of about 40,000 people, about ten miles from the Serbian border, was an early target for ethnic cleansing. It was attacked and taken over by the Serbian army in April of 1992 and its Muslim residents immediately fled out of it into the forests.

Within three weeks a reversal took place. An armed force of Muslims recaptured the town and to the surprise of the Serbs, who were more heavily armed, they drove on into Serb territory to double the amount of land they controlled. By the end of the year this Muslim force was within five miles of linking up Srebrenica and its immediate surroundings with the part of Bosnia farther west that was firmly in Muslim hands. At that point Serbs counterattacked with a large force of troops, backed by tanks and artillery, forcing the Muslims back and once again taking control of the area around Srebrenica.

The Muslim troops, who were not prepared for an extended war when they shared in the declaration of independence for Bosnia-Herzegovina, were now unable to defend themselves. The United Nations (UN), which was involved in the conflict, banned sales of arms to either side, forgetting that Serbia, as the center of power in the old Yugoslavia, was fully equipped for conflict. It was not long afterward that another action by the UN had devastating consequences for the Muslims. To protect the people of Srebrenica from being forcibly removed, the UN declared the city a safe haven and therefore under its protection.

To safeguard the people under its care, the Secretary General of the UN requested 34,000 troops from member countries for Srebrenica and other safe areas. The United States as well as other countries refused to provide the additional peacekeepers requested and the UN had to settle for less than a quarter of the number needed. Srebrenica was allocated a force of 750 lightly armed Dutch soldiers. In June of 1995, Bosnian Serb forces, claiming that several of their people had been killed by attacks from within Srebrenica, invaded it. The Dutch peacekeepers were outnumbered and were taken hostage. The UN responded with air attacks but within a day they stopped as Serb forces threatened to kill their Dutch hostages. The hostages were released soon after.

The Serbs knew then that they had nothing to fear from the UN because its power could be so easily removed. From that moment the terrible massacre of Srebrenica began to take shape. General Ratko Mladic, the Serb Commander and his assistant general, Radislav Krstic, were in charge along with Radovan Karadzic, the general in charge of all Serb forces. Thousands of Muslim residents of Srebrenica were separated by age and gender and the women and children were sent away on foot or taken by bus to places near Muslim-controlled territory. The males had their hands tied behind their backs as they were taken away, ostensibly for questioning. The litany of lies and false statements from Serb representatives deceived everyone.

At Bratunac on the Serbian border the more than 7,500 prisoners from Srebrenica were shot in a series of mass executions. Serb commanders thought that no one would ever find out what they did. Brutality was usually associated with these executions in the form of sadistic tortures. For example, some were hit with iron bars as they came off the buses, then forced to kneel in prayer before being shot. They were buried in mass graves near Bratunac but later, after news of the massacre was reported, they dug up the bodies and took them to several different locations for burial. Satellite photography was able to identify these new locations and in due course the whole story came out.

As part of their terror tactics, Serbs engaged in the mass raping of Muslim women, knowing that this would have terrible consequences in the social life of Muslims. In the year 2000, these crimes of mass rapes were recognized as crimes against humanity and successfully prosecuted as such for the first time at the International Court of The Hague. An earlier indictment of the same kind had been made in Tanzania as part of the United Nations trials of the leaders of Rwanda. Mass rapes were part of the atrocities committed by Japanese soldiers in Nanking in 1937. Sadly these terrible acts were not recognized as international crimes for a further sixty-three years.

This massacre at Srebrenica was the worst crime of the Bosnian civil war. The main problem was that the city had been declared a "safe area," when in fact the United Nations Protection Force (UNPROFOR) was incapable of defending it. The UN should have provided a full military force and that force should have attacked the Serbs before they came within the city. The Muslims were promised complete protection, by whatever military action was necessary, and the typical UN approach of impartiality put aside. The prosecution of those involved in mass rape at the International Court of the Hague has already been noted. The capture and prosecution of others who were involved became an ongoing activity.

Late on Friday, June 29, 2001, Slobodan Milosevic the former president of the Federal Republic of Yugoslavia, who had earlier been arrested by the new government of Serbia, was handed over to the International War Crimes Tribunal at The Hague in Holland. Zoran Djindjic, prime minister of Serbia, made the decision to hand him over to stand trial for crimes against humanity because of the atrocities committed in Kosovo as well as at Srebrenica. He was formally charged soon after his arrival in Holland with mass murder, deportation of Kosovo Albanians, and specific massacres in different places. The date of his trial was not determined. It was recognized that a large amount of evidence has to be assembled before these formal proceedings could begin.

The pursuit of the military men involved in the Srebrenica massacres, Krstic, Mladic, and Karadzic, continued through 2001. In August of that year, General Radislav Krstic was arrested and brought before the War Crimes Tribunal at The Hague, accused of personally helping to plan, prepare, and carry out the killings of at least 7,500 Muslim men and boys. General Krstic had taken command of the Drina Wolves unit of the Serbian Army and these were the soldiers who carried out the massacres. Judge Almiro Rodrigues, head of the three-member panel that delivered the verdict at The Hague, spelled out the charges against Krstic. He was accused of causing the persecutions suffered by the Muslims of Srebrenica, his participation consisting mainly in allowing the Drina Wolves to carry out the executions.

The 255-page indictment included the testimonies of 130 witnesses and the records of more than 1,000 pieces of evidence. There were reports of wives and children being beaten and raped, and of men, some as old as eighty, being starved and beaten before they were killed. Some of Krstic's victims were herded into a warehouse and shot at close range by Serbian execution squads who used guns and grenades to do the killing. Because those who were killed belonged to an identifiable cultural group—Muslims—Krstic was declared guilty of genocide. In defense, Krstic said that he had not known of the massacres until it was too late to stop them. He had intended to punish his soldiers for what they had done. The prosecuting judge dismissed his statements and sentenced him to forty-six years in prison, the harshest punishment up to that time for crimes against humanity in the Bosnian war.

The massacre of 7,500 or more Muslim men and boys in Srebrenica was Europe's worst civilian atrocity since World War II. There were serious inequalities from the beginning of the Bosnian war. The Serbs had all the military power they needed to conduct military operations but the others, the Croats and Muslims, were handicapped by a UN decision to ban the sale of military equipment to either side. More than four years after the massacre, Kofi Annan, UN Secretary-General, issued a report on the mistakes made by the UN. Poor judgment and an inability to recognize the truth of the situation were listed as contributing to the tragedy. While Srebrenica was a horrendous instance of genocide it pales in significance when compared with the far greater acts of genocide that began with Germany's Crystal Night. The atrocities that were initiated in 1938 with "Crystal Night," were the beginning of a massive program intended to kill every Jew in Germany.

As soon as he came to power as chancellor of Germany, Adolf Hitler began to express his anti-Jewish ideas in public. He attempted first to make life so unpleasant for Jews that they would emigrate. Crystal Night, a one-day boycott of all Jewish shops and offices, based on false charges, marked the beginning of violent action against Jews. Windows were smashed, contents of stores stolen, and any books found were publicly burned. Over 7,500 Jewish shops were destroyed and four hundred synagogues were burnt down. Ninety-one Jews were killed and an estimated 20,000 were sent to concentration camps. After Crystal Night the numbers of Jews who left Germany increased dramatically. It has been calculated that before war broke out in 1939 approximately half the Jewish population of Germany left the country. This included several Jewish scientists who were to play an important role in the fight against Nazi Germany during World War II. A higher number of Jews would probably have left German but anti-Jewish sentiment was not entirely a German prejudice. Many countries were reluctant to take Jews.

Once the Jewish population had been demonized by the various actions of the German government it became easier for Hitler to propose the mass execution of all Jews. Within three years of Crystal Night the gas chambers associated with the concentration camps were in place. Those who were about to be executed were told to strip naked so that they could be given a bath. Doctors pretended to be giving them a physical exam to allay fears and, during this process, they took note of those who had gold teeth. Their chests were marked with a distinctive sign so that after their death the gold could be recovered before the bodies were thrown into the furnaces. Once they were inside the so-called bathroom, the door was shut and locked, poisonous gas released into the room, and everyone died a painful death. For two further years, until Germany was conquered and overrun, the mass executions, referred to by Hitler as the final solution, was extended until approximately six million Jews from central, eastern, and southern Europe had been annihilated.

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Red River flood

May 4, 1997
The worst flood in more than one hundred years
covered southern Manitoba, Canada

This international waterway annually faces the risk of flooding because of the several variables that affect water levels in both countries

The Red River Flood of 1997, affecting both the United States and Canada, was a major flood that occurred in May 1997 in North Dakota, Minnesota, and southern Manitoba. It was the most severe flood of the river since 1826, causing extensive flooding and destruction on both sides of the border and damaging almost $3 billion worth of property. The Red River originates in Minnesota and flows northward through a large glacial lake basin, that of Lake Agassiz, the largest of the glacial lakes that were formed at the close of the last ice age. It covered an area of half a million square miles and left in its wake a low-lying landscape, almost completely flat in places. The Red River overflows its banks in most years and the low elevation of the surrounding terrain ensures that water covers a big area when that happens. The flatness of the river basin is evident in the gradient as the river flows northward, an average slope of six inches per mile for the whole five hundred miles of its length. Natural levees, five feet in height, rise on either side of the river.

The events of 1997 were far worse than anything previously experienced. The river reached the cities of Grand Forks and East Grand Forks, where floodwaters stretched outwards from the river for three miles, inundating virtually everything in these two cities and causing US$2 billion in damages. The situation was similar in Canada.

Floods are notoriously unpredictable as the Chinese discovered over

Figure 120 Grand Forks, North Dakota, April 1, 1997. A flooded neighborhood with cars still floating due to the flood waters from the Red River of the north.

the centuries of their history and as the United States discovered with the Mississippi River. In fact, our inability to distinguish between weather and climate in our preoccupation with the advancing global warming has tended to make us attribute every daily change in temperature or precipitation to global warming. Media commentators are worst culprits here. The last time that Winnipeg had a flood like that in 1997 was 1826 and Canadian meteorologists predicted that it would not repeat for a further five hundred years. It came back in about 170 years.

There was some sense of imminent threat in Grand Forks but the National Weather Service (NWS) had a long-standing forecast for the river to crest at forty-nine feet, the river's highest level during the 1979 flood, so people felt secure. The cities had been able to get their dikes to this level, but the river continued to rise past it in 1997, to the astonishment of the NWS that had failed to upgrade its forecast until April 16, 1997, the day the river actually reached forty-nine feet. The dikes over Grand Forks and East Grand Forks area all were overtopped on that day, flooding thousands of homes, and necessitating the evacuation of all of East Grand Forks and 75 percent of Grand Forks. School was cancelled in both cities for the remainder of the term, as were classes at the University of North Dakota.

Because all transportation was cut off between the two cities, East Grand Forks residents were evacuated to nearby Crookston, namely to the University of Minnesota, Crookston, while residents of Grand Forks went to the Grand Forks Air Force Base. Many residents also evacuated to motels and homes in neighboring communities. The river crested at 54.35 feet on April 21, 1997, and the river level would not fall below forty-nine feet until April 26 of that same year. Because water drained so slowly out of the most low-lying areas, some homeowners couldn't visit their damaged property until May. There was $2 billion USD in damage to Grand Forks and East Grand Forks. Grand Forks lost 3 percent of its population from 1997 to 2000 and didn't fare as badly as its sister city which lost nearly 17 percent of its residents. The five-foot discrepancy between the actual crest and that which the NWS had predicted led to widespread anger among locals, especially since the citizens of both cities reached and even slightly surpassed the NWS's level of protection through weeks of hard work while raising the level of the dikes.

The province of Manitoba completed the Red River Floodway in 1968 after six years of excavation, put up permanent dikes in eight towns south of Winnipeg, and built clay dikes and diversion dams in the Winnipeg area. However, even with these flood protection measures, the province was not prepared for the 1997 event, known as "The Flood of the Century." At the flood's peak in Canada on May 4, the Red River occupied an area of nine hundred square miles with more than a thousand additional square miles of land under water, appropriately named the red sea. There were 75,000 people who had to abandon their homes. Damage costs were $450 million. The U.S.–Canadian Mission that looked after the Red River Waterway immediately began to plan for better protection against floods.

In retrospect, there were five main factors that contributed to the flood's severity: (1) rainstorms in autumn of 1996 had saturated the ground so that it could not absorb much water; (2) there was overabundant snowfall during the 1996–1997 winter; (3) an abnormally cold temperature regime plagued the Upper Midwest during this same winter; (4) between November 7 of 1996 and March 18 of 1997 the air temperature reached forty degrees for three days onl,y so there was very little melting of the snow; (5) a freak blizzard dumped a large amount of snow on the area on the weekend of April 5, 1997.

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Hurricane Floyd

September 16, 1999
Rainfall from this hurricane caused enormous damage over a wide area of the eastern United States

The flooding from hurricanes can be extremely destructive as became clear in the $6 billion amount of damages caused by this one

Hurricane Floyd came ashore and made landfall near Cape Fear, North Carolina, at 2 A.M. on September 16 with wind speeds of 104 mph. The greatest damages it inflicted were along the eastern Carolinas northeast into New Jersey, and adjacent areas northeastward along the east coast into Maine. In these areas it produced more human misery and environmental impact than almost any previous one, leading to $6 billion of damages.

The twenty inches of rain that fell across the eastern half of North Carolina caused every river and stream to flood. There were fifty-seven deaths directly attributed to Floyd, and high flood damage costs. Many rivers set new flood records. Whole communities were underwater for days, even weeks in some areas. Thousands of homes were lost. Crop damage was extensive. The infrastructure of the eastern counties, including roads, bridges, and water plants, was heavily damaged.

Floyd's origin can be traced to a tropical wave that emerged from western Africa on September 2, 1999. It became a tropical depression a few days later and Tropical Storm Floyd on September 8. After developing into a hurricane on September 10, Floyd turned westward and increasingly strengthened, reaching its greatest strength a day later with winds of 156 mph. It came within 110 miles of Cape Canaveral as it paralleled the Florida coast on September 15, and then turned northward so that its center reached the east coast of North Carolina. After landfall it moved along the

Figure 121 Damage from Hurricane Floyd to the inside of a beachfront hotel.

Figure 122 Princeville, NC, November 8, 1999. The September floodwaters brought by the rains from Hurricanes Dennis and Floyd left much devastation. The historic town of Princeville, North Carolina was almost totally covered by floodwaters. Here is one of the many buildings that were not strapped to their foundations. It apparently floated atop the family truck during the flooding—both a total loss.

coasts of Long Island before reaching Maine and becoming an extra tropical storm.

Much of Floyd's impact was due to extreme rainfall. Although Floyd was moving quickly, its large circulation interacted with a pre-existing frontal zone extending from central North Carolina through the mid-Atlantic states. This caused the heaviest rainfall to fall both behind and to the left of Floyd's track. In Yorktown, Virginia, the storm's rainfall total was over eighteen inches. The second region of extreme rainfall totaled fourteen inches in parts of Maryland, Delaware, New Jersey, southeast Pennsylvania, and southeast New York. Eighteen tornadoes associated with Floyd were reported and all occurred in North Carolina on the day of landfall. The two strongest produced storms of F2 strength.

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Peru offshore earthquake

June 23, 2001
The most powerful earthquake experienced anywhere within a thirty-five-year period

Earthquakes are frequent in this part of South America where the Nazca Tectonic Plate is always moving beneath the South American Plate

In the afternoon of June 23, 2001, a magnitude 8.4 earthquake struck the offshore area of Peru immediately west of the city of Arequipa. Its epicenter was a little over one hundred miles offshore and because of its magnitude it was the largest earthquake worldwide for over thirty-five years. It occurred at the boundary between the Nazca and South American tectonic plates in an area that has a history of very large earthquakes. At least seventy-five people were killed by the 2001 earthquake, including twenty-six killed by a tsunami, around 2,700 were injured, over 17,510 homes were destroyed, and a further 36,000 homes were damaged.

It was in this same area offshore of Peru that, on February 19, 1600, South America's biggest volcanic eruption in all of recorded human history occurred. It happened in a mountain close to Arequipa. Its Volcanic Explosivity Index (VEI) was 6, the same as Krakatau's, and the type of eruption was also the same as Krakatau's. In 1784, Arequipa was hit with an earthquake that killed fifty people and destroyed almost all the buildings. Two others, in 1868 and 2001, did extensive damage. Despite the hazards, the city has grown rapidly through the years because it is located in a good agricultural area and it is strategically located for transportation. Its population has grown from about 20,000 at the end of the eighteenth century to 600,000 today, making it Peru's second biggest city.

Tsunami run up heights from the 2001 earthquake near the coastal city of Camana are estimated from field evidence to have reached twenty-two feet and at other neighboring locations the tsunami penetrated inland for almost a mile. Camana, because of its location directly in line with the tsunami, was hit hardest. Hundreds of homes, hotels, and restaurants were destroyed. Elsewhere on the Peruvian coast damage was limited to the area between Atico and Matarani. High tide gauges were registered all along the Chilean coast as far south as Coquimbo. Fortunately, as far as most coastal locations were concerned, the earthquake occurred in the southern hemisphere's winter when resort areas were deserted and thus the death toll was small. It would have been a very different story had the quake struck in January.

Officials and media reports said that fatalities and damage occurred, for the most part, in the towns of Arequipa, Moquegua and Tacna. Arequipa Mayor Manuel Guillin said that 70 percent of the homes in his town were damaged, including a number of colonial buildings and homes in the historic district. He added that the tower of an ancient church in the center of Arequipa crumbled during the quake and thousands of people fled their homes in panic when they felt the quake. The cathedral was first constructed in 1656, but rebuilt after an earthquake in 1868. In the desert region around the coastal city of Ilo, the earthquake produced intense and widespread ground-failure effects. These included landslides, pervasive ground cracking, micro fracturing, collapse of drainage banks, and widening of hillside rills, giving rise to a new term for earthquake damage, "shattered landscapes." Because of the region's familiarity with major earthquakes, relief for survivors came quickly in the form of blankets, food, shelter, medicine, and clean water.

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Nine Eleven, New York City, New York, terrorism

September 11, 2001
The second and deadliest assault on the World Trade Center

The two planes that hit the World Trade Center were accompanied by two other planes that sought to destroy two major centers in Washington, D.C.

A second and much more deadly terrorist attack than the attack on New York City in 1993 occurred on the World Trade Center (WTC) on September 11, 2001, combined as it was with a simultaneous assault on the Pentagon. It created an altogether new situation for the U.S. government. The 1993 bombing of the WTC, while it was deadly and enormously destructive of American life, was a single event organized by a small group of terrorists who were in the country. The events of September 11 were at a new scale of violence. They were multiple attacks at the heart of the nation's economic and military power and, had it developed as the hijackers intended, also at the center of political power. Furthermore, it was organized from abroad by well-known enemies of the United States and probably planned in detail soon after the 1993 failed attempt.

American Airlines Flight 11 left Boston for Los Angeles on the morning of September 11, 2001, with ninety-two passengers and crew aboard. Sometime shortly afterward it was taken over by five passengers who were hijackers. Just before 9 A.M. it crashed into the upper floors of the North WTC Tower. Fifteen minutes later a second plane, United Airlines Flight 175, also bound from Boston to Los Angeles, hit the upper part of the South Tower. It too had been taken over by hijackers. The planes were flown into the buildings at full speed in what can only be compared to the

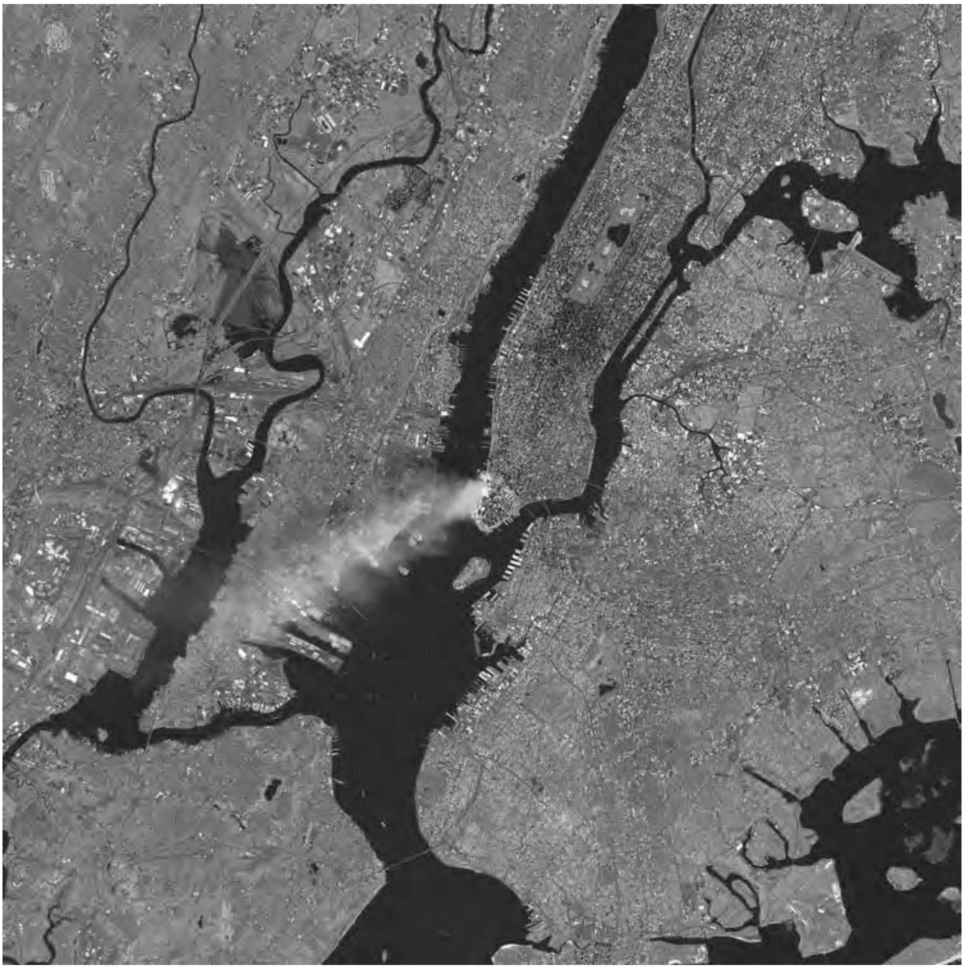

Figure 123 Aftermath of World Trade Center Attack. This image was taken by the Enhanced Thematic Mapper Plus (ETM+) aboard the Landsat 7 satellite on September 12, 2001, at roughly 11:30 A.M. EDT.

kamikaze tactics used by Japan in World War II when young pilots crashed their bomb-laden planes into American ships. Flames engulfed the upper floors of both towers within moments and every branch of New York's fire and rescue organizations sprang into action. It was a chaotic situation and they knew they faced a daunting task. The places where they were needed most were above floor eighty and they knew that both electricity and elevators would soon be cut off there.

Fortunately, there were only 14,000 people in both towers at the time of the explosions, far fewer than in the 1993 attack. Later in the day there would have been three times that number. Those inside first experienced a gigantic blast and felt the towers swaying backwards and forwards. Sprinklers came on as electricity and lights went off. For a time, the elevators below the eightieth floor continued to operate and many were able to get into them. Fires started in different places, many of them triggered by aviation fuel, then sustained by the flammable materials in the offices. Thousands of pieces of glass, papers, debris, soot and ash, even clothing and body parts from the passengers who were in the planes, rained down on the streets below. Temperatures reached thousands of degrees in parts of the towers as 10,000 gallons of aviation fuel ignited, levels of heat that even the central steel pillars could not withstand.

For about an hour the main supports of the towers held firm, allowing many to escape. Fires, sustained by chairs, desks, and other flammables, raced up from the level at which the planes struck to the twenty or more floors above, steadily weakening the main steel supports. At these heights steel is thinner as the total weight to be supported is much less than at lower levels. Finally there came a general collapse as the upper floors buckled and sides caved in. Like battering rams in ancient warfare, successive masses of thousands of tons of steel stomped on the floors below until they could no longer absorb the pressure. Both towers gave way in a cloud of dust. The noise of hundreds of thousands of tons of steel crashing down could be heard all over southern New York City as people ran from the scene as fast as they could. All public transportation had stopped. Among the most horrific of all the things that had to be endured was the sight of people jumping to their deaths from the top floors rather than be incinerated.

The scale of destruction and the reckless indifference to civilian life rightly identified the event as war, a new kind of war, and subsequent actions in Afghanistan and elsewhere were in keeping with that analysis. First response by the U.S. government was to stop all flights at U.S. airports in case further attacks might be in process. Incoming planes from other countries were routed to neighboring countries. Canada, because of its proximity to the United States received most of these flights and for a time its airports were filled to overflowing. The pilots were not informed of the changes and were only told where to go. It was felt that unnecessary panic would be avoided by maintaining silence until the planes were on the ground.

The towers had been designed to withstand an impact from a modern jet plane but not an impact that involved maximum speed and maximum amount of fuel. The flights that were hijacked were meant to fly to Los Angeles so they were fully loaded with fuel. Modern steel skyscrapers had never previously collapsed because none had ever been subjected to the levels of stress imposed on the WTC. It was feared at first that as many as 6,000 might have died within the towers. Later it became clear that the count was close to 3,000. Among them were 350 firemen who had climbed up into the towers to help. This was thirty times the greatest single loss of life ever previously experienced by the city's fire departments. The fires raged on week after week for more than three months because of the large amount of flammable material available to sustain them.

Recovery operations, including assessments of neighboring high-rises, were launched immediately. Four high-rises next door to the towers collapsed and four partially collapsed. Major structural damage occurred to a dozen others. More than a million tons of debris had to be removed at a rate of 10,000 tons a day, so it took several months just to clear the site. Some of the individual pieces of steel that had to be moved weighed twenty-five tons. Excavators with a reach of one hundred feet and cranes that could pick up as much as 1,000 tons were needed for the work. All of this debris had to be hauled by barge or truck to a landfill location on Staten Island. Nothing at this scale had ever previously been tackled and costs for the whole project soared beyond a billion dollars.

In 1993, following the bomb attack, it took six hours to get most of the people out of the towers. Those who worked above floor seventy found it was slow and difficult to make their way down to ground level. Exit stairways were pitch black and they kept bumping into walls or one another on the way down. Subsequently batteries were added to every light fixture in stairways for times when power would not be available. A public address system was added to enable those at fire command stations to address tenants. Fire drills, which previously had often been ignored, were faithfully attended after 1993. Because of these improvements, people were able to evacuate the buildings in 2001 at a faster pace than before. The total time for exiting was cut by a third, from six to two hours, and many lives accordingly saved.

The dangers from toxic materials at the time of the attack were largely ignored because more urgent matters commanded attention. All who were near the towers as they came down were covered with dust that came from fibrous glass, computer screens, asbestos, and a host of products that had been made from different chemicals. Spills of mercury, dioxin, and lead were all around. Some initial testing was done after a week and it showed levels of toxic chemicals as being below danger standards. Few of the local residents were satisfied with these results. They continued to wear masks and protective clothing and pressed the Environmental Protection Agency (EPA) to publish precise data on its measurements. Six months after September 11, the EPA had not responded to their requests and there was persistent concern over what they thought were remnants of carcinogenic materials.

Before the full impact of the destruction of the Twin Towers had been registered across the country a third plane had hit the Pentagon in Washington D.C.; and a fourth that many believe was headed for the White House, crashed in Pennsylvania when passengers, at the cost of their lives, fought the hijackers but were unable to take control of the plane. The plane that hit the Pentagon began as American Airlines Flight 77 from Dulles International Airport bound for Los Angeles. It left at 8 A.M. with sixty-four passengers and crew aboard, including five hijackers. Soon after departure it stopped responding to air control messages and was observed to turn around and head back to Washington, D.C. Shortly before 10 A.M. it slammed into the lower floors of the Pentagon, clipping trees and lampposts as it descended, plowing through floors one and two, as far as the third concentric circle.

The Pentagon, as its name suggests, is a five-sided building, constructed in five concentric rings of offices around an open center. Each ring is five stories high. On any given day 24,000 people work here. It was built in the 1940s during World War II and more recently was being renovated to provide protection against terrorist attacks. Shatter-reducing mylar had already been installed in one renovated wing to absorb some of the shocks from an explosion. Blast-resistant windows were also in place. By September 11, 2001, this was the only part of the Pentagon that had been renovated and workers had not yet moved into it. By good fortune it happened to be the part of the building that was hit by the terrorists, so casualties were few. About fifteen minutes after the plane crashed into it, the whole of the renovated segment collapsed.

The Pentagon shook violently as it was hit. Workers within heard the roar of the impact and almost immediately saw the outburst of fire and smoke. Lights went out as electricity was cut off. Even if lights had remained on it was almost impossible to see for any distance since black smoke smothered everything. Flames threatened people as they made their way along corridors seeking an escape route. Pools of aviation fuel ignited from time to time, adding to the general confusion. Vehicles posted nearby also caught fire. Emergency procedures immediately came into operation and every effort was made to get people out of the building. Arlington County police and fire departments were on the scene in less than an hour, tackling the fires and establishing order. Helicopters and ambulances took the injured to hospitals.

Special care was taken to safeguard classified documents. The National Military Command Center, which is located in the Pentagon, had not been unaffected. Despite problems with smoke, it continued its work with officers monitoring military operations worldwide. An early casualty was an overloaded cell phone network so those who were fortunate enough to get through took names and phone numbers from the others and relayed them to their contacts with the request that they follow up with calls from their own phones. By 8 P.M. on September 11, fires were still burning strongly and spreading to new sections of the building. Core materials in the layered roof that had caught fire were particularly difficult to extinguish.

Six months after the attack all traces of the original damage were gone and much of the reconstruction had been completed and one-third of the workers displaced by the events of September 11, were back at work. The renovations that were in progress at the time of the attack were included as they repaired the damaged segment and a time capsule was placed in the outer wall of the building at the point where the terrorists had struck. The capsule contained the names of all who were killed in the attack and a collection of things that represented the time and place of the attack. No date was suggested for its opening in the future. The planned improvements were also accelerated in other parts of the building. Total costs of the whole tragedy were $740 million. Altogether 126 lives were lost on the ground and sixty-four in the plane.

As for the Twin Towers, in March of 2002, the American Society of Civil Engineers published their report on the fall of the towers. Its members had spent many days investigating the steel supports at the dumpsite and, while they concluded that no changes should be made to building codes as a result of the tragedy, they did make recommendations for the future. They felt that the connectors holding trusses to walls ought to be tested as rigorously as the main walls. This was not done during construction of the WTC towers. They also felt that fire-resistant material could have been used on many internal areas instead of drywall. Their most significant recommendation was that skyscraper height be limited to sixty floors instead of the 110 of the towers. They were sure that such a change would be as efficient financially and functionally as taller buildings.

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United States anthrax terrorism

October 15, 2001

A new form of terrorism, anthrax in the mail

As anthrax powder arrived at different places on the United States East Coast, via regular mail, the entire postal system was closed down for a time

The events of nine eleven were a terrible shock to all in the United States, yet from many points of view that should not have been the case. The litany of mayhem, all of it directed toward removing U.S. influence in the Middle East, includes the truck bombing of a military base in Lebanon in 1983, killing 241 U.S. servicemen. A similar truck-bomb killed nineteen U.S. servicemen at their base in Saudi Arabia thirteen years later, and in 2000 the Navy Vessel USS Cole was attacked by suicide bombers in the harbor of Yemen, killing seventeen sailors. These assaults on U.S. people and U.S. interests abroad were not limited to installations within Middle East countries. Murderous action was taken against U.S. citizens and American interests anywhere. In August of 1998 the U.S. embassies in Kenya and Tanzania were blasted by car bombs on the same day, killing 230 people, including twelve Americans, and injuring 5,000 others. Damage amounted to $38 million.

In several of these events, the United States response was to step back from the areas in which terrorism occurred, exactly the kind of response that the perpetrators of violence hoped for. Is it, therefore, likely that the assaults of nine eleven were based on a similar hope? The long history of terrorism suggests that this may well be the case. While acts of terror date back to the beginning of human history it was in 1795 that the word "terrorism" was first used. It had its roots in the phrase "Reign of Terror," a term associated with the French Revolution, particularly with regard to the use of the guillotine by the French revolutionaries. Later the word was employed to describe the behavior of states like Nazi Germany and the Soviet Union and it even came to be used by political activists who claimed to be seeking freedom but had sought it by the most barbarous methods imaginable.

Much of modern terrorism stems from the Arab–Israeli Six Day War of 1967 when Israel occupied the West Bank and Gaza Strip and members of the Palestine Liberation Organization began to adopt terrorist tactics. They claimed to be freedom fighters and their supporters in other countries adopted similar tactics. Airliners were frequently hijacked and Israeli civilians murdered through bomb attacks. The United States was attacked on more than one occasion because it was seen to be supporting Israel. Since the 1980s, these attacks against the United States have become more and more violent, not now by terrorists fighting for Palestinians, but rather by religious extremists who were determined to force America out of the Middle East. Osama Bin Laden and his associates organized the ultimate terrorist attack in the nine eleven assault.

The aftermath of that attack, Anthrax terrorism that arrived in the U.S. a month after nine eleven, was an even more frightening act because it introduced everyone to the potential of chemical terrorism. Anthrax infection is a disease that mainly affects grazing animals like sheep, cattle, and goats. It was known 2,000 years ago, and in the nineteenth century there were vaccines developed to prevent its development. Throughout the twentieth century various governments conducted research on anthrax because of its potential use as a weapon and fortunately it was never used in warfare. An accidental release from a research facility in the former Soviet Union killed seventy people and, in 1993, there was an attempt by a secret society in Japan to release anthrax spores in downtown Tokyo. That was the first time that the dangerous bacillus was directed against a civilian population.

The anthrax bacillus is a tiny organism. Hundreds of them if laid end to end would take up less than a millimeter. When exposed to air, anthrax forms spores and these can reproduce in the body of the host that receives them. It is not a contagious disease. Skin anthrax can usually be successfully treated with antibiotics but the danger is far greater if the spores are inhaled. Very few ever survive inhalation unless antibiotic treatment is given within a day or two. In the vast majority of cases the victims are dead within a few weeks. Anthrax is found in soil all over the world in most countries and instances of human infection are frequently reported in Middle Eastern countries and in Africa. During the Gulf War of 1990–91 U.S. soldiers were inoculated with a vaccine to prevent them catching the disease. There was some fear that Iraq might use anthrax as a weapon.

In mid-October, a few weeks after the devastation of nine eleven when the World Trade Center towers were destroyed and the Pentagon hit, letters containing anthrax spores began to arrive at various U.S. media centers and government offices in Washington, D.C. A photo editor in a Florida news agency was the first to be affected. He opened an envelope that arrived on October 15 and unknowingly inhaled some of the anthrax that fell out. Several days passed before the contents of the envelope were tested and identified. By then it was too late to do anything for the photo editor. He died two weeks later. Five days after the delivery in Florida the next anthrax envelope arrived. This time it was the office of Senate Leader Tom Daschle. Over the following two weeks several more anthrax letters arrived at both media centers and different offices in Washington. There were also hoax letters that looked like the lethal ones. Most of the attacks occurred between October 15 and 31. Places in at least nine states became involved.

As long as each instance only affected the person to whom the letter was addressed there was limited concern since care in handling mail and immediate use of antibiotics could cope with the dangers. Before long, however, it became clear that the trail from sender to recipient could itself be a source of contamination. In Indiana, on October 31, a postal machine sent to Indianapolis had traces of anthrax. At the same time, in Missouri, anthrax spores were discovered in empty mailbags. There developed a general fear that the mail service might be infecting people and places everywhere it operated, both at home and abroad. Confirmation came from new infections in people who did not work in any of the affected places.

By the end of October 2001, five people were dead from anthrax, including two postal workers and a journalist, and thirteen others were ill. As a result, much of the postal system as well as several government offices had to be closed down temporarily in order to cope with ways of preventing additional infections. Thirty congressional workers had tested positive with anthrax and the Hart Senate Office Building, the House of Representatives, and even the Library of Congress all had to be evacuated at times because of the presence of anthrax spores. The mail facility in Fairfax, Virginia, which handles all the mail for Washington, was found to be contaminated with anthrax spores.

Interim measures were taken in all government offices and in various places across the country. Many school and public libraries were closed. Several affected postal stations were also closed. The White House mail was quarantined and several government offices locked in order to check for spores while their staffs met elsewhere. For the first time in its history, the Supreme Court convened away from its own chambers. The State Department cut off all mail to its 240 embassies and consulates worldwide. One expert in government administration said that nothing since the days of the Civil War had as seriously disrupted the business of government as this anthrax attack. He added that the economic losses would probably amount to billions of dollars.

As intense investigations into the source of the scourge continued, the post office began the process of irradiating all mail. At the same time, extensive tests were conducted on the anthrax powder to find out how it was made and what type of powder was used. It was known that identical material had been employed in all the attacks, proving that the campaign originated from a single source and possibly from a single terrorist. Over the following six months it was established that the kind of powder used was quite different from that used by government biological defense programs, in both the United States and other countries. This seemed to confirm FBI suspicions from the beginning that the whole enterprise was a U.S. plan, not the work of terrorists from overseas. Research workers also discovered that the anthrax had been coated with a chemical substance that would prevent the tiny spores from clumping together. Thus they would float freely into the air once a letter was opened and inhalation would be likely.

Evidence of these kinds suggested that the person behind the attack was well acquainted with the chemistry and technology of using anthrax as a weapon. Perhaps he may have worked in the U.S. government's biological defense program at some time and was now a disgruntled person seeking revenge or notoriety. Regarding the latter, he certainly gained the reputation of causing the worst acts of biological terrorism ever known in the U.S. FBI investigations are continuing, seeking data on the genetic signatures that might help them localize the specific site where the anthrax originated. FBI's earlier conviction that the culprit was a U.S. scientist with special training and skills has been strengthened by all the findings to date but, like so many other acts of terror, the culprits are still at large.

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Sumatra, Indonesia, earthquake and tsunami

December 26, 2004

Earth's rotation slowed down for a fraction of a second

The whole world was shaken by the massive earthquake and tsunami that struck Indonesia

Around 8 A.M. on December 26, 2004, an earthquake of magnitude 9.1 hit northern Sumatra in Indonesia, and then shook most of the world by causing the deadliest tsunami in human history. The earthquake was so powerful that it slowed down the earth's speed of rotation by a tiny fraction of a second. The initial shock was followed by more than a dozen aftershocks. Thailand, India, Sri Lanka, and several other places, especially the Western Sumatra Province of Indonesia, which was closest to the earthquake and experienced the full force of the tsunami, all were devastated by the tsunami. At least 250,000 people were killed and many millions of others suffered losses of all kinds.

The earthquake happened in the short space of a few minutes at the interface of the India Plate and the Burma Plate. Strains that had accumulated for centuries suddenly gave way as the India Plate pushed the overriding Burma Plate upward. When the fault line between these two plates suddenly slipped, a 750-mile-long seabed break appeared and there was a vertical displacement of forty-five feet in the depth of the ocean. The huge volume of water displaced by such an event became a tsunami, one that swept outward in all directions. The earthquake was the fourth biggest anywhere in the world since 1900. A wall of water thirty feet high, traveling at five hundred miles an hour, swept outward from the epicenter causing the greatest number of casualties in the nearby land of Western Sumatra. Within a few hours, places all over the Indian Ocean were impacted.

Figure 124 A village near the coast of Sumatra lays in ruin after the tsunami that struck South East Asia.

In the Pacific Ocean, earthquakes cannot be accurately predicted in advance. Once an earthquake is detected it is possible to give three hours notice of any tsunami risk. In addition, Pacific people are familiar with tsunamis and are always ready to run to higher ground when a warning comes. There is no similar system in the Indian Ocean. Tsunamis are rare, only seven significant ones in the last century, many of them affecting specific countries only. The first news that reached the western world from Indonesia and the countries that were affected came from Thailand, simply because that country was a tourist center and modern technology was available at the time to give signals and detailed messages to the rest of the world about the tragedy that had happened. The actual damage, of course, was quite different. The loss of life in Thailand, even though it was so close to Indonesia, was less that 5,000, whereas in Sumatra, where the earthquake and the tsunami first hit, the death toll went far beyond the 100,000 level right away. Between Sumatra and Thailand the groups of islands known as the Nicobar and the Andaman Islands were overwhelmed by the tsunami wave that swept over the area quickly after the first event.

The first formal warning came from the Pacific Tsunami Warning Center in Honolulu. That, of course, is a center that is designed for the Pacific, and because of the many tsunamis experienced, it has been widely recognized and highly valuable over the years. However, because there is no warning system available in the Indian Ocean, where all the damage would be done, the Pacific Center, immediately had some information about the earthquake and tsunami, and for example, sent out warning signals fifteen minutes after the earthquake. A bulletin was dispatched to all the countries around the Pacific and the countries around the Indian Ocean—Indonesia and Thailand—warning them that a very great earthquake had occurred and precautions should be taken immediately. At that time, within about fifteen minutes of the earthquake, the estimate was that it would be more than a magnitude 8 in terms of the Richter Scale and that, therefore, there was a strong possibility of a tsunami occurring at the same time.

There was no living memory of a major tsunami in the Indian Ocean and, in fact, there had been no adequate preparation for that eventuality, simply because of the absence of any tsunamis over the course of the twentieth century. While there was much preparation for giving out warnings, it was a very inefficient system. For example, the official in charge of Indonesia's tsunami warning system had received the e-mail from the Pacific warning center on the morning immediately following the earthquake. The e-mail message had arrived within a few hours of the earthquake, but was not seen until one day later. The official was not at work on that particular morning and so nothing was really done in time to warn any of the countries that subsequently would be affected by the tsunami, because by the next morning, about twelve or more hours later, the tsunami, certainly the first wave of the tsunami, had long before that time reached Africa and all the major damage that was going to be done had already been done. The indifference of the Indonesian officer was matched by the attitude of the equivalent officer in Thailand.

When the first news came to the duty officer in that country, his reaction was simply that the earthquake is far away from us and in 1,000 years we've never heard of a tsunami affecting this area so it doesn't seem necessary for me to give a warning out for this one. The general indifference on the part of the duty officers in Indonesia and Thailand may be understandable and, in fact, may not have made any difference to the countries and areas that were first hit. It all happened so quickly because tsunamis travel at more than five hundred mph and there was barely time, even if there had been a warning system, to do much for Thailand, the Andaman and Nicobar islands and, of course, the area that was damaged more than anywhere else, the western part of Indonesia known as Sumatra.

It was a different story for India and Sri Lanka. Because of the distance, it took an hour and a half for the main first wave of the tsunami to reach Sri Lanka, and had a warning been given, undoubtedly there would have been some better outcome and many more lives saved than was the case. That first wave caused the death of more than 30,000 in Sri Lanka and over 10,000 on the eastern shores of India before moving on to sweep still further westward over the Maldives, maybe two and a half hours after the initial earthquake, and then six and seven hours later reaching the Seychelles and the shores of Africa in Somalia. For Indonesia, Sri Lanka, and India, the countries where most lives were lost, it should be remembered that life in all of these areas is essentially sea dependant and the homes are concentrated close to the water and, therefore, in low lying areas. This is why destruction was so total. But beyond the actual numbers of people and the loss of life and homes, there was also the huge destruction of the environment and the long time it would take for recovery.

In Indonesia, for example, the largest concentration of coral reefs is located in the very area that was hit by the earthquake. These coral reefs served to trap coastal sediments and protect the coast from high waves that might come from just ordinary weather changes. They, overall, provide an ecosystem that is protective of a large variety of fish life and, therefore, on the livelihood of the people who live in that area. Large stretches of rice patties, as well as mangrove and other forests, were completely wiped out by the tsunami in this part of Indonesia. Overall, the most serious threat to the coastal environment—one that will take a long time to be corrected—was the huge amount of natural and manmade materials that were dragged back into the ocean by the receding waters from the tsunami. This could be vehicles, fuel tankers, trees, and just any imaginable kind of debris. The quantities were huge and the damage will remain there for a long time to come. It was a similar problem with water supplies. There is plenty of water available in this part of Indonesia, but the tsunami, bringing salt water many miles inland, contaminated all the surface waters. This is a very poor area in every respect. People are totally dependant on the resources of the physical environment where they live and there is no sewer system for the disposal of waste, so the septic tanks that did exist were severely contaminated by the seawater, as indeed were the various wells that serve as the source of fresh water for a number of areas.

Thailand's main concern about the tsunami relates to tourism, one of the highest income areas for the country, and so the danger of tourists not coming back to the country for fear of another tsunami was a major concern. Quite apart from that factor, the environment was profoundly impacted. Offshore there are extraordinarily rich collections of sea life, some of them quite endangered and extremely valuable. On shore, two miles of the land surface was inundated and the seawater that came with that event destroyed a large number of fresh water areas on land. Almost all of the lakes within that range of the coast, and therefore within range of the main settled areas of the country, were contaminated and it is not clear how long it will take for that to be corrected.

One other country in the path of the tsunami, the Maldives, is completely dependent on tourism, even to a greater extent than Thailand. It is located in the Indian Ocean, west of Sri Lanka. One has only to think about one simple statistic to appreciate how total the devastation was for this country. Eighty percent of the land in the group of islands that constitute this country lie less than three feet above sea level. All together there are more than 1,000 islands forming the country, and maybe two hundred of these are inhabited. Now, of those two hundred, twenty were totally devastated and fourteen of them had to be evacuated. The total population of the country is less than half a million, but it is a very popular destination for tourists because of the climate and because of the uniqueness of the ocean setting everywhere throughout the country. Approximately 13,000 people had to be rescued after the tsunami, and all together probably one-third of the entire population suffered some loss of home, possessions, or livelihood. There was so much flooding that electricity was cut off for many of the islands and there was no communication from island to island for considerable time. One out of every four of the inhabited islands had experienced serious destruction to its jetties and its harbors and, therefore, to its links with the outside world and its availability for the tourism industry.

Needless to say, there was a huge outpouring of sympathy and provision of money for rehabilitation from all over the world. Nothing on this scale had been experienced in living memory so, being a natural catastrophe, everybody felt a degree of responsibility for helping. Getting quantities of money contributed is one thing of course, but getting the supplies and resources for survival to the needy areas is quite another matter all together. If resources, medication and food are not provided almost immediately, then you have the secondary effects of the disaster—hunger and disease. So everything depends on the speed with which supplies can be delivered to the affected areas. The huge distances involved are in themselves a major hurdle for relief agencies and people providing support to the needed areas. The distance from Indonesia to Sri Lanka to Somalia really takes one halfway around the world.

Quite apart from the logistics of getting supplies to needy areas, there were two other factors that affected the recovery. Number one, there was crime and the opportunities were offered to people who want to take advantage of the situation to grab what they can. This certainly was a factor in a number of areas and relief agencies had not only got there as quickly as possible, but also were unable to come with some protection so that what they were bringing would not be stolen right away. Beyond the crime elements, there was also the range of political considerations. For example, the Indonesian government was very reluctant to accept U.S. warships near its coasts, even though that was the only available transportation method for getting food and medical supplies to the desperate needs of western Sumatra. One compromise that was arranged was to ensure that these warships would stay for a limited length of time. So even with the generosity that was being provided, there were political considerations in some countries that were far greater than the care of their own people.

In Sri Lanka there was a very special situation that confronted the relief agencies. Sri Lanka has had a civil war that has been going on for many years. The Tamal Tigers in the northern part of the country are fighting for the independence of their part of Sri Lanka. This has been a violent war with many thousands killed over the years. When the relief agencies arrived there was some dispute with government authorities in Sri Lanka about whether the relief should be equally distributed to the rebel areas of the country as well as the other parts further south. This took a lot of time and discussion and the only way it could have been resolved was when relief agencies insisted that there had to be equal distribution or they would have to leave the country entirely. They could not choose those who were going to get help and those who would get no help.

The year 2004 ended in a tragedy of unprecedented scale and dimension. Many lessons can be drawn from the disaster that affected nine countries on two continents and claimed over 300,000 lives. One important lesson that emerged from the disaster was the need for monitoring and early warning systems. The loss of human life would have been considerably less had coastal communities had more knowledge and greater awareness of a tsunami risk. The extent of the disaster brought to light the overall lack of awareness and low level of national preparedness. It was seen as imperative, therefore, to build systems to make communities safer and educate citizens on the nature of the threats. A brand new organization was set up to coordinate emergency preparations. An endorsement for it was received from six of the states that were damaged by the tsunami—Bangladesh, Cambodia, Nepal, Pakistan, Philippines, and Thailand.

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Northern California offshore earthquake

June 15, 2005

An unusually strong earthquake struck northern California

This earthquake, magnitude 7.2, was a rare event for anywhere in California. It was caused by subduction on the part of the Gorda Tectonic Plate

On June 15, 2005, a 7.2 magnitude earthquake struck the center of the Gorda Tectonic Plate about ninety miles offshore from the northern coast of California. This plate lies relatively close to the coast and can be considered a southward extension of the large Jan de Fuca Plate. Both of these plates are subducting beneath the North American Plate. The Gorda is a very active one. It produces earthquakes of magnitude 7 about every twenty years, a rare level of activity for any place in California. This particular earthquake was felt widely in Oregon, Washington, and California, and it had a significant impact as far north as Seattle and southwards to the Mexican border.

This earthquake occurred in a deformed section of the southernmost part of the Gorda Plate. Light shaking from it was widely felt along the northern Californian coastline all the way to the Oregon boundary. Preliminary analysis of the quake indicated that it resulted from slip on a left-lateral, strike-slip fault. This type of fault has been documented for other earthquakes with epicenters in the interior of the Gorda Plate. There was no tsunami. Earthquakes with strike-slip mechanisms are less likely to produce tsunamis because they cause relatively little vertical ground movement. While this earthquake was very strong and exceptional, it must be noted that in general, lesser quakes are very common in the Gorda Plate because it is subjected to north-south compression as the Pacific Plate moves toward the Northwest and collides with the southern boundary of the Gorda Plate. A tsunami warning was automatically triggered from the West Coast Tsunami Warning System for the entire U.S. West Coast because of the strength of the quake. It was withdrawn soon afterward.

Crescent City, a place that historically always suffered greatly from tsunamis on the northern Californian coast, sounded its warning sirens shortly after 8 P.M. and thousands of residents and visitors were evacuated. In many other areas, communication problems prevented the tsunami warning from reaching the public until after it had been canceled. The tsunami warning had been based on the earthquake's large magnitude, initially calculated at a higher figure than the one that was finally determined. Information that takes longer to gather is used to determine whether a tsunami warning should be expanded, continued, or canceled. Most important is direct measurement of water levels by NOAA's ocean-bottom sensors and shoreline tide gauges that relay data by satellite to the tsunami-warning centers. Well after the predicted arrival times no tsunami had been clearly detected at the three tide gauges nearest the epicenter and even in Crescent City the additional height of the tidal gauges was only four inches. After careful consideration of all available information, the National Weather Service canceled the tsunami warning at 9 P.M.

Analysis of earthquake data helped seismologists explain why only a tiny tsunami had been generated: the earthquake occurred on a strike-slip fault, now believed to be a left-lateral fault within the Gorda Plate, a fault-ridden piece of oceanic crust being compressed and deformed by the northward-moving Pacific Plate. Earthquakes on strike-slip faults produce much less vertical movement of the sea floor than do earthquakes on thrust faults. While experts knew that there was little likelihood of a tsunami in this instance, their minds were still very much occupied by the tsunamis of December 2004 in Indonesia and they were not going to take any risks. NOAA uses two types of water-level sensors to detect tsunamis: shoreline tide stations and offshore ocean-bottom sensors. NOAA operates a number of tide stations on Pacific coastlines and six buoys in the Pacific Ocean. The memory of the devastating Indonesian tsunami of 2004 is still strong and it has inspired a joint project involving USGS and NOAA to install additional buoys not only along the northern Californian coast but also in selected Atlantic and Caribbean sites.

The June 15, 2005, earthquake occurred twenty miles west of another 7.2 quake, the one that hit off the coast of Humboldt Bay on November of 1980. Between 1980 and 2005, in the same general area, there were ten others that measured between 6 and 7 in magnitude and one, that of Cape Mendocino in 1992, that was of magnitude 7.2. One has to go back a very long distance in time to find three Californian earthquakes of this magnitude occurring in the same general area in and east of the Gorda Plate. The November 1980 quake, the largest in the previous twenty-five years, injured six people and caused property damage estimated at $2 million.

Most of the damage occurred east of Fields Landing, where two sections of an overpass on U.S. Highway 101 collapsed onto the railroad tracks below. At Fields Landing, two houses were displaced from their foundations, one non-reinforced chimney fell, and gas, water and sewer lines were broken. This shock and most of its aftershocks occurred on a large, left-lateral, strike-slip fault that extends northeastward from Cape Mendocino. The earthquake was felt over a large area, including parts of Oregon, western Nevada, and northern California. Many aftershocks occurred.

The Cape Mendocino 7.2 earthquake of April 1992 was located on land near Petrolia at a depth of seven miles below ground. This location is very near the inferred position of the Cascadia subduction zone boundary between the Gorda Plate and the North American Plate; that is, the epicenter is very close to the point where the subducting plate begins to move down into the asthenosphere. It is thus the first major historic earthquake on the subduction zone. Motion was along a north-south oriented fault plane dipping gently down to the east. The North American Plate was thrust up and over the Gorda Plate. It produced measurable coastal uplift in the vicinity of Cape Mendocino on the order of 4–5 feet and a tsunami which was recorded at tide gauges from Port Orford, Oregon, to Port San Luis near San Luis Obispo. Maximum recorded wave heights were just under 2 feet in Crescent City. The main shock was followed by two magnitude 6.6 aftershocks, both intraplate Gorda earthquakes located about fifteen miles off shore. The main shock together with the large aftershocks caused $60 million worth of damage and led to a federal disaster declaration.

Figure 125 Another Californian landslide, common in northern coastal areas.

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Hurricane Katrina

August 29, 2005
New Orleans devastated by hurricane and flood

Hurricane Katrina was both the deadliest and the costliest hurricane in U.S. history

Hurricane Katrina was the costliest and one of the deadliest hurricanes in the history of the United States. It was the sixth strongest Atlantic hurricane ever recorded and the third strongest land-falling U.S. hurricane ever recorded. Katrina occurred late in August during the 2005 Atlantic hurricane season and devastated much of the north-central Gulf Coast of the United States. Most notable in media coverage were catastrophic effects in the city of New Orleans, Louisiana. Katrina's sheer size devastated a one hundred-mile stretch of the Gulf Coast. The storm surge that swept over New Orleans was as high as twenty-seven feet but that was not the main cause of the damage. The levees were fundamentally flawed. They had not been given proper foundations. The soil beneath them was washed away opening the city to the water of Lake Pontchartrain, a source of water beyond anything that the storm surges could produce. The city was drowned.

Katrina was the eleventh named storm, fifth hurricane, third major hurricane, and second category 5 hurricane of the 2005 Atlantic season. It formed over the Bahamas on August 23, 2005, and crossed southern Florida as a moderate category 1 hurricane before strengthening rapidly in the Gulf of Mexico and becoming one of the strongest hurricanes ever recorded in the Gulf. The storm weakened considerably before making its landfall near New Orleans as a category 3 storm on the morning of August 29. The storm surge caused major or catastrophic damage all along the coastlines of Alabama, Mississippi, and Louisiana, including the cities of Mobile, Biloxi, Gulfport, and Slidell. Levees separating Lake Pontchartrain from New Orleans were undermined by the surge, ultimately flooding roughly 80 percent of the city and many areas of neighboring parishes.

This hurricane formed in the third week of August 2005 off the coast of the Bahamas. Over the following seven days it grew from a tropical storm into a catastrophic hurricane. It first made landfall in Florida and then hit along the Gulf Coast in Mississippi, Louisiana, and Alabama, leaving a trail of devastation and human suffering. This hurricane caused physical destruction everywhere along its path. It flooded the historic city of New Orleans, ultimately killing over 1,300 people and it became the most destructive natural disaster in U.S. history. Katrina's winds and the storm surge that reached as high as twenty-seven feet was an extremely severe blow to New Orleans. It overwhelmed levees all around the city of

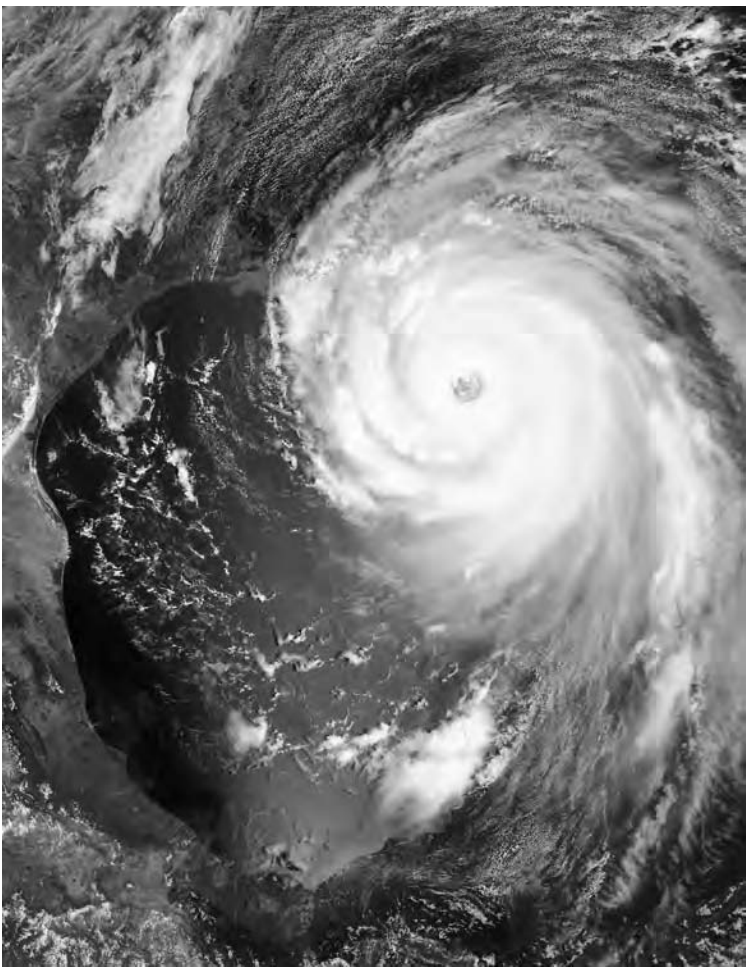

Figure 126 Hurricane Katrina approaching the Gulf Coast Credit.

New Orleans and the consequences for a city of this size, which was already standing, for the most part, below sea level, were pretty dire.

Of course the states of Florida, Alabama, Mississippi, and Louisiana all got hit by Katrina, but New Orleans became the focus for more than one reason. To begin with, it was the biggest city in the area, with a population of about a half million people, and after the first levees began to collapse the entire city was really stuck in the middle of an ocean because the water had reached a level where only boats could give access from one part of the city to another. And, of course, power and telephone communications began to collapse in the process of all this. All this flooding and the destruction of the levees by the twenty-seven-foot high storm surge completely overwhelmed the levees, which were never designed to handle that level of water. So the flooding really destroyed New Orleans, much as the fire that burned Chicago in 1871 destroyed that city and the earthquake and fire that finished off San Francisco in 1906, destroying the economic and cultural centers of that entire region. It was a similar story in Galveston in the famous hurricane of 1900. And even beyond New Orleans, the span of destruction cast by Katrina was widespread all over the coastal areas. Towns and cities, small and large, were destroyed or heavily damaged by the hurricane, but the focus remained on New Orleans. It was here that the greatest damage had occurred and it was here that the greatest challenge was presented to all levels of government as to how to secure rescue of the many stranded people.

Figure 127 New Orleans, Louisiana, September 2, 2005. FEMA and local rescue crews go into neighborhoods looking for residents unable to get out of their houses due to high water.

When we compare the reaction of the authorities in New Orleans to the approaching storm with the experiences of the people in Florida we find a sharp contrast. In Florida, because they are so accustomed to serious hurricanes, there is a highly developed system of preparation and a coordinated set of organizations that ensure predictable and safe action well ahead of the storm's arrival. New Orleans rarely has had a serious hurricane, yet it is far more vulnerable than any other place in all of the United States so one would expect that given a repeated series of warnings, all of them predictable as it turned out, there should have been much greater action in preparation than there actually was.

As early as the beginning of May, the director of the National Oceanic and Atmospheric Administration, that is the overall organization that predicts and follows the movement of hurricanes, gave a warning for the upcoming season that it was, in all likelihood, going to be much more violent than in previous years. The director's estimate was that storms for the year 2005 would have a 70 percent higher chance of an exceptional season and after the first two months of the season had passed all events confirmed that earlier prediction.

On Tuesday, August 23, almost a week before Katrina actually hit New Orleans, the National Weather Service identified a tropical depression in the area of the Bahamas and it looked as if it would develop into a serious hurricane. Military authorities and all other agencies responsible began to issue warning alerts and began to follow the path of this storm every moment of every day. Within a day this tropical storm off the Bahamas had been identified, given the name Katrina, and on the following day it had strengthened to a tropical storm. A day later, on August 25, Katrina was a category 1 hurricane. It made landfall in south Florida later that day and winds were up to eighty mph at that time. The volume of rain and destruction was quite severe. Fourteen to fifteen inches of rain were dropped in some parts and the overall death toll during its one-day passage over Florida was more than a dozen. Over a million people lost power and flooding was found in a number of areas. The total damage to Florida amounted to about $2 billion.

As the storm passed into the Gulf of Mexico and traveled northwards, federal authorities arranged for emergency quantities of food and water to be shipped to all of the states along the Gulf, including Georgia, Alabama, Louisiana, Texas, and South Carolina as well. The recognition was made at that stage that, on the evening of August 25, a very serious hurricane was moving towards the coastal area of the northern part of the Gulf of Mexico. On the afternoon of August 26, a forecast was issued by the National Hurricane Center regarding Katrina. This forecast pointed out that Katrina would make its next landfall as a category 4, or even 5, the highest possible, somewhere along the Gulf Coast, just east of New Orleans. As the hurricane moved it seemed more and more certain, to a degree that the National Health Service had not experienced before, that the path it projected was being followed precisely as anticipated. On top of the direction of landfall and location of landfall, the prediction was that flooding to the level of as much as twenty feet above normal tide levels could be anticipated.

This one factor alone should have been sufficient to terrify every person in New Orleans, had it been observed with greater care, because it is well known that a flood tide of twenty feet was beyond what the levees could withstand. This was now well into August 26, three days before the landfall that would cause all the trouble at New Orleans. But at that point, apart from issuing a state of emergency, the governor of Louisiana had not taken any additional direct action and the mayor of New Orleans, who was responsible for the evacuation of half a million people, took no action either on that day, nor indeed on the following day, August 27. It was late on August 27, after the governor of Louisiana was aware of the indifference on the part of large numbers of people, that she decided to enact what is called the counter flow traffic arrangements. That is a system whereby all incoming traffic to New Orleans is cut off and only exit from New Orleans is permitted. That action made a beginning late on August 27. Action had still to be taken by the mayor to get people moving and get them out of the city, especially those who had no transportation of their own and required buses to be made available for them. By this time, because the storm was moving northwards from the Gulf of Mexico and because there was no outlet for the heightened waves that were created ahead of the storm, the water level at Louisiana and at New Orleans was already rising far above the highest tide level.

In fact, this rise in the water level began to leak through one of the levees, not overtopping it, but simply creating a leak by the pressure from outside and so a beginning was made to the destruction of the levees long before the height of the water caused it. So serious did the danger of the hurricane appear to the director of the National Hurricane Center, that he did what he had never previously done in his life—he personally called the mayor of New Orleans, warning him of the extreme danger from the hurricane and urging him to do everything possible. Despite that further warning and another call from the headquarters of the Hurricane Center, the mayor of New Orleans did not begin a mandatory evacuation until the following morning, Sunday, August 28. In fact, it was too late for many of the people who had no cars and no friends who could accommodate them in their cars. From that time; the disaster that happened when the stadium that so many of these stranded people used as a refuge was damaged to the point where it ceased to provide protection.

Like Chicago in its early battles with flooding, New Orleans' principal concerns center on water but to a far greater extent than Chicago ever experienced. It might even be said that the greatest engineering challenge facing this city at the mouth of the Mississippi is to keep it from drowning. Additionally, the city has very weak conditions in its foundation, so much so that it has been described as the flattest, lowest, and geologically youngest of any major city in the United States. Average elevation is less

Figure 128 Devastation wrought by Hurricane Katrina between The Rigolets and Chef Menteur Pass.

Figure 129 Views of inundated areas in New Orleans following breaking of the levees surrounding the city as the result of Hurricane Katrina.

than two feet above sea level and no surficial deposits are older than 2,500 years. About half of the urbanized area is at or below sea level. Floods on the Mississippi at times reach twenty feet above sea level and hurricane surges on Lake Pontchartrain to the north of the city have exceeded six feet above sea level. Rainfalls of ten inches within a period of twelve hours have been recorded on several occasions!

It is rare to find a city whose unconsolidated foundations date within the period of human history. They belong to the Holocene Epoch and range in depth from fifteen feet to more than forty-five feet. New Orleans is about forty-five miles from the Gulf of Mexico and more than twice that distance from the mouth of the Mississippi. It is part of that river's delta, a broad region of bayous and wetlands. Nowadays the main built up part of the city is free from marshes as a result of the extensive measures taken to drain or pump away the water. Both natural and built levees run east and west within the city between the Mississippi River and the Lake Pontchartrain that stretches northwards for more than twenty miles.

Levees extend along both sides of the lower Mississippi for a total distance of 1,500 miles. Farther up the valley of the river these levees are quite high, as much as thirty-six feet with base widths of 360 feet, but those around the city area average only fifteen feet above the natural levee ridges on which they were built. Because the differences in elevation between the water level inside the levees and the lowest parts of the city are so big, there is a great need for a thoroughly dependable levee system. Fortunately the natural levees overlie coarse-grained inorganic deposits and these are the best shallow foundation soils in the New Orleans area. In addition to the levees, there is a floodway through which water can be by passed during a river flood.

As far as the city is concerned, hurricane-induced flooding can be just as catastrophic as a Mississippi flood. Rarely does a hurricane pass over the center of New Orleans but when it happens the devastation is widespread and costs are enormous. Flooding of populated areas is a certainty. The amount of advance warning is usually less than a day because, although its path can be traced for several days before it strikes land, its behavior as it approaches landfall is unpredictable. What can be done when flooding occurs? To move even a small percentage of the city's population to safe ground out of town cannot be done in a day. The only practicable alternative is to evacuate vertically, that is move people to floors of homes or buildings that are above flood level.

Diversion of water is the usual method of minimizing threats to the city. To the west is a large floodway beginning far upstream and continuing down the Atchafalaya Basin into the Gulf, affectionately named Old River Control Structure. Half of all the water in the Mississippi when it is at flood stage can be bypassed in this way. On the western outskirts of the city, on the main river, is another diversion, the Bonnet Carre Spillway. It can be opened to divert water from the river into Lake Pontchartrain. It is seldom used but is always available. There is a continuing concern about the stability of these protective measures because of the nature of the underlying sediments. During a major flood in 1973, for instance, part of the Atchafalaya was undermined and one wall failed.

Because there is so much unconsolidated material everywhere in and around the city, compaction of these sediments from time to time is the major cause of subsidence. Land sinking, shoreline erosion, and salt water encroachment all are active and add to this problem of maintaining a consistent level of land. At times these forces cause sudden changes to buildings and facilities. Differential settlement, along with bank failures and flooding are the sorts of things that happen. If allowance is made for sea level variations, the general picture of subsidence rates is about seven inches a century. Local groundwater withdrawals further aggravate the situation.

About one in ten homes and the same proportion of commercial buildings, plus one out of every three streets and sidewalks show signs of differential subsidence. Structures on the natural levees rarely are at risk but the large number built on organic swamp and marsh deposits stand on a very unstable base. Typical conditions include buckling of patios and exposure of foundation slabs. Driveways too subside to such an extent that it is impossible to drive into carports. Gas and water leaks occur as underground utility lines sag. The problem worsens with development as new impermeable coverings of streets, parking lots, and buildings lead to dewatering and compaction in the organic soils beneath and hence subsidence.

When the first settlers occupied some high ground on the banks of the Mississippi almost three hundred years ago, there was little thought about the problems of growth but the risks gradually increased as the settlement expanded. Today the city continues to push its frontiers farther and farther into low-lying marshy tracts where building is possible only with the best of modern technology. Structures six hundred feet tall stand where formerly the ground could not support the weight of one person. Water levels, when the river is in flood, can be as high as twenty-seven feet above the lowest areas of the city. There seems to be great faith in the stability of the dikes, but those responsible for them are always on alert, especially when strong winds blow. Early building techniques used the natural levees. Crossed timber supports and masonry footings constituted the foundations. Later, piles were introduced for the bigger structures. These piles were driven down to the first sand stratum at a fairly shallow depth where sufficient resistance was encountered to indicate a safe foundation. In the late 1930s, one twenty-story hospital was constructed in this way, with piles that went down twenty feet, but within a year or two the building began to settle and before long it had to be abandoned.

Unstable layers of deposits beneath the sandy foundation gave way. At that time there was little detailed knowledge of subsurface geology so no one knew about this weakness. Over time, thousands of borings to depths of 180 feet or more identified the nature of the underlying layers, not only the sand strata that seemed to be strong enough to hold up buildings but beyond that into the deeper Pleistocene deposits. When, in the late 1950s, a second hospital was built close to the site of the former failed one, over 2,000 piles were driven seventy-five feet into the ground, deep enough to reach the Pleistocene deposits even though the building had only nine stories. Some settlement of the ground was anticipated and construction plans took account of this. That building has stood well. The Pleistocene deposits are now the bedrock on which buildings need to rest. Where they are close to the surface pile lengths and numbers can be few. Even so there are deeper strata within the Pleistocene where compaction occurs if the load is great enough. The general rule now is this, the higher the building the deeper the piles. Both the number and type of concrete piles are other considerations. A 1968 building of forty-five stories had piles going down 150 feet, and a still more recent one, having fifty stories, used octagonal piles with diameters of twenty inches and depths of two hundred feet.

In summary, the significance of Katrina in the history of the United States may best be seen when it is compared, as in the following list, with the deadliest and costliest U.S. natural disasters since 1900, even when that list is expanded to include the costs of the Nine Eleven Terrorist assaults.

Top Disasters	Estimated Deaths	Estimated Damage (in $ billions)
Galveston Hurricane, 1900	8,000	1
San Francisco Earthquake, 1906	5,000	6
Atlantic–Gulf Hurricane 1919	600	1
Mississippi Floods 1927	246	2
Hurricane San Felipe 1928	2,750	1
New England Hurricane 1938	600	4
Northeast Hurricane 1944	390	1
Hurricane Diane 1955	184	5
Hurricane Audrey 1957	390	1
Hurricane Betsy 1965	75	7
Hurricane Camille 1969	335	6
Hurricane Agnes 1972	122	8
Hurricane Hugo 1989	86	11
Hurricane Andrew 1992	61	33
East Coast Blizzard 1993	270	4
Major 2004 hurricanes (Charley, Frances, Ivan, Jeanne)	167	46
Hurricane Katrina 2005	1,330	96
Nine-Eleven Terrorist Attacks	2,981	18

Katrina is estimated to be responsible for $75 billion (2005 U.S. dollars) in damages, making it the costliest hurricane in U.S. history. The storm killed at least 1,836 people, making it the deadliest U.S. hurricane since the 1928 Okeechobee hurricane. Criticism of the federal, state, and local government's reaction to the storm was widespread and resulted in an investigation by the United States Congress and the resignation of FEMA head Michael Brown.

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Pakistan earthquake

October 8, 2005
The high inaccessible mountains of Pakistan experienced a powerful earthquake

Both the mountainous location and the political setting of the earthquake led to delays and massive transportation problems

An earthquake of magnitude 7.6 struck Pakistan on October 8, 2005, and, because the epicenter as well as most of the destruction occurred in the Pakistani-controlled portion of Kashmir, it also came to be known as the Kashmir earthquake. Because of the inaccessibility of the high mountainous area that was hit, casualties and costs were both very high. More than 73,000 lost their lives and costs mounted to $5 billion.

Immediately after the earthquake, landslides blocked the steep, winding paths and donkey trails that constituted the only access roads to where most of the people lived. The United Nations estimated that at least four million people were affected and the medical, food, and clothing needs were acute as winter was approaching. In addition, it took some time to arrange for permission for assistance to be sent from the Indian side through Kashmir. The border is tightly controlled and there is frequent fighting between guards on both sides. In addition to the destruction in Pakistan, many parts of Afghanistan and India experienced substantial damage.

Kashmir lies in the area of collision of the Eurasian and Indian tectonic plates. These plates are constantly moving against each other with the Indian Plate subducting beneath the Eurasian Plate. This movement was how the Himalayas came into existence. It is a land illustration of the subducting actions that take place all the time all around the Pacific Rim. Wherever activity of this kind is happening there are earthquakes as frictions or stuck plates allow tensions to build up until there is a sudden release. The earthquake in this Kashmir earthquake had an epicenter sixty miles northeast of the Capital of Pakistan, Islamabad, and sixteen miles below the surface. Numerous aftershocks occurred, some of them as strong as 6.2.

As Saturday is a normal school day in the region, most students were at schools when the earthquake struck. Many were buried under collapsed school buildings and parents were seen frantically digging with their hands to rescue children. Two days after the quake, the World Food Program pointed out that 500,000 people in remote areas had not yet received any aid. One of the biggest problems was meeting the demand for tents that could provide shelter as the cold weather worsened. Fears mounted about a second wave of deaths from untreated injuries and exposure. UNICEF distributed 110,000 winter kits for children living above the snowline, including snow boots, padded jackets, shawls and socks, as well as half a million blankets. An additional 350,000 quilts were being provided thanks to the support of IKEA. Many volunteer agencies from many countries including the United States were on hand to help, but often it was almost impossible to reach those in need. Even helicopters had trouble landing on the slopes because they are so steep.

The Earthquake Engineering Corporation of Pakistan showed that most of the buildings in the earthquake zone were built of non-reinforced concrete blocks and, accordingly, most buildings collapsed. Landslides were another contributing factor in the high level of destruction. They buried homes and the occupants inside were killed when their homes came down. In Islamabad two residential high-rise buildings collapsed from the shaking that accompanied the quake. An international rescue corps was able to rescue some people a few days after the earthquake but they had great difficulty securing silence in order to use sensitive sound equipment for detecting life.

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Taiwan earthquake

December 26, 2006
Most of Taiwan was affected by a strong earthquake
in the South China Sea

A sequence of disruptions to communications because of this earthquake closed down business activities for a time in many parts of Asia and North America

The 2006 Taiwan earthquake of magnitude 7.1 occurred on December 26, 2006, with an epicenter fifteen miles off the southwest coast of Taiwan and fourteen miles deep in the South China Sea. It not only caused casualties and building damages, but also damaged several undersea cables, disrupting telecommunication services in various parts of Asia. It coincided in time with both the second anniversary of the 2004 Indian Ocean earthquake and tsunami that devastated the coastal communities across Southeast and South Asia and the third anniversary of the 2003 earthquake that devastated the southern Iranian city of Bam.

News agencies reported collapsed houses in southern Taiwan along with buildings on fire, hotel guests trapped in elevators, and telephones out of operation due to severed lines. Two people were reported killed and forty-two injured. The earthquake was felt all over Taiwan, including the capital city of Taipei, three hundred miles north of the epicenter. Power was lost in 3,000 homes, but service was restored within a day. A nuclear power plant was affected by the severe shaking that followed the earthquake from aftershocks and emergency procedures were put in place immediately to prevent leakage of radiation. Residents in Hong Kong were so alarmed by the impact of the quake that they ran out into the streets in large numbers, fearing the collapse of their apartment buildings. Reaction was similar in Macau except that residents there thought the earthquake had occurred in

Macau. In Mainland China the earthquake was felt in the provinces of Guangdong and Fujian but there were no reports of major damage.

Perhaps the coincidence of the earthquake's timing with the devastating events in Sumatra in 2004 made Taiwanese authorities particularly sensitive to the dangers from tsunamis. A tsunami warning was issued at once, informing Philippine authorities that a ten-foot-high tsunami was heading toward them. No tsunami wave from Taiwan was subsequently recorded anywhere. The Pacific Tsunami Warning Center in Hawaii announced that there was no threat of a region-wide tsunami. The damage that caught everyone's attention was the disruption of undersea cable connections to many places in Asia. Taiwan's biggest telecom provider, Chunghwa Telecom Company, reported that it had lost 98 percent of its links with Malaysia, Singapore, Thailand, and Hong Kong, and added that repairs would take up to three weeks. Japanese operators also reported trouble.

Taiwan lies in one of the most earthquake-prone regions of the world. As recently as September 21, 1999 another earthquake measuring 7.6 on the Richter Scale struck it and killed more than 2,000 people in northern and central regions. Both the initial quake and the first aftershock from the 2006 quake were felt throughout Taiwan. A reporter's hotel room swayed in Taipei and the building creaked for fifteen seconds. Many streets in the city were cracked and a major bridge was damaged. Several fires broke out, apparently caused by downed electric power lines. Many buildings in Taipei swayed and knocked objects off the shelves.

In several southern cities power was cut off, hindering reports of damage from residents. At one hotel the shaking was so violent that many guests panicked and ran out of their rooms and into the streets. Taiwanese television stations showed rescuers using power equipment to dig through the remains of an offshore aging beach resort that had collapsed and trapped eight inside it. The main story, however, remained the destruction of Asia-wide communications and the associated reality that since there were only a limited number of cable repair ships, it would take at least weeks to fish up the undersea cables and repair them.

China Telecommunications Group said its connections with the United States and Europe had been broken. Internet connections had been cut off, and phone links and dedicated business lines had also been cut. As a result, Chinese access services were reduced for some days to the slow pace of land telephone lines and currency trading was stopped. China and South Korea lost their connections with the rest of the world because of this earthquake and many people in North America took note, at the time, of the sudden drop in the numbers of spam messages that were arriving. While spam messages come to North America from all over the world it became clear that a big part of that world of unwelcome communications comes from China and South Korea. One large network in North America saw its mail from Korea drop by 90 percent and from China by 99 percent.

This earthquake became a reminder to the world of the fragility of telecom cables. The destruction of distance that is attributed to the Internet may still be more of a dream than a reality. So widespread was the loss of communications with the rest of the world on the part of Asian countries due to this one earthquake that the demand quickly arose for alternative connections. With such large expanses of water separating countries around the Pacific Rim, the region will need to come up with more innovative and robust backup plans. After the tsunami of December 26, 2004, satellite communication was the solid backup for voice communication. But this service might be too small to handle high-speed Internet traffic. In the process we can learn more about the Internet when it's not working than when it is.

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Greensburg, Kansas, tornado

May 4, 2007
Greensburg, Kansas

This devastating Greensburg tornado was an F5 tornado, rarely seen, and not previously experienced in Kansas for decades. This tornado was four miles wide at touch down and it devastated 95 percent of Greenburg

The first EF-5 tornado in the United States since 1999 destroyed the town of Greensburg in southwest Kansas May 4, 2007, as part of a major, weekend outbreak of severe weather and flooding in the Central Plains, according to NOAA National Weather Service reports. Greensburg was evacuated after the tornado, and the town remains closed except to residents and emergency workers. A spokesman for the Kansas Department of Transportation office in Pratt said routing U.S. Highway 54 traffic around Greensburg is likely to continue for a week. The detour totals about eighty-five miles. The National Weather Service confirmed that the twister that hit Greensburg on Friday at about 9:45 P.M. was an F5, the highest on the scale. With winds of 205 mph, it stayed on the ground about an hour, traveling for twenty-two miles and wreaking a path of destruction nearly two miles wide. Ninety-five percent of the town was wiped out.

NOAA forecasters in Dodge City were able to issue a Tornado Warning thirty-nine minutes before the 1.7 mile wide wedge tornado hit the town. Noting intensification in radar images and a bearing directly toward Greensburg, Dodge City weather staff updated with a Tornado Emergency message 10–12 minutes before the twister hit. NOAA confirmed that the twister was an EF5 with wind speeds of about 205 mph. A broad area of low pressure moving slowly from the west encountered a warm front

Figure 130 Aerial photo of the devastation caused by the Greensburg, Kansas, tornado.

extending from western Nebraska into the Oklahoma and Texas Panhandles. Fed by copious amounts of moisture from the Gulf of Mexico, the collision spawned an active period of severe weather. Since Friday, May 4, the NOAA Storm Prediction Center in Norman, Okla., received 136 tornado reports, 109 reports of high winds and 429 reports of large hail, mostly concentrated on the plains.

Greensburg, like much of Kansas, is familiar with severe tornadoes but it has been many years since anything approaching the severity of the 2007 tornado occurred. Perhaps it is because of the state's history that it was selected as the imaginary setting for the famous Judy Garland movie "The Wizard of Oz." Greensburg is located in the southwest part of the state and about fifty miles north of the Oklahoma border. It is a town of about 1500 people and, for such a place, the loss of nine lives from this tornado was a severe blow. Two additional deaths occurred nearby. The Federal government immediately declared Greensburg a disaster scene, meaning that there would be federal financial assistance for the stricken town. President Bush visited the scene within a few days of the event.

NOAA, an agency of the U.S. Commerce Department, is celebrating two hundred years of science and service to the nation. From the establishment of the Survey of the Coast in 1807 by Thomas Jefferson to the formation of the Weather Bureau and the Commission of Fish and Fisheries in the 1870s, much of America's scientific heritage is rooted in NOAA. NOAA is dedicated to enhancing economic security and national safety through predicting and conducting research into weather and climate-related events, providing and delivering an information service for transportation, and by providing environmental stewardship of the nation's coastal and marine resources. Through the emerging Global Earth Observation System of Systems (GEOSS), NOAA is working with its federal partners, more than sixty countries and the European Commission to develop a global monitoring network that is as integrated as the planet it observes, predicts and protects.

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Appendix 1: USGS List of Worldwide Earthquakes (1500–2007)

1556 01 23—Shensi, China—Magnitude 8.0
1663 02 05—Charlevoix, Quebec, Canada—Magnitude 7.0
1668 08 17—Anatolia, Turkey—Magnitude 8.0
1692 06 07—Jamaica
1700 01 26—Cascadia Subduction Zone—Magnitude 9.0
1727 11 10—Northern Cape Ann region, Massachusetts
1755 11 01—Lisbon, Portugal—Magnitude 8.7
1755 11 18—Cape Ann, Massachusetts
1780 02 06—Northwest Florida
1783 11 30—New Jersey—Magnitude 5.3
1791 05 16—Moodus, Connecticut
1811 12 16—New Madrid Region—Magnitude 8.1
1812 01 23—New Madrid Region—Magnitude 7.8
1812 02 07—New Madrid Region—Magnitude 8.0
1812 12 08—Southwest of San Bernadino County, California—Magnitude 6.9
1812 12 21—West of Ventura, California—Magnitude 7.1
1823 06 02—South flank of Kilauea, Hawaii—Magnitude 7.0
1838 06—San Francisco Area, California—Magnitude 6.8
1843 01 05—Northeast Arkansas—Magnitude 6.3
1857 01 09—Fort Tejon, California—Magnitude 7.9
1865 08 17—Memphis, Tennessee—Magnitude 5.0
1865 10 08—Santa Cruz Mountains, California—Magnitude 6.5
1867 04 24—Manhattan, Kansas—Magnitude 5.1
1867 11 18—Puerto Rico Region
1868 03 29—Ka'u District, Island of Hawaii—Magnitude 7.0

1868 04 03—Ka'u District, Island of Hawaii—Magnitude 7.9
1871 02 20—Lanai, Hawaii—Magnitude 6.8
1871 10 09—New Jersey—Delaware border
1871 10 09—New Jersey—Delaware border
1872 03 26—Owens Valley, California—Magnitude 7.4
1872 12 15—Lake Chelan, Washington—Magnitude 6.8
1873 11 23—California—Oregon Coast—Magnitude 7.3
1877 11 15—Eastern Nebraska—Magnitude 5.1
1879 01 13—St. Augustine, Florida
1882 11 08—Denver, Colorado—Magnitude 6.2
1884 08 10—New York City, New York—Magnitude 5.5
1884 09 19—Near Lima, Ohio—Magnitude 4.8
1886 09 01—Charleston, South Carolina—Magnitude 7.3
1887 05 03—Northern Sonora, Mexico
1892 02 24—Imperial Valley, California—Magnitude 7.8
1895 10 31—Charleston, Missouri—Magnitude 6.6
1896 06 15—Sanriku, Japan—Magnitude 8.5
1897 05 31—Giles County, Virginia—Magnitude 5.9
1897 06 12—Assam, India—Magnitude 8.3
1899 04 16—Eureka, California—Magnitude 7.0
1899 09 04—Cape Yakataga, Alaska—Magnitude 7.9
1899 09 10—Yakutat Bay, Alaska—Magnitude 8.0
1899 09 23—Copper River delta, Alaska—Magnitude 7.0
1900 10 09—Kodiak Island, Alaska—Magnitude 7.7
1901 05 17—Near Portsmouth, Ohio—Magnitude 4.2
1901 12 31—Cook Inlet, Alaska—Magnitude 7.1
1904 03 21—Southeast Maine—Magnitude 5.1
1904 08 27—Fairbanks, Alaska—Magnitude 7.3
1905 04 13—Iowa
1905 07 09—Mongolia—Magnitude 8.4
1906 01 31—Off the Coast of Ecuador—Magnitude 8.8
1906 04 18—San Francisco, California—Magnitude 7.8
1906 07 12—Socorro area, New Mexico—Intensity VII
1906 08 17—Valparaiso, Chile—Magnitude 8.2
1906 11 15—Socorro area, New Mexico—Intensity VII
1908 05 15—Gulf of Alaska—Magnitude 7.0
1909 05 16—North Dakota—Magnitude 5.5
1909 05 26—Aurora, Illinois—Magnitude 5.1
1909 09 27—Wabash River Valley, Indiana—Magnitude 5.1
1910 08 05—Oregon—Magnitude 6.8
1910 09 09—Rat Islands, Aleutian Islands, Alaska—Magnitude 7.0
1911 06 02—South Dakota—Magnitude 4.5
1912 07 07—Paxson, Alaska—Magnitude 7.2
1914 03 05—Georgia—Magnitude 4.5
1915 10 03—Pleasant Valley, Nevada—Magnitude 7.1
1916 02 21—Waynesville, North Carolina—Magnitude 5.2
1916 10 18—Irondale, Alabama—Magnitude 5.1
1918 10 11—Mona Passage—Magnitude 7.5
1918 12 06—Vancouver Island, British Columbia, Canada—Magnitude 7.0
1922 01 31—Eureka, California—Magnitude 7.3

1922 11 11—Chile–Argentina Border—Magnitude 8.0
1923 01 22—Humbolt County, California—Magnitude 7.2
1923 02 03—Kamchatka—Magnitude 8.5
1925 03 01—Charlevoix, Quebec, Canada—Magnitude 6.3
1925 06 28—Clarkston Valley, Montana—Magnitude 6.6
1925 06 29—Santa Barbara, California—Magnitude 6.8
1927 10 24—Southeast Alaska—Magnitude 7.1
1927 11 04—Lompoc, California—Magnitude 7.1
1928 11 03—Eastern Tennessee—Magnitude 4.5
1929 03 07—Fox Islands, Aleutian Islands, Alaska—Magnitude 7.8
1929 05 26—South of Queen Charlotte Islands, Magnitude 7.0
1929 10 06—Holualoa, Hawaii—Magnitude 6.5
1929 11 18—Grand Banks, Nova Scotia, Canada—Magnitude 7.3
1930 10 19—Napoleonville, Louisiana—Magnitude 4.2
1931 08 16—Valentine, Texas—Magnitude 5.8
1931 12 17—Charleston, Mississippi—Magnitude 4.6
1932 12 21—Cedar Mountain, Nevada—Magnitude 7.2
1933 03 02—Sanriku, Japan—Magnitude 8.4
1933 03 11—Long Beach, California—Magnitude 6.4
1933 11 20—Baffin Bay, Canada—Magnitude 7.4
1934 01 15—Bihar, India—Magnitude 8.1
1934 01 30—Excelsior Mountains, Nevada—Magnitude 6.5
1934 03 12—Kosmo, Utah—Magnitude 6.5
1934 05 04—Chugach Mountains, Alaska—Magnitude 7.1
1935 10 12—Helena, Montana—Magnitude 5.9
1935 10 19—Helena, Montana—Magnitude 6.25
1935 11 01—Timiskaming, Quebec, Canada—Magnitude 6.2
1937 03 09—Western Ohio—Magnitude 5.4
1937 07 22—Central Alaska—Magnitude 7.3
1938 01 23—Maui, Hawaii—Magnitude 6.8
1938 02 01—Banda Sea, Indonesia—Magnitude 8.5
1938 11 10—Shumagin Islands, Alaska—Magnitude 8.2
1940 05 19—Imperial Valley, California—Magnitude 7.1
1940 12 20—Ossipee Lake, New Hampshire—Magnitude 5.5
1940 12 24—Ossipee Lake, New Hampshire—Magnitude 5.5
1943 11 03—Skwenta, Alaska—Magnitude 7.4
1944 01 15—San Juan, Argentina—Magnitude 7.8
1944 07 12—Sheep Mountain, Idaho—Magnitude 6.1
1944 09 05—Between Massena, New York and Cornwall, Magnitude 5.8
1944 12 07—Tonankai, Japan—Magnitude 8.1
1946 04 01—Unimak Island, Alaska—Magnitude 8.1
1946 06 23—Vancouver Island, British Columbia, Canada—Magnitude 7.3
1946 08 04—Dominican Republic—Magnitude 8.0
1946 12 20—Nankaido, Japan—Magnitude 8.1
1947 05 06—Wisconsin
1947 08 10—Southern Michigan—Magnitude 4.6
1947 10 16—Wood River, Alaska—Magnitude 7.2
1947 11 23—Southwest Montana—Magnitude 6.25
1949 04 13—Puget Sound, Washington—Magnitude 7.1
1949 08 22—Queen Charlotte Islands—Magnitude 8.1

1950 08 15—Assam, Tibet—Magnitude 8.6
1951 08 21—Kona, Hawaii—Magnitude 6.9
1952 04 09—El Reno, Oklahoma—Magnitude 5.5
1952 07 21—Kern County, California—Magnitude 7.3
1952 11 04—Kamchatka—Magnitude 9.0
1953 01 05—Near Islands, Alaska—Magnitude 7.1
1954 03 29—Spain—Magnitude 7.9
1954 07 06—Fallon–Stillwater area, Nevada—Magnitude 6.8
1954 12 16—Dixie Valley, Nevada—Magnitude 7.1
1957 03 09—Andreanof Islands, Alaska—Magnitude 8.6
1957 03 09—Fox Islands, Alaska—Magnitude 7.1
1957 03 12—Andreanof Islands, Alaska—Magnitude 7.0
1957 03 14—Andreanof Islands, Alaska—Magnitude 7.1
1957 03 16—Andreanof Islands, Alaska—Magnitude 7.0
1957 12 04—Gobi–Altai, Mongolia—Magnitude 8.1
1958 04 07—Huslia, Alaska—Magnitude 7.3
1958 07 10—Lituya Bay, Alaska—Magnitude 7.7
1958 11 06—Kuril Islands—Magnitude 8.3
1959 07 21—Arizona—Utah Border—Magnitude 5.6
1959 08 18—Hebgen Lake, Montana—Magnitude 7.3
1959 08 18—Wyoming—Magnitude 6.5
1960 02 29—Agadir, Morocco—Magnitude 5.7
1960 05 22—Chile—Magnitude 9.5
1962 04 10—Vermont—Magnitude 4.2
1963 10 13—Kuril Islands—Magnitude 8.5
1964 03 28—Prince William Sound, Alaska—Magnitude 9.2
1964 03 28—Merriman, Nebraska—Magnitude 5.1
1965 02 04—Rat Islands, Alaska—Magnitude 8.7
1965 03 30—Rat Islands, Alaska—Magnitude 7.61
1965 04 29—Puget Sound, Washington—Magnitude 6.5
1966 01 23—Dulce, New Mexico—Magnitude 5.1
1966 08 07—Rat Islands, Alaska—Magnitude 7.0
1966 10 17—Near the Coast of Peru—Magnitude 8.1
1967 08 09—Denver, Colorado—Magnitude 5.3
1968 11 09—Southern Illinois—Magnitude 5.3
1969 10 02—Santa Rosa, California—Magnitude 5.6
1969 11 20—Southern West Virginia—Magnitude 4.5
1970 05 31—Peru—Magnitude 7.9
1970 06 24—South of Queen Charlotte Islands, Magnitude 7.0
1970 07 31—Colombia—Magnitude 8.0
1971 02 09—San Fernando, California—Magnitude 6.5
1971 05 12—Western Turkey—Magnitude 6.3
1971 05 22—Eastern Turkey—Magnitude 6.9
1972 07 30—Sitka, Alaska—Magnitude 7.6
1972 12 23—Nicaragua—Magnitude 6.2
1974 12 28—Northern Pakistan—Magnitude 6.2
1975 02 02—Near Islands, Alaska—Magnitude 7.6
1975 03 28—Eastern Idaho—Magnitude 6.1
1975 06 30—Yellowstone National Park, Wyoming—Magnitude 6.1
1975 07 09—Western Minnesota—Magnitude 5.0

1975 11 29—Kalapana, Hawaii—Magnitude 7.2
1976 02 04—Guatemala—Magnitude 7.5
1976 03 11—Newport, Rhode Island—Magnitude 3.5
1976 07 27—Tangshan, China—Magnitude 7.5
1977 11 23—San Juan, Argentina—Magnitude 7.4
1979 02 28—Mt. St. Elias, Alaska—Magnitude 7.6
1979 05 20—Alaska Peninsula—Magnitude 7.0
1979 10 15—Imperial Valley, Mexico—California Border—Magnitude 6.4
1979 12 26—Carlisle, Northern England—Magnitude 4.5
1980 01 24—Livermore Valley, California—Magnitude 5.8
1980 01 27—Livermore, California—Magnitude 5.4
1980 05 18—Mount St. Helens, Washington—Magnitude 5.2
1980 07 27—Northeast Kentucky—Magnitude 5.1
1980 11 08—Humboldt County, California—Magnitude 7.2
1983 05 02—Coalinga, California—Magnitude 6.5
1983 10 07—Blue Mountain Lake, New York—Magnitude 5.1
1983 10 28—Borah Peak, Idaho—Magnitude 6.9
1983 11 16—Kaoiki, Hawaii—Magnitude 6.7
1985 01 26—Mendoza, Argentina—Magnitude 6.0
1985 09 19—Michoacan, Mexico—Magnitude 8.0
1985 12 23—Nahanni region, Northwest Territories, Canada—Magnitude 6.8
1986 01 31—Northeast Ohio—Magnitude 5.0
1986 05 07—Andreanof Islands, Alaska—Magnitude 7.9
1986 07 08—North Palm Springs, California—Magnitude 6.1
1987 06 10—Near Olney, Illinois—Magnitude 5.1
1987 10 01—Whittier Narrows, California—Magnitude 5.9
1987 11 30—Gulf of Alaska—Magnitude 7.8
1988 03 06—Gulf of Alaska—Magnitude 7.7
1988 11 25—Saguenay, Quebec, Canada—Magnitude 5.9
1989 10 18—Loma Prieta, California—Magnitude 6.9
1990 01 13—Maryland—Magnitude 2.5
1992 04 25—Cape Mendocino, California—Magnitude 7.2
1992 06 28—Landers, California—Magnitude 7.3
1993 08 08—South of the Mariana Islands—Magnitude 7.8
1993 09 21—Oregon—Magnitude 6.0
1994 01 17—Northridge, California—Magnitude 6.7
1994 06 09—Bolivia—Magnitude 8.2
1995 01 16—Kobe, Japan—Magnitude 6.9
1996 06 10—Andreanof Islands, Alaska—Magnitude 7.9
1997 05 10—Northern Iran—Magnitude 7.3
1997 10 14—South of Fiji Islands—Magnitude 7.8
1997 12 05—Near East Coast of Kamchatka—Magnitude 7.8
1998 01 04—Loyalty Islands Region—Magnitude 7.5
1998 01 30—Near Coast of Northern Chile—Magnitude 7.1
1998 02 04—Afghanistan-Tajikistan Border Region—Magnitude 5.9
1998 03 14—Northern Iran—Magnitude 6.6
1998 04 25—Balleny Islands Region—Magnitude 8.1
1998 05 03—Southeast of Taiwan—Magnitude 7.5
1998 05 30—Afghanistan-Tajikistan Border Region—Magnitude 6.6
1998 07 17—Near North Coast of New Guinea, P.N.G.—Magnitude 7.0

1998 08 04—Near Coast of Ecuador—Magnitude 7.2
1998 09 25—Pennsylvania—Magnitude 5.2
1999 01 25—Colombia—Magnitude 6.1
1999 02 06—Santa Cruz Islands—Magnitude 7.3
1999 05 10—New Britain Region, P.N.G.—Magnitude 7.1
1999 05 16—New Britain Region, P.N.G.—Magnitude 7.1
1999 06 15—Central Mexico—Magnitude 7.0
1999 07 11—Honduras—Magnitude 6.7
1999 08 17—Izmit, Turkey—Magnitude 7.6
1999 08 20—Costa Rica—Magnitude 6.9
1999 09 07—Greece—Magnitude 6.0
1999 09 20—Taiwan—Magnitude 7.6
1999 09 30—Oaxaca, Mexico—Magnitude 7.5
1999 10 16—Hector Mine, California—Magnitude 7.1
1999 11 12—Turkey—Magnitude 7.2
2000 06 04—Southern Sumatera, Indonesia—Magnitude 7.9
2000 06 18—South Indian Ocean—Magnitude 7.9
2000 10 06—Western Honshu, Japan—Magnitude 6.7
2000 11 16—New Ireland Region, P.N.G.—Magnitude 8.0
2000 11 16—New Ireland Region, P.N.G.—Magnitude 7.6
2000 11 17—New Britain Region, P.N.G.—Magnitude 7.6
2001 01 01—Mindanao, Philippines—Magnitude 7.5
2001 01 13—El Salvador—Magnitude 7.7
2001 01 26—India—Magnitude 7.6
2001 01 26—Gujarat, India—Magnitude 7.7
2001 02 13—El Salvador—Magnitude 6.6
2001 02 28—Washington—Magnitude 6.8
2001 06 23—Near Coast of Peru—Magnitude 8.4
2001 07 07—Near Coast of Peru—Magnitude 7.6
2002 01 02—Vanuatu Islands—Magnitude 7.3
2002 02 03—Turkey—Magnitude 6.5
2002 02 06—Near Knik, Alaska—Magnitude 4.9
2002 02 22—Near Mexicali, Mexico—Magnitude 5.7
2002 03 03—Hindu Kush Region, Afghanistan—Magnitude 7.4
2002 03 05—Mindanao, Philippines—Magnitude 7.5
2002 03 16—Near Channel Islands Beach, California—Magnitude 4.6
2002 03 25—Hindu Kush Region, Afghanistan—Magnitude 6.1
2002 03 31—Northern Taiwan—Magnitude 7.1
2002 04 20—Plattsburgh, New York—Magnitude 5.1
2002 04 26—Mariana Islands—Magnitude 7.1
2002 05 13—Gilroy, California—Magnitude 4.9
2002 05 15—Taiwan—Magnitude 6.2
2002 05 24—Plattsburgh Aftershock—Magnitude 3.3
2002 06 16—Kitsap Peninsula, Washington—Magnitude 3.7
2002 06 17—Bayview, California—Magnitude 5.3
2002 06 18—Chile-Argentina Border Region—Magnitude 6.5
2002 06 18—Darmstadt, Indiana—Magnitude 5.0
2002 06 22—Western Iran—Magnitude 6.5
2002 06 28—Priamurye-Northeastern China border region—Magnitude 7.2
2002 06 29—Near Mt. Hood Volcano, Oregon—Magnitude 4.5

2002 08 19—Fiji Islands—Magnitude 7.5
2002 08 19—Fiji Islands—Magnitude 7.7
2002 09 03—Yorba Linda, California—Magnitude 4.6
2002 09 05—Southern Italy—Magnitude 5.9
2002 09 08—New Guinea, Papua New Guinea—Magnitude 7.6
2002 09 20—Friday Harbor, Washington—Magnitude 4.1
2002 09 22—United Kingdom—Magnitude 4.8
2002 10 10—Irian Jaya, Indonesia—Magnitude 7.6
2002 10 12—Peru–Brazil Border Region—Magnitude 6.8
2002 10 21—Alpine Northeast, Wyoming—Magnitude 4.3
2002 10 23—Denali, Alaska—Magnitude 6.7
2002 10 23—Lake Tanganyika Region—Magnitude 6.2
2002 10 31—Adriatic Sea—Magnitude 5.9
2002 11 01—Adriatic Sea—Magnitude 5.8
2002 11 02—Northern Sumatera, Indonesia—Magnitude 7.5
2002 11 03—Denali Fault, Alaska—Magnitude 7.9
2002 11 11—Seabrook Island, South Carolina—Magnitude 4.2
2002 11 16—Kuril Islands, Russia—Magnitude 7.5
2002 11 20—Northwestern Kashmir—Magnitude 6.4
2002 11 24—Swarm near San Ramon, California—Magnitude 3.9
2002 12 10—Mexicali, Baja California, Mexico—Magnitude 4.8
2002 12 24—Pacifica, California—Magnitude 3.6
2002 12 25—Kyrgyzstan–Xinjiang border region—Magnitude 5.5
2002 12 25—Redford, New York—Magnitude 3.0
2003 01 10—New Ireland, Papua New Guinea, Region—Magnitude 6.7
2003 01 16—Blanco Fracture Zone—Offshore Oregon—Magnitude 6.2
2003 01 20—Solomon Islands—Magnitude 7.3
2003 01 22—Tecoman, Colima, Mexico—Magnitude 7.8
2003 01 25—Keene, California—Magnitude 4.2
2003 01 27—Turkey—Magnitude 6.1
2003 02 02—Dublin, CA, Swarm—Magnitude 4.2
2003 02 19—Unimak Island Region, Alaska—Magnitude 6.6
2003 02 22—Big Bear City, California—Magnitude 5.4
2003 02 24—Southern Xinjiang, China—Magnitude 6.4
2003 03 11—Twentynine Palms Base, California—Magnitude 4.6
2003 03 11—New Ireland Region, Papua New Guinea—Magnitude 6.8
2003 03 17—Rat Islands, Aleutian Islands, Alaska—Magnitude 7.0
2003 04 29—Blytheville, Arkansas—Magnitude 4.0
2003 04 29—Alabama—Magnitude 4.6
2003 05 01—Eastern Turkey—Magnitude 6.4
2003 05 04—Kermadec Islands, New Zealand—Magnitude 6.7
2003 05 05—Virginia—Magnitude 3.9
2003 05 21—Northern Algeria—Magnitude 6.8
2003 05 23—Brawley, California—Magnitude 4.0
2003 05 25—Santa Rosa, California—Magnitude 4.3
2003 05 25—South Dakota—Magnitude 4.0
2003 05 26—Seven Trees, California—Magnitude 3.8
2003 05 26—Muir Beach, California—Magnitude 3.4
2003 05 26—Near the East Coast of Honshu, Japan—Magnitude 7.0
2003 05 26—Halmahera, Indonesia—Magnitude 7.0

2003 05 27—Northern Algeria—Magnitude 5.8
2003 05 29—Port Orchard, Washington—Magnitude 3.7
2003 06 06—Western Kentucky—Magnitude 4.0
2003 06 07—New Britain Region, Papua New Guinea—Magnitude 6.6
2003 06 19—Carnation, Washington—Magnitude 3.5
2003 06 19—Carnation, Washington—Magnitude 3.6
2003 06 20—Amazonas, Brazil—Magnitude 7.1
2003 06 20—Near the Coast of Central Chile—Magnitude 6.8
2003 06 23—Rat Islands, Aleutian Islands—Magnitude 6.9
2003 07 15—Carlsberg Ridge—Magnitude 7.6
2003 07 21—Yunnan, China—Magnitude 6.0
2003 07 22—Gulf of Maine—Magnitude 3.6
2003 07 27—Primor'ye, Russia—Magnitude 6.8
2003 08 04—Scotia Sea—Magnitude 7.5
2003 08 14—Greece—Magnitude 6.3
2003 08 15—Humboldt Hill, California—Magnitude 5.1
2003 08 21—Southeastern Iran—Magnitude 5.9
2003 08 21—Wyoming—Magnitude 4.6
2003 08 21—South Island of New Zealand—Magnitude 7.2
2003 08 26—Val Verde, California—Magnitude 3.8
2003 08 26—New Jersey—Magnitude 3.8
2003 08 27—Volcano, Hawaii—Magnitude 4.7
2003 09 04—Near Piedmont, California—Magnitude 3.9
2003 09 11—Near Mexicali, Baja, CA, Mexico—Magnitude 3.7
2003 09 12—Near Simi Valley, California—Magnitude 3.4
2003 09 21—Myanmar—Magnitude 6.6
2003 09 22—Dominican Republic Region—Magnitude 6.5
2003 09 22—Rathdrum, Idaho—Magnitude 3.3
2003 09 25—Hokkaido, Japan Region—Magnitude 8.3
2003 09 27—Russia–Kazakhstan–Xinjiang Border Region—Magnitude 7.3
2003 10 01—Southwestern Siberia, Russia—Magnitude 6.7
2003 10 07—Near Imperial Beach, California—Magnitude 3.6
2003 10 08—Hokkaido, Japan Region—Magnitude 6.6
2003 10 19—Near Orinda, California—Magnitude 3.5
2003 10 31—Off the East Coast of Honshu, Japan—Magnitude 7.0
2003 11 06—Vanuatu Islands—Magnitude 6.6
2003 11 17—Rat Islands, Aleutian Islands, Alaska—Magnitude 7.8
2003 11 18—Samar, Philippines—Magnitude 6.5
2003 12 05—Komandorskiye Ostrova, Russia Region—Magnitude 6.7
2003 12 09—Virginia—Magnitude 4.5
2003 12 10—Taiwan—Magnitude 6.8
2003 12 22—San Simeon, California—Magnitude 6.5
2003 12 26—Southeastern Iran—Magnitude 6.6
2003 12 27—Southeast of the Loyalty Islands—Magnitude 7.3
2004 01 07—Wyoming—Magnitude 5.0
2004 01 28—Seram, Indonesia—Magnitude 6.7
2004 02 05—Irian Jaya, Indonesia—Magnitude 7.0
2004 02 07—Irian Jaya, Indonesia—Magnitude 7.3
2004 02 11—Dead Sea Region—Magnitude 5.1
2004 02 24—Near North Coast of Morocco—Magnitude 6.4

2004 04 05—Hindu Kush Region, Afghanistan—Magnitude 6.6
2004 04 07—Wyoming—Magnitude 4.0
2004 05 03—Bio-Bio, Chile—Magnitude 6.6
2004 05 28—Northern Iran—Magnitude 6.3
2004 05 29—Off the East Coast of Honshu, Japan—Magnitude 6.5
2004 05 30—Pine Mountain Club, California—Magnitude 3.0
2004 06 10—Kamchatka Peninsula, Russia—Magnitude 6.9
2004 06 15—Offshore Baja California, Mexico—Magnitude 5.3
2004 06 28—Illinois—Magnitude 4.2
2004 06 28—Southeastern Alaska—Magnitude 6.8
2004 07 01—Eastern Turkey—Magnitude 5.2
2004 07 12—Offshore Oregon—Magnitude 4.9
2004 07 25—Southern Sumatra, Indonesia—Magnitude 7.3
2004 08 19—Alabama—Magnitude 3.5
2004 08 24—Greece—Magnitude 4.3
2004 08 29—Wyoming—Magnitude 3.8
2004 09 05—Near the South Coast of Western Honshu, Japan—Magnitude 7.2
2004 09 05—Near the South Coast of Honshu, Japan—Magnitude 7.4
2004 09 06—Near the South Coast of Honshu, Japan—Magnitude 6.7
2004 09 17—Eastern Kentucky—Magnitude 3.7
2004 09 28—Central California—Magnitude 6.0
2004 10 08—Solomon Islands—Magnitude 6.8
2004 10 08—Mindoro, Philippines—Magnitude 6.5
2004 10 09—Near the Coast of Nicaragua—Magnitude 6.9
2004 10 15—Taiwan Region—Magnitude 6.7
2004 10 23—Near the West Coast of Honshu, Japan—Magnitude 6.6
2004 10 27—Romania—Magnitude 5.9
2004 11 02—Vancouver Island, Canada Region—Magnitude 6.7
2004 11 08—Taiwan Region—Magnitude 6.3
2004 11 09—Solomon Islands—Magnitude 6.9
2004 11 11—Solomon Islands—Magnitude 6.7
2004 11 11—Kepulauan Alor, Indonesia—Magnitude 7.5
2004 11 15—Near the West Coast of Colombia—Magnitude 7.2
2004 11 20—Costa Rica—Magnitude 6.4
2004 11 21—Leeward Islands—Magnitude 6.3
2004 11 22—Off West Coast of South Island, N.Z.—Magnitude 7.1
2004 11 26—Papua, Indonesia—Magnitude 7.1
2004 11 28—Hokkaido, Japan Region—Magnitude 7.0
2004 12 06—Hokkaido, Japan Region—Magnitude 6.8
2004 12 14—Cayman Islands Region—Magnitude 6.8
2004 12 23—North of Macquarie Island—Magnitude 8.1
2004 12 26—Sumatra-Andaman Islands—Magnitude 9.1
2005 01 01—Off the West Coast of Northern Sumatra—Magnitude 6.6
2005 01 16—State of Yap, Fed. States of Micronesia—Magnitude 6.6
2005 02 05—Celebes Sea—Magnitude 7.1
2005 02 08—Vanuatu—Magnitude 6.8
2005 02 10—Arkansas—Magnitude 4.1
2005 02 19—Sulawesi, Indonesia—Magnitude 6.5
2005 02 22—Central Iran—Magnitude 6.4

2005 02 26—Simeulue, Indonesia—Magnitude 6.8
2005 03 02—Banda Sea—Magnitude 7.1
2005 03 06—St. Lawrence Valley Reg., Quebec, Canada—Magnitude 4.9
2005 03 20—Kyushu, Japan—Magnitude 6.6
2005 03 28—Northern Sumatra, Indonesia—Magnitude 8.6
2005 04 10—Kepulauan Mentawai Region, Indonesia—Magnitude 6.7
2005 04 11—Southeast of the Loyalty Islands—Magnitude 6.8
2005 05 01—Arkansas—Magnitude 4.1
2005 05 06—Central California—Magnitude 4.1
2005 05 14—Nias Region, Indonesia—Magnitude 6.8
2005 05 19—Nias Region, Indonesia—Magnitude 6.9
2005 06 12—Southern California—Magnitude 5.2
2005 06 13—Tarapaca, Chile—Magnitude 7.8
2005 06 14—Rat Islands, Aleutian Islands, Alaska—Magnitude 6.8
2005 06 15—Off the Coast of Northern California—Magnitude 7.2
2005 06 16—Greater Los Angeles Area, California—Magnitude 4.9
2005 06 17—Off the Coast of Northern California—Magnitude 6.7
2005 07 02—Near the Coast of Nicaragua—Magnitude 6.6
2005 07 05—Nias Region, Indonesia—Magnitude 6.7
2005 07 13—Tarapaca, Chile—Magnitude 7.8
2005 07 15—Hawaii Region, Hawaii—Magnitude 5.3
2005 07 17—Hawaii Region, Hawaii—Magnitude 5.2
2005 07 23—Near the South Coast of Honshu, Japan—Magnitude 6.0
2005 07 24—Nicobar Islands, India Region—Magnitude 7.3
2005 07 26—Western Montana—Magnitude 5.6
2005 08 10—New Mexico—Magnitude 5.0
2005 08 16—Near the East Coast of Honshu, Japan—Magnitude 7.2
2005 09 02—Brawley Seismic Zone Swarm, Southern California—Aug 31–Sep 2
2005 09 09—New Ireland Region, Papua New Guinea—Magnitude 7.7
2005 09 22—Central California—Magnitude 4.7
2005 09 26—Northern Peru—Magnitude 7.5
2005 09 29—New Britain Region, Papua New Guinea—Magnitude 6.7
2005 10 08—Pakistan—Magnitude 7.6
2005 10 19—Near the East Coast of Honshu, Japan—Magnitude 6.4
2005 10 31—Western Montana—Magnitude 4.6
2005 11 14—Off the East Coast of Honshu, Japan—Magnitude 7.0
2005 11 17—Potosi, Bolivia—Magnitude 6.9
2005 11 19—Simeulue, Indonesia—Magnitude 6.5
2005 11 27—Southern Iran—Magnitude 6.0
2005 12 02—Near the East Coast of Honshu, Japan—Magnitude 6.5
2005 12 05—Lake Tanganyika Region, Congo–Tanzania—Magnitude 6.8
2005 12 11—New Britain Region, Papua New Guinea—Magnitude 6.6
2005 12 12—Hindu Kush Region, Afghanistan—Magnitude 6.7
2005 12 19—New Mexico—Magnitude 4.2
2006 01 02—East of South Sandwich Islands—Magnitude 7.4
2006 01 02—Illinois—Magnitude 3.6
2006 01 04—Gulf of California—Magnitude 6.6
2006 01 08—Southern Greece—Magnitude 6.8
2006 01 27—Banda Sea—Magnitude 7.6
2006 02 10—Colorado—Magnitude 3.8

2006 02 22—Mozambique—Magnitude 7.0
2006 02 26—South of the Fiji Islands—Magnitude 6.4
2006 03 14—Seram, Indonesia—Magnitude 6.7
2006 03 22—Western Montana—Magnitude 4.2
2006 03 31—Western Iran—Magnitude 6.1
2006 04 20—Koryakia, Russia—Magnitude 7.6
2006 05 03—Tonga—Magnitude 7.9
2006 05 16—Kermadec Islands Region—Magnitude 7.4
2006 05 16—Nias Region, Indonesia—Magnitude 6.8
2006 05 26—Java, Indonesia—Magnitude 6.3
2006 06 11—Kyushu, Japan—Magnitude 6.3
2006 07 17—South of Java, Indonesia—Magnitude 7.7
2006 07 27—Southern Alaska—Manitude 4.8
2006 08 11—Michoacan, Mexico—Magnitude 5.9
2006 08 20—Scotia Sea—Magnitude 7.0
2006 09 01—Bougainville Region, Papua New Guinea—Magnitude 6.8
2006 09 10—Gulf of Mexico—Magnitude 5.8
2006 09 28—Samoa Islands Region—Magnitude 6.9
2006 10 02—Maine—Magnitude 3.8
2006 10 15—Hawaii Region, Hawaii—Magnitude 6.7
2006 10 17—New Britain Region, Papua New Guinea—Magnitude 6.7
2006 10 20—Near the Coast of Central Peru—Magnitude 6.7
2006 10 20—Northern California—Magnitude 4.5
2006 11 13—Santiago del Estero, Argentina—Magnitude 6.8
2006 11 15—Kuril Islands—Magnitude 8.3
2006 12 26—Taiwan Region—Magnitude 7.1
2006 12 26—Taiwan—Magnitude 6.9
2007 01 13—East of the Kuril Islands—Magnitude 8.1
2007 01 21—Molucca Sea—Magnitude 7.5
2007 01 30—West of Macquarie Island—Magnitude 6.8
2007 01 31—Kermadec Islands, New Zealand—Magnitude 6.5
2007 03 06—Southern Sumatra, Indonesia—Magnitude 6.4
2007 03 25—Vanuatu—Magnitude 7.1
2007 03 25—Near the West Coast of Honshu,Japan—Magnitude 6.7
2007 04 01—Solomon Islands—Magnitude 8.1
2007 05 08—Western Montana—Magnitude 4.5
2007 05 09—Offshore Northern California—Magnitude 5.2
2007 06 13—Offshore Guatemala—Magnitude 6.7
2007 06 28—Bougainville region, Papua New Guinea—Magnitude 6.7
2007 07 16—Near the west coast of Honshu, Japan—Magnitude 6.6
2007 07 16—Sea of Japan—Magnitude 6.8
2007 07 17—Tanzania—Magnitude 5.9
2007 08 01—Vanuatu—Magnitude 7.2
2007 08 02—Andreanof Islands, Aleutian Islands, Alaska—Magnitude 6.7
2007 08 08—Java, Indonesia—Magnitude 7.5
2007 08 14—Island of Hawaii, Hawaii—Magnitude 5.4
2007 08 15—Andreanof Islands, Aleutian Islands, Alaska—Magnitude 6.5
2007 08 15—Near the Coast of Central Peru—Magnitude 8.0
2007 08 16—Solomon Islands—Magnitude 6.7
2007 09 02—Santa Cruz Islands—Magnitude 6.9

Appendix 2: U.S. Natural Environments

LARGEST EARTHQUAKES BY STATE

For each of the fifty states, the following list gives the largest historical earthquake that had its epicenter in that state. The earthquakes are those with the highest magnitudes as measured by the Richter Scale or as inferred from the Modified Mercalli Scale intensities produced by the earthquakes. Where the largest earthquake occurs before the Richter Scale was in use, an estimated intensity value is given. For some states where there is uncertainty about the location of the epicenter two records are included. Data for this list is taken from USGS records.

State	Date	Magnitude	Intensity
Alabama	10-18-1916	5.1	VII
Alaska	03-28-1964	9.2	X
Arizona	07-21-1959	5.6	VI
Arkansas	12-16-1811	8.1	XI
California	01-09-1857	7.9	IX
California	04-18-1906	7.8	XI
Colorado	11-08-1882	6.2	VII
Connecticut	05-16-1791	—	VII
Delaware	10-09-1871	—	VII
Florida	01-13-1879	—	VI
Florida	02-06-1780	—	VI
Georgia	03-05-1914	4.5	V
Hawaii	04-03-1868	7.9	X

State	Date	Magnitude	Intensity
Idaho	10-28-1983	6.9	IX
Illinois	11-09-1968	5.3	VII
Indiana	09-27-1909	5.1	VII
Iowa	04-13-1905	—	V
Kansas	04-24-1867	5.1	VII
Kentucky	07-27-1980	5.1	VII
Louisiana	10-19-1930	4.2	VI
Maine	03-21-1904	5.1	VII
Maryland	01-13-1990	2.5	V
Massachusetts	11-18-1755	—	VIII
Michigan	08-10-1947	4.6	VI
Minnesota	07-09-1975	5.0	VI
Mississippi	12-17-1931	4.6	VI
Missouri	02-07-1812	8.0	XII
Montana	08-18-1959	7.3	X
Nebraska	11-15-1877	5.1	VII
Nevada	12-21-1932	7.2	X
New Hampshire	12-20-1940	5.5	VII
New Jersey	11-30-1783	5.3	VI
New Mexico	11-15-1906	—	VII
New York	09-05-1944	5.8	VIII
North Carolina	02-21-1916	5.2	VII
North Dakota	05-16-1909	5.5	VI
Ohio	03-09-1937	5.4	VIII
Oklahoma	04-09-1952	5.5	VII
Oregon	08-05-1910	6.8	felt
Oregon	09-21-1993	6.0	VII
Pennsylvania	09-25-1998	5.2	VI
Rhode Island	03-11-1976	3.5	VI
South Carolina	09-01-1886	7.3	X
South Dakota	06-02-1911	4.5	V
Tennessee	08-17-1865	5.0	VII
Texas	08-16-1931	5.8	VIII
Utah	03-12-1934	6.5	VIII
Vermont	04-10-1962	4.2	V
Virginia	05-31-1897	5.9	VIII
Washington	12-15-1872	6.8	IX
West Virginia	11-20-1969	4.5	VI
Wisconsin	05-06-1947	—	V
Wyoming	08-18-1959	6.5	felt

EARTHQUAKES WITH MAGNITUDES 7.8 OR GREATER WITHIN THE UNITED STATES

Alaska	1964	9.2	Alaska	1996	7.9
Alaska	1965	8.7	Alaska	1987	7.9
Alaska	1957	8.6	Alaska	1899	7.9
Alaska	1938	8.2	Hawaii	1868	7.9
Alaska	1986	8.0	California	1857	7.9
Missouri	1811	8.1	Alaska	2003	7.8
Alaska	1899	8.0	Alaska	1988	7.8
Missouri	1812	8.0	California	1906	7.8
Alaska	2002	7.9	California	1892	7.8

TWENTY-FIVE OF THE COSTLIEST HURRICANES TO STRIKE THE CONTIGUOUS UNITED STATES

Rank	Name and Year	Hurricane Category
1.	Andrew, FL, LA, 1992	5
2.	Hugo, SC, 1989	4
3.	Floyd, Northeast U.S., 1999	2
4.	Fran, NC, 1996	3
5.	Opal, FL, AL, 1995	3
6.	Georges, FL, MS, AL, 1998	2
7.	Frederic, AL, MS, 1979	3
8.	Agnes, FL, Northeast U.S., 1972	1
9.	Alicia, TX, 1983	3
10.	Bob, NC, Northeast U.S., 1991	2
11.	Juan, LA, 1985	1
12.	Camille, MS, LA, VA, 1969	5
13.	Betsy, FL, LA, 1965	3
14.	Elena, MS, AL, FL, 1985	3
15.	Gloria, Eastern U.S., 1985	3
16.	Diane, Northeast U.S., 1955	1
17.	Bonnie, NC, VA, 1998	2
18.	Erin, FL, 1995	2
19.	Eloise, FL, 1975 3	
20.	Carol, Northeast U.S., 1954	3
21.	Celia, Northeast U.S., 1954	3
22.	Carla, TX, 1961	4
23.	Donna, FL, 1960	4
24.	David, FL, 1979	2
25.	Unnamed, Northeast U.S., 1938	3

TWENTY-FIVE OF THE DEADLIEST TORNADOES IN THE CONTIGUOUS UNITED STATES

Rank	Name and Year	Deaths
1.	Tri-State, MO, IL, IN, 1925	689
2.	Natchez, MS, 1840	317
3.	St. Louis, MO, 1896	255
4.	Tupelo, MS, 1936	216
5.	Gainesville, GA, 1936	203
6.	Woodward, OK, 1947	181
7.	Amite, LA, MS, 1908	143
8.	New Richmond, WI, 1899	117
9.	Flint, MI, 1953	115
10.	Waco, TX, 1953	114
11.	Goliad, TX, 1902	114
12.	Omaha, NE, 1913	103
13.	Mattoon, IL, 1917	101
14.	Shinnston, WV, 1944	100
15.	Marshfield, MO, 1880	99
16.	Gainesville, GA, 1903	98
17.	Poplar Bluff, MO, 1927	98
18.	Snyder, OK, 1905	97
19.	Natchez, MS, 1908	91
20.	Worcester, MA, 1953	90
21.	Starkville, MS, TX, AL, 1920	88
22.	Lorain, OH, 1924	85
23.	Udall, KS, 1955	80
24.	St. Louis, MO, 1927	79
25.	Louisville, KY, 1890	76

Appendix 3: World's Deadliest Disasters

EARTHQUAKES AND TSUNAMIS

Event and Year	Deaths
Shaanxi, China, 1556	830,000
Indonesian earthquake and tsunami, 2004	286,000
Tangshan, China, 1976	242,000
Aleppo, Syria, 1138	230,000
Gansu, China, 1920	200,000
Xining, China, 1927	200,000
Damghan, Iran, 856	200,000
Ardabil, Iran, 893	150,000
Great Kanto, Japan, 1923	140,000
Ashgabat, Turkmenistan, 1948	110,000
Messina earthquake and tsunami, 1908	100,000
Lisbon earthquake and tsunami, 1755	100,000
Chihli, China, 1290	100,000
Kashmir, Pakistan, 2005	90,000
Shemakha, Caucasus, 1667	80,000
Tabriz, Iran, 1727	77,000
Gansu, China, 1932	70,000
Ancash, Peru, 1970	66,000
Sicily, Italy, 1693	60,000
Quetta, Pakistan, 1935	60,000
Calabria, Italy, 1783	50,000
Iran, 1990	50,000
Bam, Iran, 2003	36,000
Erzincan, Turkey, 1939	33,000
Spitak, Armenia, 1988	25,000
Guatemala, 1976	23,000
Gujarat, India, 2001	20,000
Valparaiso, Chile, 1960	20,000
Izmit, Turkey, 1999	18,000
Tonghai, China, 1970	16,000
Naples, Italy, 1857	11,000
Bihar, India, 1934	11,000
Agadir, Morocco, 1960	10,000
Michoacan, Mexico, 1985	10,000
Kobe, Japan, 1995	6,500
Chi-Chi, Taiwan, 1999	2,500
Skopje, Yugoslavia, 1963	1,000
San Francisco, 1906	700
Zarand, Iran, 2005	600
Napier, New Zealand, 1931	300
Alaska, 1964	130
Long Beach, CA, 1933	120
Loma Prieta, CA, 1989	70
Northridge, CA, 1994	60

VOLCANIC ERUPTIONS

Event and Date	Deaths	Event and Date	Deaths
Tambora, Indonesia, 1815	92,000	Vesuvius, Italy, 79	4,000
Pelee, Martinique, 1902	40,000	El Chichon, Mexico, 1982	3,500
Krakatoa, Indonesia, 1883	36,000	Soufriere, St. Vincent, 1902	2,000
Nevado del Ruiz, Colombia, 1885	23,000	Cotopaxi, Ecuador, 1887	1,000
		Pinatubo, Philippines, 1991	700
Vesuvius, Italy, 1631	18,000	Nyiragongo, Congo, 2002	250
Unzen, Japan, 1792	15,000	Mount St. Helens, Washington, 1980	60
Kelut, Indonesia, 1586	10,000		
Laki, Iceland, 1783	9,000		

NON-U.S. TORNADOES

Event and Date	Deaths	Event and Date	Deaths
Manikganj, Bangladesh, 1989	1,300	Assam, India, 1963	140
Jessore, Bangladesh, 1964	500	Dhaka, Bangladesh, 1888	120
West Bengal, India, 1998	160	Buenos Aires, Argentina, 1973	50
Orissa, India, 1978	150		

NON-U.S. TROPICAL CYCLONES

Event and Date	Deaths	Event and Date	Deaths
Bhola, Bangladesh, 1970	500,000	Vera, Japan, 1958	5,000
India, 1839	300,000	Dominican Republic, 1899	3,500
Nina, China, 1975	230,000	Cuba, 1932	3,000
Chittagong, Bangladesh, 1991	140,000	Haiti, 2004	3,000
		Cuba, 1791	3,000
China, 1922	60,000	Calcutta, India, 1737	3,000
Calcutta, India, 1864	60,000	India, 1996	2,500
China, 1912	50,000	China, 1959	2,300
India, 1942	40,000	Mexico, 2005	1,500
Bangladesh, 1965	30,000	China, 1960	1,500
Barbados, 1780	22,000	Windward Islands, 1831	1,500
Pakistan, 1963	22,000	Philippines, 1984	1,300
India, 1977	20,000	Jamaica, 1780	1,100
Bangladesh, 1965	17,000	India, 1998	1,000
Karachi, Pakistan, 1965	10,000	Cuba, 1926	700
Orissa, India, 1999	10,000	Cuba, 1952	600
Hong Kong, 1906	10,000	Mahina, Australia, 1899	400
India, 1999	10,000	Hattie, Belize, 1961	400
Dominican Republic, 1930	8,000	Windward Islands, 1898	400
Honduras, 1974	8,000	Mexico, 1955	200
Cuba, 1963	7,000	Tracy, Australia, 1974	65
Thelma, Philippines, 1991	6,000	Leeward Islands, 1996	40

FLOODS AND LANDSLIDES

Event and Date	Deaths
Huang He flood, China, 1931	2,000,000
Huang He flood, China, 1887	1,000,000
Yangtze flood, China, 1935	145,000
North Vietnam flood, 1971	100,000
Yangtze flood, China, 1911	100,000
Yangtze flood, China, 1954	30,000
Storm tide, Netherlands, 1362	25,000
Iran flood, 1954	10,000
Johnstown flood, PA, 1889	2,200
Storm tide, Netherlands, 1953	2,100
Gujarat dam burst, India, 1979	2,000
Vaiont dam burst, Italy, 1963	2,000
Leyte, Philippines, mudslide, 2006	1,800
Mumbai flood, India, 2005	1,000
St. Francis dam burst, CA, 1928	400
North Sea flood, Germany, 1962	300
Sheffield dam burst, England, 1864	300
New Orleans dike failure, LA, 2005	70
Brisbane flood, Australia, 1974	20

Appendix 4: Measuring Natural Disasters

FUJITA SCALE FOR TORNADOES

Created by Japanese-American meteorologist Tetsuya Fujita in 1951 to classify tornadoes according to the damage they cause.

F0 40–72 mph	Light
F1 73–112 mph	Moderate
F2 113–157 mph	Significant
F3 158–206 mph	Severe
F4 207–260 mph	Devastating
F5 261–318 mph	Incredible
F6 319 or + mph	Inconceivable

Half of all tornados worldwide are F1 or less. Only 1 percent of all tornados are F5 or more.

SAFFIR-SIMPSON SCALE FOR HURRICANES

Developed in the later 1960s by Herbert Saffir to quantify potential wind damage from hurricanes; expanded in the early 1970s by Robert Simpson, Director of the National Hurricane Center. Wind speed is the determining factor in the scale but storm surges caused by wind are highly dependent on the slope of the continental shelf and the shape of the coastline.

1 minimal	74–95 mph
2 moderate	96–110 mph
3 extensive	111–130 mph
4 extreme	131–155 mph
5 catastrophic	155 or + mph

RICHTER EARTHQUAKE SCALE

An earthquake magnitude scale, developed by Charles F. Richter, a geologist, in 1935. It is based on two things: the amount of ground motion and the distance from the epicenter. This scale is logarithmic; that is, each number is ten times greater than its predecessor. There are en levels of magnitude in the scale, from 0 to 9, and within each level there are tenths and hundreds to indicate variations within each level; for examples 6.5, 7.55.

MODIFIED MERCALLI INTENSITY SCALE

The Mercalli Scale originated with the Italian Geologist Giuseppe Mercalli in 1902. It was modified in later years to take account of changes in design and construction standards and is now the most widely used scale for measuring earthquake intensity, that is to say, the felt experience of an earthquake rather than its magnitude.

I	Not felt at all most times
II	Felt indoors by a few, especially on upper floors
III	Felt indoors by several, motion usually rapid vibration
IV	Felt indoors by many, outdoors by few
V	Felt indoors by practically all, outdoors by many
VI	Felt by all both indoors and outdoors
VII	Everyone frightened, all ran outdoors
VIII	General fright, alarmed to the point of panic
IX	General panic, cracked ground very evident
X	Ground generally cracked up to widths of several inches
XI	Numerous and widespread disturbances in ground
XII	Damage is total, all structures greatly damaged or destroyed

VOLCANIC EXPLOSIVITY INDEX (VEI)

To compare the magnitudes of volcanic eruptions, geologists have developed a volcanic explosivity index, VEI. It is similar to the Richter Scale in that each level is ten times the previous level. There are eight scales from 1 to 8 and the VEI of any eruption is based on the volume of rocks and ash that is emitted. A VEI of one could represent a Hawaiian eruption, a gentle oozing of lava with no violent activity while a VEI of 8, a very rare event, would apply to Toba, an Indonesian eruption of gigantic proportions that occurred 74,000 years ago. Krakatau of 1883 had a VEI of 6. Mount St. Helens of 1980 had a VEI of 5.

GEOLOGIC TIME SCALE

Era	Period	Epoch	Age (in millions of years)
		Holocene	0.01
		Pleistocene	2.5
		Pliocene	7
		Miocene	26
		Oligocene	38
		Eocene	54
Cenozoic		Paleocene	65
	Cretaceous		136
	Jurassic		190
Mesozoic	Triassic		225
	Permian		280
	Carboniferous		345
	Devonian		395
	Silurian		430
	Ordovician		500
Paleozoic	Cambrian		570
Precambrian			4030

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