Stratigraphy and structure of the Lower Cretaceous of Lampazos, Sonora, (northwest Mexico) and its relationship to the Gulf Coast succession

Rogelio Monreal and Jose F. Longoria

ABSTRACT

The stratigraphy and structure of the Lower Cretaceous (Aptian–Albian) rocks exposed in the area of Lampazos, Sonora, are redefined and correlated to well-known stratigraphic successions of Chihuahua and northeast Mexico (Coahuila and Nuevo Leon). Originally, seven stratigraphic units were proposed for the Cretaceous rocks exposed in the Lampazos area, but in this article only five units (El Aliso, Agua Salada, Lampazos, Espinazo del Diablo, and Los Picachos formations) have been used, and we propose herein to discontinue usage of the other two (Nogal and La Mesa formations). This Aptian–Albian succession of east-central Sonora yields facies and fossil content remarkably similar to coeval sequences in the Gulf of Mexico realm (Chihuahua, Coahuila, and Nuevo Leon). These sections contain abundant microfossils (benthic and planktonic foraminifera, colomiellids, nannoconids, and radiolarians) that permit detailed biostratigraphic determinations. A complete Aptian–lower Albian section (base of K-6 through top of K-15 of the biochronologic scheme of Longoria, 1984) was identified. Abrupt lithic changes through the Aptian–Albian section of Lampazos revealed three major paleoceanographic events having an overall regional marine transgression, including an early Aptian (K-6 to K-7) event, a late Aptian (K-10 to K-11) event, and an early Albian (K-13 to K-14) maximum flooding phase. We used physical and biochronologic data to tie the aforementioned events to geochemically constrained Aptian–Albian oceanic anoxic events (OAEs) in Santa Rosa Canyon of Nuevo Leon.

The close correlation between the oceanic events in east Sonora (northwest Mexico) and central Nuevo Leon (northeast Mexico) invokes the closer paleogeographic development of the two regions

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and undoubtedly links the area of Lampazos to a rapid encroachment of the paleo–Gulf of Mexico through north-central Mexico (the Mexican Sea) into northwestern Mexico (Chihuahua trough and Sonoran basin). The early Aptian (biozones K-6 to K-7) transgression has its maximum extension during the early Albian (biozones K-13 to K-14), culminating with the drowning of the carbonate platforms.

The Lower Cretaceous rocks exposed in the Lampazos area are complexly folded and faulted. The more conspicuous structures are isoclinal and box-shaped folds and thrust faults, mostly oriented north-south and northwest-southeast, having vergences to both the northeast and southwest. A very conspicuous feature is the opposite vergence of thrust faults, either converging or diverging. Two dextral strike-slip faults (northeast-southwest and east-west) separate the area into three large blocks that have different patterns of folds and thrust faults. Also, it is evident that the area was affected by at least two episodes of normal faulting. Furthermore, the structural style of deformation present in the Lampazos succession is remarkably similar to the style of deformation of coeval rocks in northeastern Mexico, especially to the structure of the Chihuahua tectonic belt. The Lampazos succession is paleogeographically and tectonically related to the Chihuahua tectonic belt, and it is considered to be the westernmost extension of the ancestral Gulf of Mexico.

The fact that the Lampazos succession can be lithocorrelated to known sequences in northeastern Chihuahua (Lucero, Ahumada, and Loma Plata formations) and northeast Mexico (Cupido, San Angel, La Peña, and Tamaulipas formations), which are know to be source rocks in exploration wells in Nuevo Leon and Coahuila, makes the Lampazos area of Sonora potentially attractive as an exploration target.

INTRODUCTION

Lower Cretaceous rocks exposed in Sonora are considered to have been deposited within the Bisbee basin, which represents the northwesternmost extension of the ancestral Gulf of Mexico into Texas, New Mexico, and Arizona in the United States (Hayes, 1970) and extends into eastern Sonora (Scott and González-León, 1991; Monreal et al., 1994a) and into north-central Sonora (González-León, 1994; Monreal, 1995). Most of the Lower Cretaceous rocks of Sonora have been assigned to the Bisbee Group of southern Arizona (Monreal et al., 1994b). In contrast, the Cretaceous succession exposed in the area of Lampazos in east-central Sonora (Figure 1) represents deeper water sedimentation related to the Chihuahua trough facies. Furthermore, the close paleogeographic affinity of the Lower Cretaceous facies of Lampazos to the Gulf of Mexico succession bears significance as a potential target for the future oil exploration of this region of western Mexico.

The Lampazos area is poorly known, as little regional stratigraphic work is available. Geophysical data for this area are not existent, and there are no exploration wells. Despite previous stratigraphic work in the area of Lampazos (Solano-Rico, 1970; Herrera and Bartolini, 1983; Bartolini and Herrera, 1986; González-León, 1988; Scott and González-León, 1991), the Aptian–Albian succession exposed in this area has remained uncleared. Our previous work proved that the Lower Cretaceous sequence of Lampazos bears significant information for understanding the paleogeographic and structural evolution of north Mexico during the Lower Cretaceous (Monreal, 1995; Monreal et al., 1994a). For example, the Mural Limestone of the Cretaceous Bisbee Group exposed in north and central Sonora represents the platform facies of southern Arizona (Monreal et al., 1994b; Monreal, 1995). In contrast, the Aptian–Albian rocks exposed in Lampazos and adjacent areas in east-central Sonora represent deeper basinal facies. In addition, the style of deformation of the Lampazos succession clearly refers it to the Chihuahua tectonic belt. Consequently, the Lower Cretaceous succession of eastern Sonora bears significant information on the petroleum potential of these rocks, because the same facies (the La Peña, Tamaulipas, San Angel, Cupido, and Aurora formations) have shown to be of economic significance in the states of Chihuahua, Coahuila, and Nuevo Leon.

The purpose of this article is to attempt to unravel the paleogeographic relationships between the Lower Cretaceous succession of the Lampazos area in east-central Sonora and coeval successions of the Gulf of Mexico region in northern Mexico (Chihuahua, Coahuila, Nuevo Leon) and to indicate the possible relation to better-known oil-bearing coeval units in northeast Mexico. To do this, we present an overview of the stratigraphy and structure of the Cretaceous of Lampazos and the Cretaceous of Chihuahua (Sierra Banco de Lucero). In addition, we present a comparison with coeval Aptian–Albian successions in Coahuila (Los Chorros Canyon) and Nuevo Leon (La Boca and Santa Rosa canyons).

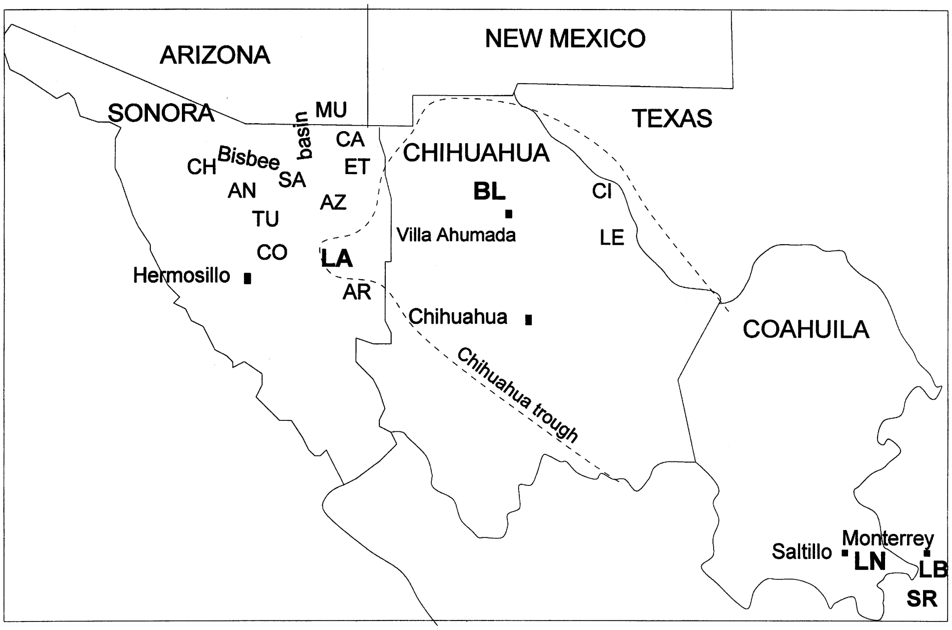

Figure 1. Location map showing the states of northwestern Mexico depicting the location of Lower Cretaceous outcrops: LA = Lampazos area; BL = Sierra Banco de Lucero; CI = Sierra Cieneguilla; LE = Sierra la Espernza; LN = Sierra La Nieve. Bisbee Group outcrops: AN = Santa Ana area; AR = Arivechi area; CA = Cabullona area; CH = El Sierra El Chanate; CO = Cerro de Oro area; ET = Sierra El Tigre; MU = Mule Mountains; SA = Sierra Azul; TU = Tuape area. Northeastern Mexico outcrops: LN = Los Chorros Canyon in Sierra la Nieve, Coahuila; LB = La Boca Canyon (La Silla Anticline), Nuevo Leon; SR = Santa Rosa Canyon, Nuevo Leon.

GEOLOGIC SETTING OF NORTHERN MEXICO

The Lampazos Area of Sonora

The Lower Cretaceous rocks exposed in the Lampazos area are strongly folded and faulted. The more conspicuous structures are isoclinal and box-shaped folds and thrust faults, mostly oriented north-south and northwest-southeast and having vergences to both the northeast and southwest (Figures 2, 3, 4). Although the rocks are metrically folded (Figure 5), the megastructures (kilometrical folds) are the most conspicuous ones (Figures 3, 6). Another important feature of the area is that many of the folds are twisted, that is, the vergences of folds change to opposite directions from one extreme of the fold to the other, as is the case for the structure on the northeastern slope of the Cerro El Encinal and on the southwestern slope of Sierra Espinazo del Diablo (Figures 2, 3). Another significant feature is the opposite vergence of thrust faults, as is the case for Las Minitas and Cañada El Sauz faults (Figures 3, 4).

Two major faults, the Las Rionillas fault, oriented about NE45°SW, and the Rosa María fault, oriented roughly east-west, cut and separate the area into three large blocks (I, II, and III) that have different patterns of folds and thrust faults (Figure 2). Block I, located northwest of Las Rionillas fault, is characterized by wrenched folds mostly oriented northwest-southeast. Block II, between the Las Rionillas and Rosa María faults, is characterized by bent fold traces and thrust faults that have opposite vergences. Block III is characterized by conspicuously bent fold traces and thrust faults that have opposite vergences.

In addition, the area was affected by at least two episodes of normal faulting, as evidenced by the different orientations of the normal faults. Also, it seems that during the extension episode, some of the thrust faults were reactivated as normal faults; for example, the El Palmarito fault set, located west of Sierra Las Azules, and possibly the two mayor faults, possibly strike-slip, that separate the area into three blocks, were at least partially reactivated as normal faults (Figure 2, 3).

The Chihuahua Tectonic Belt

The Chihuahua tectonic belt is characterized by a series of north to northwest–oriented ranges, most of which are antiformal structures. Mountain ranges are in most cases continuous for lengths that range from 10 to 70 km. The ranges display an en echelon pattern, and their traces vary from straight to sinuous (or

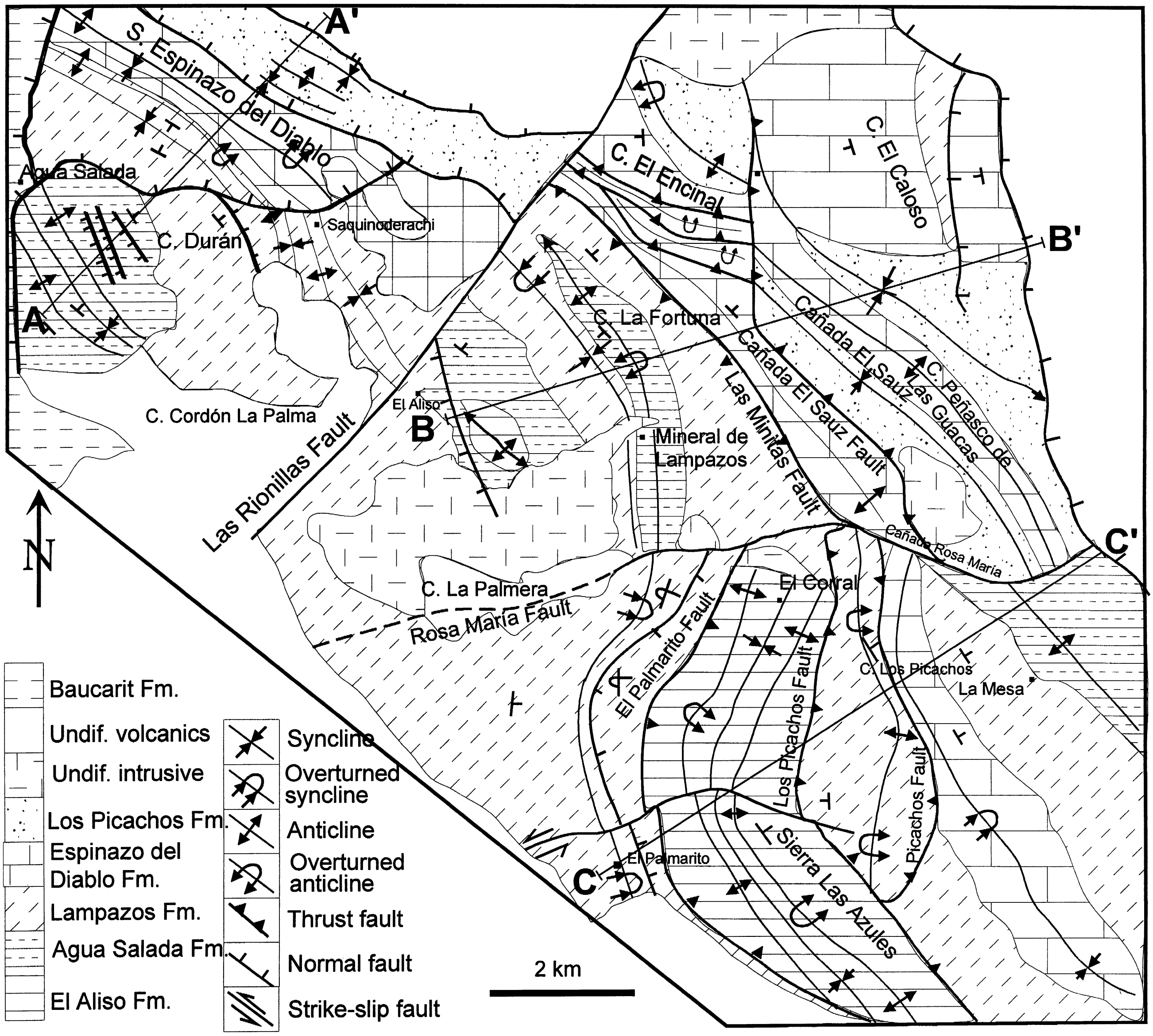

Figure 2. Geologic map of the Lampazos area, eastern Sonora. The sections AA′, BB′, and CC′ are depicted in Figure 3.

S-shaped) to curved and twisted. Also, the majority of the mountain ranges are anticlines, although some are synclines. In many cases the structures are upright, but in many others they display overturning and twisting (Monreal and Longoria, 1995). Furthermore, a characteristic feature of the Chihuahua tectonic belt is the opposite vergences of folds and thrust faults, that is, some overturned folds and thrust faults verge to the west, whereas others verge to the east.

The morphostructural pattern of the belt shows close similarities to an experimental model (Odonne and Vialon, 1983) that simulates a wrench fault system in a rigid basement under a sedimentary cover that is deformed during fault movement (Monreal and Longoria, 1995).

The Aptian–Albian of Northeast Mexico

Excellent exposures of Aptian–Albian marine sections are found in the Victoria segment of the Mexican Cordillera of Nuevo Leon and Coahuila in northeast Mexico (Longoria, 1998). These successions are better known because numerous authors have studied them. The Mexican Cordillera (the Sierra Madre Oriental of some authors) forms a prominent continuous morphologic unit extending from the south across Mexico in a

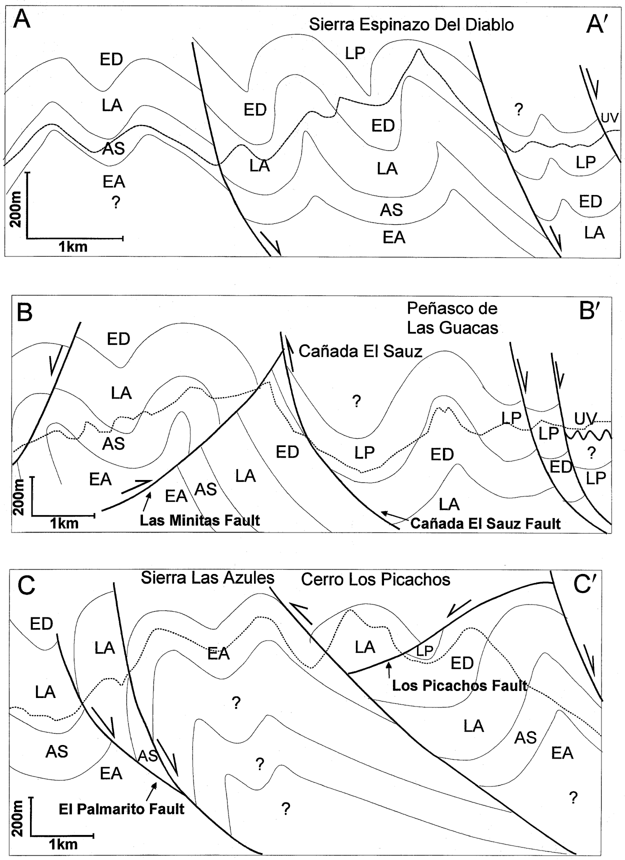

Figure 3. Schematic cross sections in the Lampazos area. The dotted lines are the present topography. EA = El Aliso Formation, AS = Agua Salada Formation, LA = Lampazos Formation, ED = Espinazo del Diablo Formation, LP = Los Picachos Formation, UV = undifferentiated volcanic rocks. The location of sections is shown in Figure 2.

north-northwest direction toward Monterrey, Nuevo Leon, where it makes an abrupt oroclinal bend to the west into the state of Coahuila. The exposed features of this orogenic belt include (1) kilometric-scale anticlinal ridges and narrow synclinal valleys of the Mesozoic sedimentary cover (ranging from Triassic to Upper Cretaceous) commonly displaying box (fan-shaped) folds; (2) a well-developed pattern of en echelon anticlinal folds; (3) juxtaposition of tectonostratigraphic domains; (4) asymmetrical overturned anticlines associated with doubly plunging faulted anticlines; (5) disrupted, long and sinuous fold trends; (6) lack of large horizontal displacement due to overthrusting; (7) folding being predominant over faulting; (8) local thrusting having opposite vergences; and (9) lack of volcanism. All these features clearly reflect the style of deformation occurring in thin-skinned tectonics.

The morphostructural pattern of this tectonic belt shows many similarities to an experimental model (Odonne and Vialon, 1983) that simulates the deformation of a thin sedimentary cover above a wrench fault system in a rigid basement deformed during fault movement (Monreal and Longoria, 1995), and it is in agreement with earlier work in wrench tectonics by Wilcox et al. (1973), Harding (1985), and Harding and Lowell (1979).

BIOSTRATIGRAPHY

We carried out a detailed sampling of the Lampazos succession. Samples were collected at regular intervals and at lithological changes. All the rocks were studied in thin section, and their microfossil content was studied in a transmitted light petrographic microscope using variable magnifications between 120× and 1000×. Microfossil groups studied included benthic and planktonic foraminifera, calpionellids, nannoconids, and radiolarians. The microfossil content of the samples varied from sparse to abundant. The planktonic microfossil biozonation (K-biozones) established by Longoria (1984) from the Gulf Coast region was used as a standard reference in biochronology. This procedure allowed us to use the same reference biohorizons in all the sections studied and to obtain a precise biocorrelation between the Aptian–Albian sections of Sonora and those in northeast Mexico.

Diagnostic benthic foraminifera from the carbonate facies include *Ammobaculites plummerae*, *A. goodlandensis*, *Choffatella decipiens*, *Dictioconus walnutensis*, *Gaudryna cushmani*, *Massilina texasensis*, *Nezzazatinella* sp., *Nummoloculina heimi*, *Palorbitolina lenticularis*, *Quinqueloculina lirelangula*, *Q. minima*, *Textularia taylorensis*, and *Trocholina aptiensis*.

Planktonic species identified include *Caucasella hauterivica*, *Favusella confusa*, *F. papagayoensis*, *F. quadrata*, *F. scitula*, *F. washitensis*, *F. hedbergelliformis*, *Globigerinelloides algerianus*, *G. aptiensis*, *G. barri*, *G. blowi*, *G. duboisi*, *G. maridalensis*, *G. sigali*, *Hedbergella excelsa*, *H. gorbachickae*, *H. luterbacheri*, *H. occulta*, *H. semielongata*, *H. sigali*, *H. similis*, *H. trocoidea*, *Leupoldina postulans*, *L. cabri*, *Ticinella bejaouanesis*, *T. breggiensis*, *T. primula*, and *T. roberti*.

Nannoconids identified in thin section of indurated limestone samples include *Nannoconus colomi*, *N. globulus*, *N. kamptneri*, *N. steinmanni*, *N. truiti*, *N. minutus*, and *N. wassalli*. Calpionellids identified include *Colomiella mexicana*, and *C. recta*. The majority

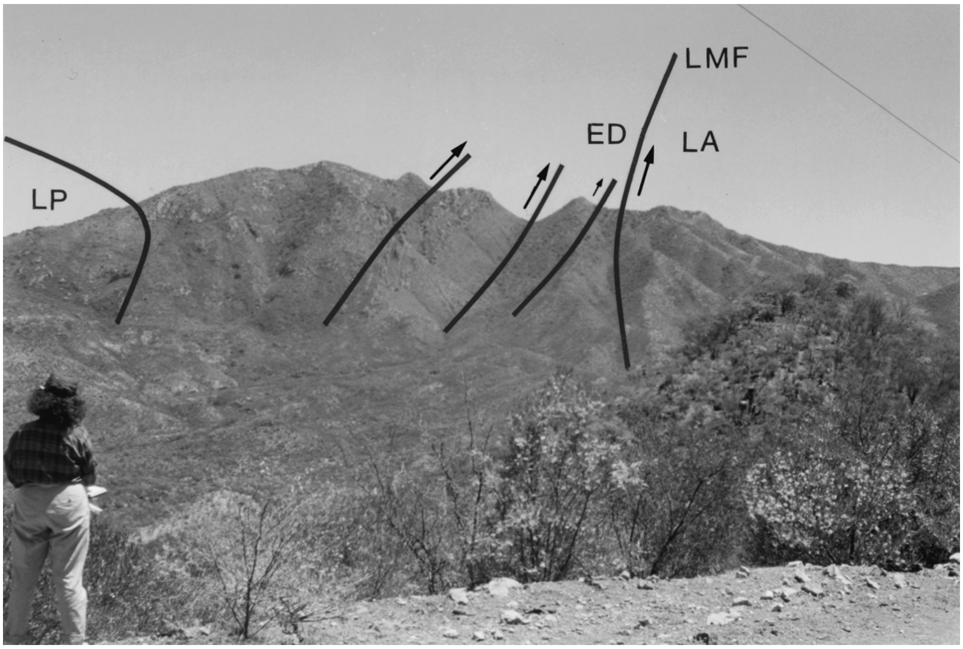

Figure 4. Panoramic view of the northwestern flank of Cerro El Encinal, showing the folding and faulting of the Lampazos (LA), Espinazo del Diablo (ED), and Los Picachos (LP) formations. LMF = Las Minitas fault.

of radiolarians found in the Aptian–Albian deep water facies are calcified and undetermined.

LITHOSTRATIGRAPHY

Lampazos Area of Sonora

Bartolini and Herrera (1986) separated the Lower Cretaceous stratigraphic sequence exposed in this area into ten units. González-León (1988) and Scott and González-León (1991) only used seven units, arguing stratigraphic repetitions. Nevertheless, only five of the units proposed by González-León are taken into consideration in this article: the El Aliso, Agua Salada, Lampazos, Espinazo del Diablo, and Los Picachos formations (Figure 7). We consider that the Nogal Formation is a facies change of the Espinazo del Diablo Formation, having the same overall physical features, and thus the name Nogal is not used in this article. Similarly, the La Mesa Formation, which was referred to as the Los Picachos Formation by Bartolini and Herrera (1986), lithologically resembles part of the Agua Salada Formation, and therefore the La Mesa name is not used either.

The following is an overview of the Lower Cretaceous stratigraphic succession exposed in the Lampazos area. A general lithologic description and the microfacies characteristic of each unit is included. The units are described stratigraphically from older to younger.

El Aliso Formation

The term “El Aliso” was originally introduced in the literature by Herrera and Bartolini (1983) and later redefined by González-León (1988). The base of this unit is a package of thin-bedded, black, siliceous shale pervasively fractured, followed by a sequence of medium-bedded to thick-bedded limestone intercalated with clay mudstone that has limestone nodules and layers. The middle part is thin-bedded to medium-bedded, nodular, orbitolinid-rich limestone intercalated with thin-bedded shale. The upper part is an alternation of thin-bedded, oyster-bearing, sparsely nodular limestone and shale. The base of this unit is covered, but the exposed section is about 200 m thick. This unit is exposed only in a hill located 1 km southeast of Rancho El Aliso (Figure 2).

The microfacies of this unit consists of fossiliferous micrite, biomicrite, and biosparite having intraclasts and peloids as the main nonskeletal constituents. It also contains various amounts of mollusk fragments (including gastropods), miliolids, and echinoderm fragments. Orbitolinids and other benthic foraminifera, as well as green algae, are present at some intervals. Recrystallization features and solution seams are conspicuous features, dolomitization is present near the base, and terrigenous quartz grains are scattered throughout

Figure 5. Metrically folded and pervasively fractured shale of the upper part of the Agua Salada Formation east of Rancho Agua Salada, Lampazos area. Clipboard for scale at the bottom left of photograph is 30 cm long.

the unit. Some shale beds at the base of the unit contain abundant radiolarians and minor amounts of echinoderm and mollusk fragments. The microfacies of the El Aliso Formation are characteristic of shallow-water, open marine to restricted environments of deposition.

According to Scott and González-León (1991), the El Aliso Formation is Barremian to lower Aptian.

Agua Salada Formation

The Agua Salada Formation was originally introduced in the literature by Herrera and Bartolini (1983) and was later redefined by González-León (1988). It consists of alternations of thin-bedded to massive-bedded fossiliferous black shale, thin-bedded to thick-bedded oyster-bearing limestone, and thin-bedded to medium-bedded black chert (Figures 8, 9). Chert is more abundant at the base, whereas the shale intervals become thicker and more abundant toward the top of the unit (Figure 9). Limestone nodules up to 50 cm in diameter are present in shale intervals of the lower part. Olistostromal beds made of fossiliferous thick-bedded limestone are common at the middle part of the unit. The Agua Salada is about 350 m thick and transitionally overlies the El Aliso Formation. The Agua Salada is exposed only west of Cerro Duran and south of Rancho Agua Salada and in the Cerro La Fortuna anticline (Figure 2).

The microfacies of the calcareous shale and limestone beds in this unit are characterized mainly by wackestone and less common mudstone and floatstone. Main skeletal allochems include radiolarians, echinoderm fragments (including planktonic crinoids), planktonic foraminifera, and abundant mollusk fragments. Intraclasts are present at some intervals, and terrigenous quartz recrystallization features, as well as solution seams, are conspicuous features throughout the unit, although authigenic pyrite is present at some intervals. The microfacies of the Agua Salada Formation are characteristic of pelagic to basin environments of deposition, including turbiditic facies in a topographic slope, as evidenced by the olistostrome beds.

This unit was assigned to the upper Aptian by Scott and González-León (1991); however, we found *Caucasella hauterivica* in the middle part of the unit, which is indicative of the lower Aptian.

Lampazos Formation

The Lampazos Formation was originally introduced in the literature by Solano Rico (1970) and Herrera and Bartolini (1983) and later redefined by González-León (1988). It mainly consists of alternating limestone and shale beds having some intervals of sandstone and siltstone. In Sierra Las Azules, where the unit may be as much as 1200 m thick, it is divisible into two parts, from base to top: (1) an approximately 600 m thick interval of regular alternations of thin-bedded to medium-bedded nodular limestone and thin-bedded shale that has uncommon fine-grained sandstone beds (Figure 10); (2) a 600 m thick interval of calcareous

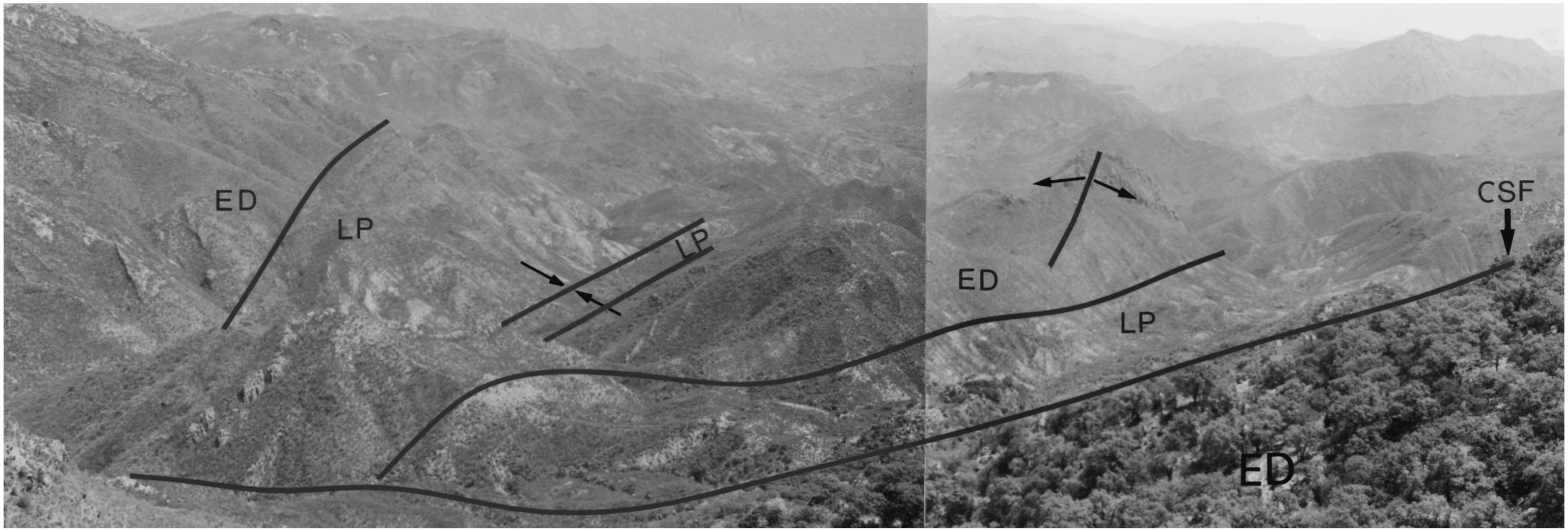

Figure 6. Panoramic view looking to southeast toward Cañada El Sauz and Cerro Peñasco de Las Guacas, showing the type of folding in the Espinazo del Diablo (ED) and Los Picachos (LP) formations. CSF = Cañada El Sauz fault.

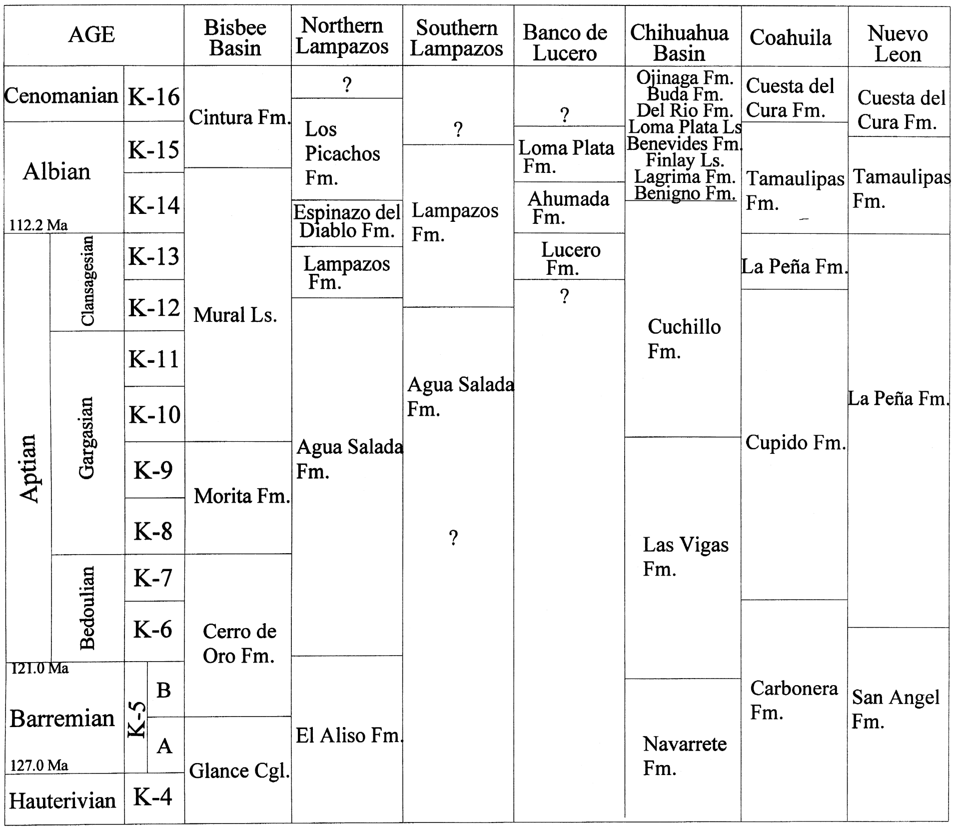

Figure 7. Correlation of the Cretaceous units of Lampazos to the Chihuahua, Coahuila, and Nuevo Leon stratigraphy.

dark gray shale and fine-grained sandstone having alternations of thin-bedded to medium-bedded marly limestone. The Lampazos Formation is approximately 500 to 600 m thick and is the most widespread Cretaceous unit in the Lampazos area (Figure 2).

The microfacies of the calcareous beds of the lower part of the formation are characterized by mudstone and wackestone, having conspicuous but minor amounts of intraclasts and peloids throughout this interval. Main biological allochemical features include abundant planktonic foraminifera, less abundant calpionellids and mollusk fragments, and minor amounts of benthic foraminifera, ostracods, and calcified radiolarians. Planktonic crinoids are present only at some intervals. Main diagenetic features include abundant solution seams and some dolomitization and porosity. The main autigenic mineral is pyrite, along with some quartz crystals.

The microfacies of the limestone beds of the upper part of the formation are characterized by mudstone and wackestone that have low percentages of intraclasts and peloids. Main skeletal allochems include only minor amounts of planktonic and benthic foraminifera, mollusk fragments, otracods, echinoderm fragments, planktonic crinoids, calpionellids, and radiolarians. Calcisphaeres are present only at some intervals. Main diagenetic features include solution seams, and dolomitization is present only at some intervals.

The microfacies in the Lampazos Formation are characteristic of outer-neritic to pelagic environments of deposition.

González-León and Buitrón (1984), based on the presence of *Orbitolina texana* (Roemer), assigned the Lampazos Formation to the lower-middle Albian. In contrast, based on planktonic foraminifera and calpionellid assemblages, we assign this unit as exposed in the northern part of the area north of the Rosa Maria fault to the upper Aptian, and the outcrops south of the same fault to upper Aptian to middle Albian.

Espinazo del Diablo Formation

The Espinazo del Diablo Formation was originally introduced in the literature by Herrera and Bartolini (1983) and was later redefined by González-León (1988). It is divisible into two parts: (1) the lower part, about 15 to 20 m thick, is a thick-bedded to massive-bedded light gray limestone that has abundant rudists, corals, and orbitolinids; (2) the upper

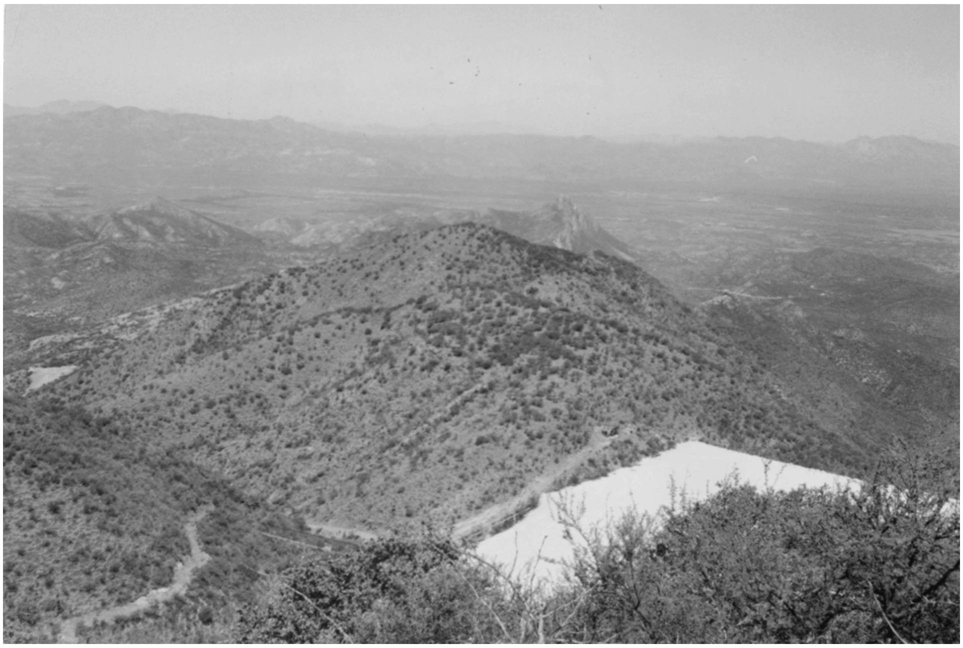

Figure 8. Panoramic view looking northwest to Cerro La Fortuna, showing an overturned anticline in the Agua Salada Formation. White area at the bottom foreground is the old milling dam of the Lampazos mine.

Figure 9. Alternations of black chert and limestone of the lower part of the Agua Salada Formation in Arroyo Agua Salada, near the ranch of the same name in the Lampazos area. People at the bottom of photograph for scale.

part, about 100 m thick, consists of an alternation of nodular thin-bedded to medium-bedded locally fossiliferous limestone and thin-bedded to thick-bedded shale and sandstone (Figures 11, 12). The Espinazo del Diablo Formation ranges in thickness approximately from 100 to 400 m and is mainly exposed in Sierra Espinazo del Diablo, Cerro El Caloso, Cerro El Encinal, Sierra Las Azules, and Peñasco de Las Guacas (Figure 2).

The microfacies of the lower part of the formation is characterized by wackestone and floatstone that contain minor amounts of intraclasts and peloids and abundant sponges and mollusk fragments (including rudists, other bivalves, and gastropods), miliolids, orbitolinids, other benthic foraminifera, echinoderm fragments, and spines. Terrigenous quartz grains, solution seams, and dolomitization, as well as partial silicification, are other features also present.

Figure 10. Thin-bedded nodular limestone of the Lampazos Formation, west of Sierra Las Azules, Lampazos area. Rock pick for scale at the center of photograph.

Figure 11. Panoramic view of the southwestern flank of Sierra Espinazo del Diablo, looking to exposures of the Espinazo del Diablo Formation.

The microfacies of the upper part is characterized by mudstone, wackestone, packstone, and some floatstone having conspicuous presence of intraclasts and peloids. Ooids are present at the uppermost part. Skeletal content consists of abundant mollusk fragments (including gastropods) and minor amounts of echinoderm fragments and benthic foraminifera. Green algae and ostracods are present in low quantities at some intervals. Terrigenous quartz grains, solution seams, and dolomitization are common features throughout the unit, whereas silicification occurs only in the uppermost part.

The microfacies of the Espinazo del Diablo Formation are characteristic of shallow-water shelf varying from open to restricted marine environments of deposition and having development of rudists and coral bioherms.

Scott and González-León (1991) assigned the Espinazo del Diablo Formation to the middle Albian; however, based on the presence of *Ticinella*

Figure 12. Close up of a massive rudist-bearing limestone bed of the Espinazo del Diablo Formation in Sierra Las Azules. Pocketknife for scale.

sp., *Favusella* sp., and *Colomiella* sp. occurring at the top of the unit, we assign it to the upper Aptian to lower Albian.

Los Picachos Formation

Los Picachos Formation was originally introduced in the literature by Herrera and Bartolini (1983) and was later redefined by González-León (1988). This unit is an irregular alternation of thin-bedded to medium-bedded sometimes fossiliferous limestone intercalated with shale and sandstone beds. At the base, it contains an interval of thin-bedded to medium-bedded calcareous conglomerate having limestone clasts up to 8 cm in diameter. This unit ranges approximately from 400 to 900 m in thickness. Los Picachos is exposed northeast of Sierra Espinazo del Diablo and in the northeastern corner of the study area (Figure 2).

The microfacies of the limestone beds in this unit are mainly mudstone, wackestone, and packstone. The mudstone and wackestone contain minor amounts of intraclasts and only traces of calcisphaeres and echinoderm and mollusk fragments. The packstone beds contain abundant ooids and green algae and only traces of reworked echinoderm fragments and miliolids. Solution seams are the only conspicuous diagenetic feature present. The limestone clasts of the conglomerate beds are mainly mudstone having scattered amounts of calpionellids. The microfacies in Los Picachos Formation are characteristic of shallow-water neritic environments of deposition, having local development of ooidal high energy banks. The limestone conglomerate at the base, being intraformational, is evidence of reworking substrate in a shallow-water marine shelf.

Scott and González-León (1991) assigned the Los Picachos Formation to the upper Albian, however, based on the presence of *Colomiella* sp. and *Favusella* sp. present at the base of the unit, we consider it ranges from middle to upper Albian.

The Chihuahua Connection: Sierras Banco de Lucero, La Esperanza, and Cieneguillas

In general the Lower Cretaceous stratigraphic succession of Chihuahua is made of the Navarrete, Las Vigas, Cuchillo, Benigno, Lagrima, Finlay, Benevides, and Loma Plata formations. Nevertheless, in some areas of northeastern Chihuahua, like in Sierras Banco de Lucero, La Esperanza, and Cieneguilla, the Lucero and Ahumada formations replace the Cuchillo, Benigno, Lagrima, Finlay, and Benevides formations (Figure 7).

The stratigraphic succession of Lampazos is quite similar to the stratigraphic succession exposed in Sierra Banco de Lucero (Figure 1), located 19.7 km northwest of the town of Villa Ahumada; in north-central Chihuahua; in Sierra La Esperanza, located 55 km northwest of the town of Ojinaga in northeastern Chihuahua; and in Sierra Cieneguilla, in northeasternmost Chihuahua. The units exposed in Sierra Banco de Lucero are the Lucero, Villa Ahumada, and Loma

Plata formations, and in Sierra La Esperanza the Lucero and Ahumada formations are exposed, whereas in Sierra Cieneguilla the Loma Plata Formation is exposed. The Lampazos Formation is similar in lithology and microfacies to the Lucero and Ahumada formations, whereas the Espinazo del Diablo Formation is remarkably similar to the Loma Plata Formation.

The stratigraphic succession exposed in Sierra Banco de Lucero consists, from base to top, of the Lucero, Ahumada, and Loma Plata formations (Figure 7). In Sierra La Esperanza the Lucero and Ahumada formations are exposed, whereas in Sierra Cieneguilla the Loma Plata is exposed.

Lucero Formation

The Lucero Formation (Rodríguez-Torres and Guerrero, 1969; and Guerrero, 1969) is exposed on the eastern side of Sierra Banco de Lucero. The formation is a 386 m thick calcareous-argillaceous sequence forming smooth hills, topped by a thick-bedded, ridge-forming limestone. Guerrero (1969) divided the formation into three parts: the lower part is an interval of fine-grained to medium-grained black limestone having dark gray medium-bedded calcareous siltstone interbeds; the middle part is an intercalation of medium-grained black thin-bedded limestone and siltstone; and the upper part is a black fine-grained limestone.

In Sierra La Esperanza, the Lucero Formation is thicker and is also divisible into three parts:

1. The lower part consists of an irregular alternation of fairly resistant limestone and shale. The limestone beds are medium-bedded to thick-bedded, black to gray, and weather medium gray. Shale intervals are medium-bedded to thick-bedded, black carbonaceous, and weather medium gray. The base of the unit is covered, and therefore it was not observed. Its estimated exposed thickness is 300 m.
2. The middle part, about 300 m thick, is a medium-bedded to thin-bedded slope-forming dark gray shaly and somewhat nodular limestone, that weathers from gray to light brown to light tan.
3. The upper part, approximately 350 meters thick, is an irregular alternation of thick-bedded to massive-bedded, resistant ridge-forming, dark gray limestone and minor shale intervals.

The microfacies of the limestone beds present in the Lucero Formation are characterized by mudstone varying from fossiliferous micrite to biomicrite. Main allochems present include planktonic crinoids, calpionellids *(Colomiella)*, other echinoderm fragments, favusellid planktonic foraminifera, thin-shelled pelecypods, ostracods, minor calcified radiolarians(?), calcisphaerulids(?), and benthic foraminifera. Some allochems are reworked, including miliolids at the top of the formation. Abundant authigenic quartz is present throughout the formation. Some sutured solution seams are also present, as well as dolomite crystals, especially at the base of the formation. The textural characteristics and the presence of planktonic crinoids, calpionellids, planktonic foraminifera, and radiolarians(?) are evidences that the Lucero Formation was deposited in a shelf having middle-neritic to outer-neritic to upper-bathyal water depths. The shale intervals at the base and top of this unit are evidence for a variable terrigenous influx.

Guerrero (1969) assigned the Lucero Formation to the lower and middle Albian, because in Sierra de Presidio, located 80 km northeast of Sierra Banco de Lucero, a similar lithologic unit is exposed below beds that contain *Orbitolina* sp. In contrast, we assign the Lucero Formation to the upper Aptian–lower Albian, based on the presence of *Colomiella mexicana* and the genus *Favusella*. According to Longoria's (1984) biostratigraphic scheme *C. mexicana* ranges from upper Aptian to lower Albian, whereas *Favusella* ranges from upper Aptian to Cenomanian.

Ahumada Formation

The Ahumada Formation (Rodríguez-Torres and Guerrero, 1969) includes 352 m of a nonresistant, slope-forming, thin-bedded to medium-bedded, medium gray to black limestone and black calcareous shale alternating irregularly.

Guerrero (1969) described the Ahumada as a lithic sequence divisible into three parts. The lower part is black, thin-bedded, fine-grained limestone that weathers brown to beige and contains black shale interbeds. The middle part is black, fine-grained, thin-bedded limestone having thinly bedded layers of calcareous gray shale, which weather to a yellowish to brown color. The upper part is dark gray, fine-grained, medium-bedded limestone. The Ahumada Formation was originally reported in Sierra Banco de Lucero, but it is also exposed in Sierra La Esperanza, located 55 km northwest of Ojinaga.

The microfacies of the Ahumada Formation are characterized by mudstone that varies from fossiliferous micrite to biomicrite and uncommon fossiliferous intrapelmicrite. The most abundant allochems present include planktonic foraminifera, echinoderm fragments, and planktonic crinoids. Less important allochems include thin-shelled bivalves, calpionellids, calcified radiolarians(?), calcisphaerulids, ostracods, and benthic foraminifera (including miliolids). Some of the bioclasts are reworked, and authigenic quartz and oxides are also present.

The textural characteristics of the limestone and the presence of planktonic crinoids, planktonic foraminifera, and calpionellids in the lower part of the Ahumada Formation represent deposition in a shelf having outer-neritic water depth. A high terrigenous influx in a fluctuating anoxic environment of deposition is evidenced by the abundance of black shale intervals. Similarly, the presence of planktonic foraminifera and planktonic crinoids, decreasing abundance of calpionellids, presence of reworked fauna, and the presence of traces of miliolid foraminifera in the upper part of the Ahumada suggest deposition in slightly shallower waters than the lower part, probably a shelf having middle-neritic water depth.

Guerrero (1969) assigned a middle to upper Albian age to the Ahumada Formation based on fossil content (*Pecten [Neithea]* sp., *Alectryonia carinata* [Lamarck], *Oxytropidoceras trinitense*); however, this fauna might be reworked or erroneously identified, because the microfauna present in this unit suggest a different age. Based on the last appearance of *Colomiella* sp., which occurs near the top of the unit, along with other microfauna (*Hedbergella*? and *Pithonella ovalis)*, we assign the Ahumada Formation to the lower to middle Albian.

The Loma Plata Limestone

The Loma Plata Limestone has a complex nomenclature history (Monreal and Longoria, 1999), and because this matter is beyond the scope of this work, we will only mention that Amsbury (1957, 1958) proposed the name Loma Plata Limestone to designate a 220 m thick sequence of nodular limestone and shale capped by a thick-bedded to massive limestone that crops out between the Benevides and Grayson formations in the Pinto Canyon area of Presidio County, Texas. The following is a description of the lithostratigraphy and microfacies of this unit.

The Loma Plata Limestone (Amsbury, 1958) was first described in the Pinto Canyon area of Presidio County, Texas. In Chihuahua it consists of light gray to medium gray, thick-bedded, massive, micrograined, in part nodular, resistant limestone weathering yellowish-brown and having few thin interbeds of shale. Silicified fossils, chert nodules, and ropy chert bands are common in massive bioherm facies.

The Loma Plata Limestone is widely exposed in west Texas and Chihuahua. In Chihuahua it ranges in thickness from 100 m in Sierra de La Alcaparra to 500 m in northern Sierra Pilares.

In Sierra Banco de Lucero the microfacies of the Loma Plata Limestone is characterized by mainly floatstone and wackestone, varying from biomicrites, packed biomicrites, packed intraclast-biomicrites, and biomicrudites to intraclast-biomicrudites. Main allochems present are bivalve shell fragments (including rudists), gastropods, orbitolinid and miliolid foraminifera, and echinoderm fragments. Some allochems show micritic envelopes. Intraclasts are also abundant.

In Sierra Cieneguilla, in northeastern Chihuahua, only the lower member makes up the Loma Plata and is characterized by mudstone and floatstone (biomicrites and biomicrudites). Main allochems include calcisphaerulids (including *Bonetocardiella*), planktonic and benthic foraminifera, echinoderm and shell fragments, gastropods, and ostracods?. The upper part is characterized by rudist-bearing, foraminiferal-algal biomicrudites (Reaser, 1974) having dasycladacean green algae and gastropods.

According to Haenggi (1966, p. 181), the Loma Plata Limestone was deposited in a neritic environment "with local shoaling over reefs." In addition, the lithology, fossil content, and microfacies of this unit in Sierra Banco de Lucero suggest deposition in a well-aerated, well-circulated, shallow-water carbonate ramp having development of rudist reefs and lagoonal environments.

The Loma Plata Limestone has been considered upper Albian to lowermost Cenomanian by many geologists (Amsbury, 1958; Twiss, 1959; Spiegelberg, 1961; Haenggi, 1966; Cordoba, 1969; Guerrero, 1969; Rodríguez-Torres, 1969; Cordoba et al., 1970; De Ford and Haenggi, 1970; and Underwood, 1962, 1963, 1980), but it is difficult to assign an accurate age to this unit, because of the lack of index fossils. However, the presence of the calcisphaerulid *Bonetocardiella*, restricted to the upper Albian (Masters and Scott, 1978) in the middle part of the Loma Plata Limestone in Sierra Cieneguilla, is indicative of an upper Albian age, at least for this part of the unit. Therefore, based on its stratigraphic position and fossil content, we consider the Loma Plata Limestone to range from middle to upper Albian.

The Gulf of Mexico Connection: Los Chorros Canyon, La Boca Canyon, and Santa Rosa Canyon

We compared the Aptian–Albian succession of Lampazos, Sonora, with well documented sections in Coahuila and Nuevo Leon (Figure 7). These sections include the Los Chorros Canyon of Sierra La Nieve (Longoria and Monreal, 1991) and the La Boca and Santa Rosa canyons (Longoria, 1998) (Figure 1).

Los Chorros Canyon

The Los Chorros Canyon section is exposed in the breached southern limb of the Sierra La Nieve anticline. The Aptian–Albian section was studied along highway 57. It includes the Cupido Limestone (934 m) and the La Peña (55 m) and Tamaulipas formations (85 m). The Cupido Limestone–La Peña Formation contact marks the drowning of the Cupido carbonate platform, corresponding to the early Albian (K-13) transgressive event. The Aptian events are contained in the Cupido platform facies, which is composed of about 49 different microfacies types, but the identification of the early and late Aptian events was not possible at this locality. In the adjacent San Juan Bautista anticline about 5 km to the east, however, a similar stratigraphic succession was studied (Longoria et al., 1996). At this locality the late Aptian (K-10) event is marked by a influx of deep-water facies within the Cupido Limestone that contain abundant planktonic foraminifera, among which *Globierinelloides algerianus* is recognized. This clearly corresponds to the late Aptian event from Santa Rosa Canyon described in a following section.

La Boca Canyon

The La Boca Canyon succession includes hemipelagic sediments referred to as the San Angel Limestone (682 m), the La Peña Formation (95.7 m), and the Tamaulipas Limestone (162 m). The San Angel–La Peña contact corresponds to the early Aptian (K-6) event, and the early Albian (K-13) pulse is defined by the La Peña–Tamaulipas contact.

The Santa Rosa Canyon

The Santa Rosa Canyon succession is composed of the San Angel Limestone (619 m) and the Tamaulipas Limestone (150 m). These successions contain an excellent biostratigraphic and geochemical record (Bralower et al., in press) that allows the recognition of a detailed C isotope stratigraphy, including the recognition of the well-known oceanic anoxic events (OAEs) OAE-1a and the OAE-1b based on the total organic carbon (TOC) content of the Aptian–Albian succession. In addition, a third event in the late Aptian (K-11) was established. These events are tied to global changes in sea level marked as a major phase of marine transgression.

PALEOGEOGRAPHIC AND TECTONIC IMPLICATIONS

It has been previously stated that the Lampazos succession bears close similarity to the Aptian–Albian succession of the Chihuahua trough and represents an intermediate paleogeographic element between the Bisbee basin (González-León, 1988; Scott and González-León, 1991; Monreal et al., 1994a; Monreal 1995) and the deep water facies of the Mexican Sea (Figure 13). In addition, our comparative stratigraphic analysis shows that this succession can be lithocorrelated to better-known successions in northeastern Chihuahua (Sierra Banco de Lucero), Coahuila (Los Chorros Canyon), and Nuevo Leon (La Boca and Santa Rosa canyons) (Figure 7).

The Aptian–Albian of north Mexico is characterized by four contrasting facies belts, including (1) clastic, (2) grainy, (3) hedbergelloid, and (4) pelagic facies belts. These facies belts are time transgressive to the north-northwest. The grainy facies represents the shallow water carbonates corresponding to the Cupido and El Aliso platforms in northeast and northwest Mexico, respectively. The beginning of the Cupido Limestone carbonates remains to be defined, because there is not a clear biochronologic control of the basal shallow-water sediments. The majority of the age assignations of the base of Cupido Limestone by previous authors lack documentation and are basically done on superposition, assuming the Hauterivian–lower Barremian age of the Taraises Formation that underlies it at numerous localities in Coahuila and Nuevo Leon. We find that the beginning of the Cupido platform in Nuevo Leon and Coahuila should be linked to the initiation of the Aptian (K-6) transgression. The shallow-water carbonates of the Cupido Limestone of the San Juan Bautista anticline of Nuevo Leon are abruptly onlapped by deep-water facies, rich in planktonic foraminifera, including *Globigerinelloides algerianus*, which is indicative of biozone K-10, defining a transgressive event of short duration. The K-10 transgressive sediments are sandwiched by shallow-water carbonates of the Cupido Limestone. Finally at this locality, the

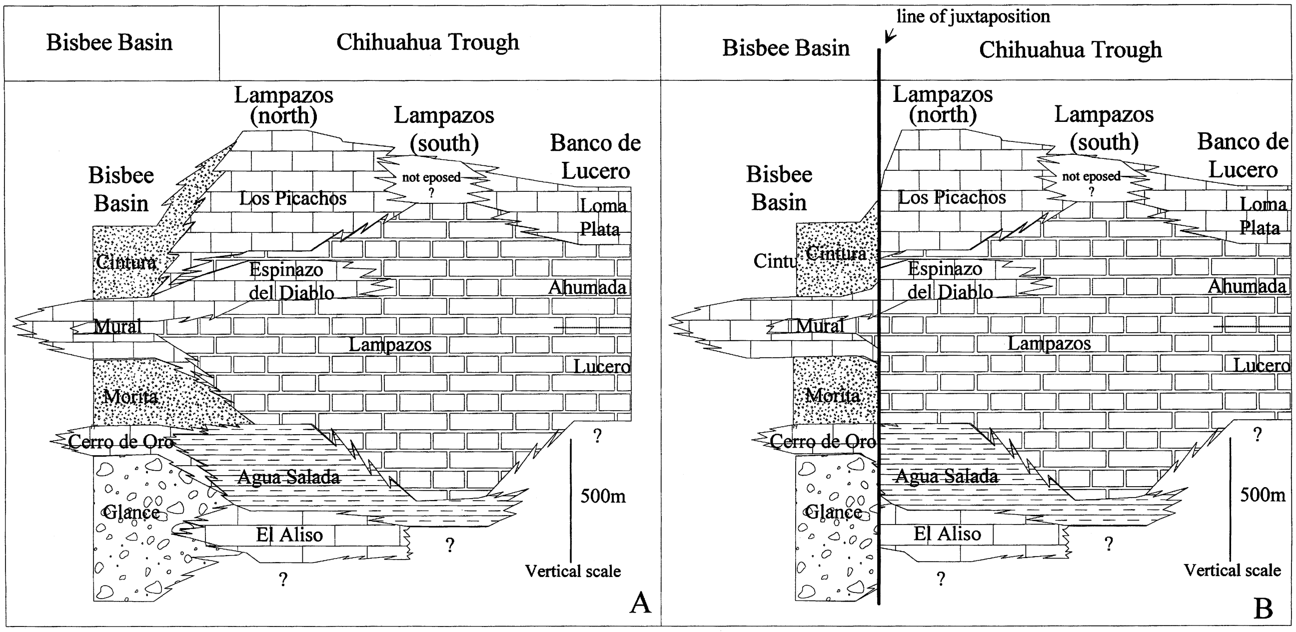

Figure 13. Lateral relationships of the Aptian–Albian formations between the Chihuahua and Bisbee basins. (A) Pretectonic translation. (B) After tectonic translation resulting in the juxtaposition of facies.

maximum flooding and drowning of the Cupido platform is marked by the beginning of the deposition of La Peña at the base of biozone K-13.

The compressional structures of the Lampazos succession are very similar to the style of deformation of the coeval rocks in the states of Chihuahua, Coahuila, and Nuevo León, especially to the kind of structures present in the Chihuahua tectonic belt (Monreal and Longoria, 1995). Nonetheless, the Lampazos area differs from the Chihuahua area by the extension structures that originated during the Basin and Range deformational episode.

Despite the close geographic proximity of the Lampazos succession to the Bisbee Group outcrop belt (Figure 1), this succession is undoubtedly paleogeographically and tectonically related to the Chihuahua tectonic belt. Thus the origin of the Lampazos block could be explained by abrupt facies changes from shallow-water in the Bisbee to deep-water in the Lampazos area. In this scenario one would expect to find sediments from the platform to be shed into the basinal facies. However, our combined analysis of field work and microfacies readily rules out this model, because of the absolute lack of shallow-water components or debris in the Lampazos sequence derived from the platform. Alternatively, we suggest that the Lampazos block represents the tectonic translation of deep-water sediments originally deposited in the Chihuahua trough, resulting in the present day anomalous outcrop distribution, whereby outcrops of the Lampazos succession encroach into the Bisbee Group outcrop belt (Figures 1, 13, 14).

The aforementioned juxtaposition model agrees with the widely documented tectonic transpressional model for northern Mexico during and some time after Mesozoic time (Longoria, 1985, 1987, 1988, 1993, 1994; Monreal, 1989, 1990, 1993, 1996; Monreal and Longoria, 1995) and also corresponds to theoretical models of wrench tectonics as postulated by the work of Wilcox et al. (1973), Harding and Lowell (1979), and Harding (1985). This transpressional deformation translated the Lampazos block from the southeast, somewhere in the ancestral Chihuahua trough, to the northwest, into eastern Sonora, by the mechanism of strike-slip faulting and its associated folding and thrusting. This phenomenon is evidenced by the presence of several stratigraphic juxtapositions in Sonora (Monreal, 1995) and Chihuahua (Monreal, 1989, 1990, 1993).

ECONOMIC SIGNIFICANCE

The Aptian–Albian succession of Lampazos is biochronologically continuous, representing a complete record of paleoceanographic events from biozone K-6

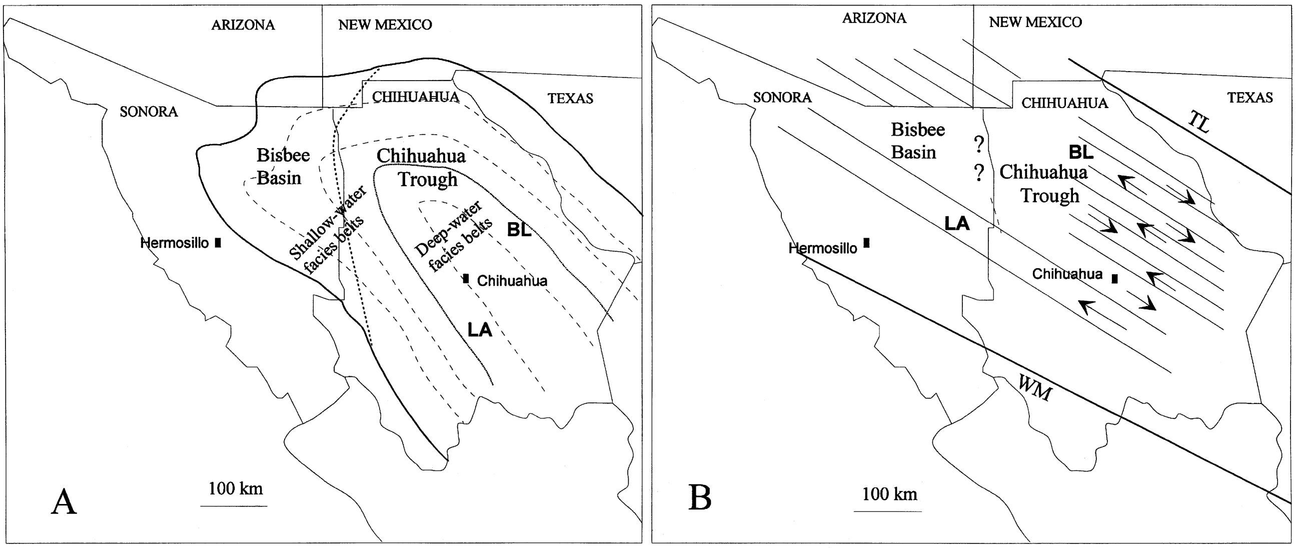

Figure 14. Relationship between the Bisbee and Chihuahua basins. (A) Aptian–Albian facies distribution in Chihuahua and Sonora. (B) Disruption and translation of deep-water facies resulting in the juxtaposition of the Lampazos block and the embayment into the Bisbee Group outcrop belt. LA = Lampazos area, BL = Sierra Banco de Lucero. Faults in southeastern Arizona correspond to Titley's (1976) discontinuities. Faults in northeastern Chihuahua correspond to the basements faults proposed by Monreal (1989, 1990, 1993). TL = Texas lineament, WM = Walper megashear.

through K-15 (Longoria, 1984), and is represented by two contrasting paleogeographic settings: (1) a platform shallow-water succession and (2) a deep-water basinal sequence (Figure 15). The sections studied record three paleogeographic events (changes in relative sea level): (1) early Aptian (K-6 to K-7); (2) late Aptian (K-10 to K-11); and (3) early Albian (K-13 to K-14). These events mark changes in sea level corresponding to the early (K-6) and late Aptian (K-10) transgressions and the early Albian (K-14) maximum transgression

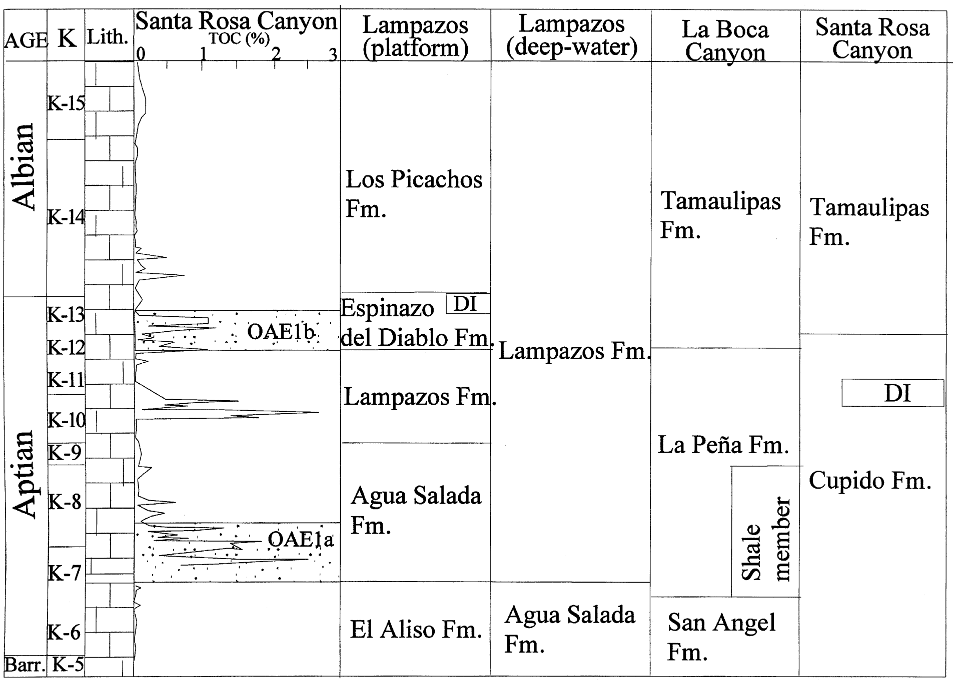

Figure 15. Lithostratigraphic, biostratigraphic, and chemostratigraphic correlation of Aptian–Albian successions across northern Mexico. Ocean anoxic events (OAEs) identified in Santa Rosa Canyon (Bralower et al., in press) seem to correspond to lithic changes in other sections in northern Mexico: Agua Salada/El Aliso and Lampazos/Espinazo del Diablo in Sonora, and San Angel/La Pena and La Pena/Tamaulipas in Nuevo Leon. K-1 to K-15 = Cretaceous biozones from Longoria (1984); DI = drowning interval.

(peak of flooding), respectively. In Sonora these Aptian–Albian changes in sea level coincide with lithic changes marked by the drowning of the El Aliso, Espinazo del Diablo, and Los Picachos carbonate platforms (Figure 15).

Similar sea level changes have been observed in coeval successions in Chihuahua, whereby the early Albian transgressive event is marked by the Loma Plata–Ahumada contact (Monreal, 1989). In western Chihuahua the early Aptian event is represented by the Cuchillo–Las Vigas contact, the upper Aptian event is marked by the Benigno-Cuchillo contact, and the early Albian event is marked by the Loma Plata–Ahumada contact. Further to the east in Los Chorros Canyon (Coahuila state), the Cupido–La Peña contact represents the early Albian event (Longoria and Monreal, 1991). In Nuevo Leon state, the San Angel–La Peña contact represents the early Aptian event, and the Tamaulipas–La Peña contact defines the early Albian event (Longoria, 1998). Similarly, in the shallow-water facies of the Cupido Limestone of Nuevo Leon, the late Aptian event (K-10 to K-11) is represented by an early drowning event of the Cupido platform, as observed in the San Juan Bautista anticline of Nuevo Leon, whereas the early Albian event is marked by the Cupido-Tamaulipas contact (Longoria et al., 1996).

The aforementioned paleogeographic events correspond to three OAEs that were recently documented in the Aptian–Albian succession of the Santa Rosa Canyon of central Nuevo Leon, based on detail geochemical analysis, including organic carbon and carbonate content and stable isotopes (Bralower et al., 1994, in press). Carbon isotope stratigraphy of the Aptian–Albian succession of the Santa Rosa Canyon shows three abrupt peaks in C_{org} content that correlate to the early Aptian OAE-1a (K-6–K-7), the late Aptian (K-10–K-11) event, and the early Albian (K-13–K-14) OAE-1b (Figure 15). These oceanic anoxic events are evidently global in nature, because they correlate to the same events in the European and Pacific deep-sea sections (Weissert and Breheret, 1991; Rohl and Ogg, 1996; Weissert et al., 1998). These events resulted as a response to the mid-Cretaceous global change (Barron and Washington, 1982). This interval was marked by global warmth and low latitudinal temperature gradients (Barron and Peterson, 1990). This greenhouse was coincident with a worldwide pulse in ocean crustal production (Larson, 1991). Also, this time coincides with increased sea-floor spreading rates (Hays and Pittman, 1973).

Aptian–Albian oceanic environments favored the deposition and burial of organic-rich sediments known as black shales (Arthur and Premoli Silva, 1982). However, warm deep-water temperatures and slow water circulation led to widespread dysoxia and anoxia in deep-water masses. According to Schlanger and Jenkins (1976), the mid-Cretaceous black shales were not deposited randomly through time, but they were concentrated in intervals known as OAEs. The well-known OAE-2 (Turonian–Cenomanian boundary) is proved to be of global extent (Schlanger et al., 1987), whereas the Aptian–Albian OAE is recognized as consisting of four separate phases of organic-carbon deposition, but only the early Aptian (K-6) OAE-1a and the early Albian (K-14) OAE-1b are documented as global events (Sliter, 1989). All of these OAEs are clearly observed through the Aptian–Albian succession of northeast Mexico; for example, at the La Boca and Santa Rosa canyons of Nuevo Leon (Longoria, 1998), these events are identified in the carbonate, TOC, and $\delta^{13}C_{org}$ stratigraphy of the Santa Rosa Canyon (San Angel–La Peña formations). These intervals correspond to oil-bearing zones (oil plays) in Nuevo Leon (Buena Suerte field) and in Coahuila (Polvorín play). However, the lack of oil exploration wells in Sonora hinders, at this time, making any direct evaluation of these rocks as potential oil sources in the state of Sonora. Nonetheless, the fact that the Sonoran succession is coeval with and of the same environment as producing rocks in northeastern Mexico makes the Lampazos area worthy of further oil exploration work.

CONCLUSIONS

The Aptian–Albian succession of Lampazos (east-central Sonora) is the result of a global transgression from the ancestral Gulf of Mexico into the Mexican Sea and to the west-northwest into east-central Sonora. Thus, the El Aliso, Agua Salada, Lampazos, Espinazo del Diablo, and Los Picachos formations of east-central Sonora represent the western migration of the marine incursion from the ancestral Gulf of Mexico. It is also evident that several sea level fluctuations took place within the overall large Aptian transgressive phase. These fluctuations in sea level controlled the development and final drowning of the carbonate platforms in northern Mexico in a similar way to that described by Weissert et al. (1998). In general most of the samples analyzed for organic carbon and carbonate content contain low (<0.1%) TOC; however, three marked peaks have values up to 2.7% TOC, which in the Santa Rosa Canyon section correspond to the lower Aptian (K-6 to K-7), the upper Aptian (K-10 to K-11), and the lower Albian (K-13 to K-14). We can use the foraminiferal biochronology of Longoria (1984) to correlate, with a high degree of confidence, the three TOC peaks in the sections from northeast Mexico (Santa Rosa Canyon) with coeval sea level fluctuations as interpreted from the physical stratigraphy.

In the Santa Rosa Canyon section, the high TOC intervals correspond to the oil-bearing intervals in the La Peña and Tamaulipas formations (Bralower et al., in press; Alfonso Zwanzinger, 1978). In Chihuahua, Coahuila, and Nuevo Leon these Aptian–Albian organic-rich units (San Angel, La Peña, and Tamaulipas formations) are known to be the source rock of hydrocarbons (Alfonso Zwanzinger, 1978) in exploration wells in Tamaulipas (Nr. 2A Buena Suerte well) and in Coahuila (Nr. 1 Polvorin well). However, the lack of exploration wells in the Sonora state area, as well as the lack of geologic work addressing the petroleum systems represented in the state of Sonora and in the Lampazos area in particular, impedes at this time any further discussion of the petroleum potential of the area. However, the remarkable similarity in physical properties of the Sonoran succession to coeval oil-bearing units from northeastern Mexico, as well as the existence of the same OAE record, as inferred from the changes in sea level in both areas, opens new insights into the petroleum potential of this poorly explored region of northwestern Mexico.

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