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A REVISION OF THE STRATIGRAPHIC NOMENCLATURE FOR THE CRETACEOUS OF NORTHERN SONORA, AND SOME PALEOGEOGRAPHIC IMPLICATIONS

Rogelio MONREAL[1] [2], Manuel VALENZUELA[1], and Carlos GONZALEZ-LEON[3]
[1] Carrera de Geociencias, CESUES, Apartado Postal No 11, Admon. de Correos No 4, Hermosillo, Sonora, México.
[2] Departamento de Geología Uni-Son, Hermosillo, Sonora, México 83000.
[3] ERNO, Instituto de Geología UNAM, Apdo. Postal 1039, Hermosillo, Sonora, México 83000.

ABSTRACT

The Cretaceous sedimentary strata of northern Sonora have been referred to with several formational names by many workers, which has led to a proliferation of a varied lithostratigraphic nomenclature. Based on the recommendations set for by the North American Stratigraphic Code (NACSN, 1983), the present work intends to bring consistency into the Cretaceous lithostratigraphic nomenclature of northern Sonora, namely Sierra Azul, Cerro Bandera, Sierra El Tigre, Arizpe, Tuape, Cerro de Oro, Santa Ana and Sierra El Chanate areas.

Lower Cretaceous units in these areas are recognized as belonging to the Bisbee Group, although some variations in its formational content do occur. In Sierra Azul and Cerro La Bandera areas, the strata are assigned to the Glance, Morita, Mural and Cintura formations, whereas those of Sierra El Tigre are assigned to the Mural Limestone. In the Cerro de Oro area, the Bisbee Group is composed of the Cerro de Oro, Morita, Mural and Cintura formations. In Arizpe and Tuape areas, previous lithostratigraphic schemes are abandoned and replaced by the Bisbee Group. However, the Glance Conglomerate is not present and is replaced by the Cerro de Oro Formation. The stratigraphic sequence exposed in the Santa Ana area is assigned to the Bisbee Group, and it is suggested in this work that the Represo and Arroyo Sásabe names be dropped from usage in this area. In Sierra El Chanate, the Bisbee Group nomenclature should be retained, including the Glance, Morita, Arroyo Sásabe and Cintura Formations

Sedimentary Upper Cretaceous rocks are exposed only in Cabullona, Arizpe, Cerro de Oro and El Chanate areas. In contrast with the Lower Cretaceous lithostratigraphy, the Upper Cretaceous units of those areas bear no resemblance to each other and therefore, separate nomenclatural schemes are accepted for them. In Cabullona area, the Cabullona Group is recognized as consisting, in ascending order, of the Corral de Enmedio Formation, the Camas Sandstone, the Packard Shale, the Lomas Coloradas Formation, and the El Cemento Conglomerate which is a lateral equivalent of the Packard and Lomas Coloradas formations. In Arizpe, the El Aguila conglomerate, an informal unit which overlies the Lower Cretaceous Bisbee Group, is herein retained but caution is advised when using this name. In

the Cerro de Oro area the La Palma name is retained with a formational rank and applied to an Upper Cretaceous unit. In Sierra El Chanate, the El Chanate Group is lowered in rank and treated as a formation composed of the Pozo Duro, Anita and Escalante members. On the other hand the El Charro Formation needs to be formally revised.

The paleogeographic distribution of the Bisbee Group during Early Cretaceous time was variable, which includes thickness variations and facies changes during Morita and Mural times. This is recorded by the Cerro de Oro and Arroyo Sásabe formations.

RESUMEN

Las rocas sedimentarias del Norte de Sonora han sido asignadas, por muchos autores, a diferentes formaciones, lo que ha causado proliferación de una nomenclatura litoestratigráfica muy variada. En base a las recomendaciones del Código Norteamericano de Nomenclatura Estratigráfica (NACSN, 1983), el presente trabajo pretende generar consistencia en la nomenclatura litoestratigráfica del Norte de Sonora, particularmente en las áreas de Sierra Azul, Cerro Bandera, Sierra El Tigre, Arizpe, Tuape, Cerro de Oro, Santa Ana y Sierra El Chanate.

Se reconoce que las unidades estratigráficas del Cretácico Inferior pertenecen al Grupo Bisbee, aunque existen algunas variaciones en su contenido formacional. En las áreas de Sierra Azul y Cerro La Bandera, las rocas cretácicas se asignan a las formaciones Glance, Morita, Mural y Cintura, mientras que aquellas de la Sierra El Tigre son asignadas a La Caliza Mural. En el área de Cerro de Oro, el Grupo Bisbee esta compuesto de las formaciones Cerro de Oro, Morita, Mural y Cintura. En Arizpe y Tuape, los esquemas litoestratigráficos previos son abandonados y reemplazados por el Grupo Bisbee. Sin embargo, el Conglomerado Glance no se encuentra presente siendo reemplazado por la Formación Cerro de Oro. La secuencia estratigráfica expuesta en el área de Santa Ana es asignada al Grupo Bisbee, y se sugiere en este trabajo que los nombres Represo y Arroyo Sásabe sean abandonados en esa área. En la Sierra El Chanate, la nomenclatura del Grupo Bisbee debe retenerse, incluyendo a las formaciones Glance, Morita, Arroyo Sásabe y Cintura.

Rocas del Cretácico Superior están expuestas solamente en Cabullona, Arizpe, Cerro de Oro y El Chanate. A diferencia de la litoestratigrafía del Cretácico Inferior, las unidades del Cretácico Superior de esas áreas no tienen parecido unas con otras, por lo que se aceptan diferentes esquemas litoestratigráficos para ellas. En el área de Cabullona se reconoce el Grupo Cabullona consistente, en orden ascendente, de la Formación Corral de Enmedio, la Arenisca Camas, la Lutita Packard, la Formación Lomas Coloradas, y el Conglomerado El Cemento, el cual es un equivalente lateral de las formaciones Packard y Lomas Coloradas. En Arizpe, el conglomerado Aguila, una unidad informal que sobreyace al Grupo Bisbee es aquí retenido, aunque se sugiere cautela al usar dicho nombre. En el área de Cerro de Oro, el nombre La Palma es retenido con un rango formacional y aplicado a una unidad del Cretácico Inferior. En la Sierra El Chanate, el Grupo El Chanate es bajado de rango y es tratado como formación compuesta de los miembros Pozo Duro, Anita y Escalante. Por otra parte es necesario que la Formación el Charro sea revisada formalmente.

La distribución paleogeográfica del Grupo Bisbee durante el Cretácico Temprano fue variable, lo cual incluye variaciones en espesor y cambios de facies durante el tiempo de depositación de las formaciones Morita y Mural. Esto es evidenciado por los sedimentos de las formaciones Cerro de Oro y Arroyo Sásabe.

INTRODUCTION

A preliminary revision of the lithostratigraphic nomenclature in the state of Sonora, shows that more than 60 names have been used for Cretaceous units (Monreal, 1993). This proliferation of names, that complicates the lithostratigraphic nomenclature of Sonora, stems

from the lack of adherence to any stratigraphic code or guide by workers who either have named such units, or have not been able to recognize obvious lithocorrelations with previous formally named units.

Obviously, having that many names in use for the Cretaceous units of Sonora indicates several stratigraphic problems, among which are: (1) Synonymy, that is, different names have been applied to the same units; (2) lithostratigraphic units that have been introduced with poor on inadequate geologic work and not following stratigraphic regulations or guidance, which resulted in the need to revise, redefine or subdivide them, in order to make them useful for geologic work, and related to this, (3) the introduction of units lacking complete descriptions and other relevant information, so that they can be used for comparisons with sections described from other areas. Evidently, this also reflects the lack of adherence to procedures and recommendations given by stratigraphic codes and guides, like the North American Stratigraphic Code (NACSN, 1983), which are set up to avoid stratigraphic problems and to facilitate scientific progress.

The inconsistencies and conflicts in the terminology for the Cretaceous of Sonora can only lead to confusion to the geologic community making more difficult future work. For instance, applying different names to the same lithostratigraphic units can conduct to important correlation mistakes and to further difficulties in establishing their geographic extension and diachronism, which are very important in paleogeographic reconstructions. Therefore, keeping names to a minimum facilitates geologic work.

However, the time is right to bring order to the stratigraphic practice for the Cretaceous nomenclature of Sonora, since much work still remains to be done. Not making an effort to bring order into it, will make things worse and much more difficult to correct in the future. Therefore, the purpose of this work is to provide an objective revision of the nomenclature applied to Cretaceous rocks of selected areas in northern Sonora (Fig. 1), following the rules set by the North American Commission on Stratigraphic Nomenclature (NACSN, 1983). Also, the paleogeographic implications of the results here obtained are discussed.

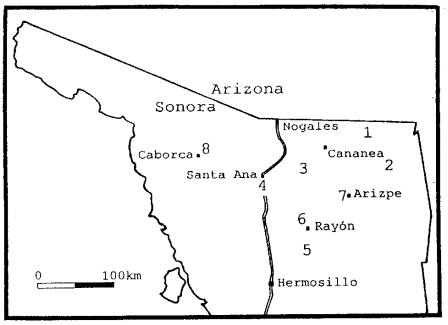

Fig. 1 - Map of northern Sonora showing location of selected areas where Cretaceous rocks are exposed: Cabullona area (1), Sierra del Tigre (2), Sierra Azul (3), Santa Ana (4), Cerro de Oro (5), Tuape (6), Arizpe (7), Sierra El Chanate (8).

Since most of the Lower Cretaceous rocks of Sonora either resemble the Bisbee Group, or have been referred to as part of it, we believe it is of crucial importance to review the lithostratigraphic characteristics of this group as well as those of the Upper Cretaceous strata, as originally described in southeastern Arizona and northeastern Sonora. This, in order to provide a stratigraphic framework against which the selected successions in Sonora are compared.

Following is a discussion on the nomenclature and stratigraphic problems of the Cretaceous successions exposed in Cabullona, Sierra del Tigre, Sierra Azul, Santa Ana, Cerro de Oro, Tuape, Arizpe and Sierra El Chanate (Fig. 1). Excluded from this work are the mostly volcanic sequence of supposed Late Cretaceous to Early Tertiary age because their chronostratigraphic position for the most part are uncertain and no lithostratigraphic nomenclature has been proposed for the majority of them. The descriptions of the Bisbee Group given by Ransome (1904) and Hayes (1970) are summarized in Table 1, along with the general characteristics of the Bisbee

Group units as known in the areas under consideration in this work.

The revised lithostratigraphic scheme for the Cretaceous of Sonora here proposed includes the revision, redefinition and abandonment of previously established units, following the recommendations contained in the North American Stratigraphic Code (NACSN, 1983). For the sake of objectivity, our revision is based, as much as possible on: (1) lithic characteristics and independence from both geologic history and time concepts, (2) priority, (3) need, and (4) clarity and simplicity. Although most workers introducing new lithostratigraphic units do not comply with the requirements of the North American Stratigraphic Code, for the purpose of this work, those units proposed in periodicals and publications of relatively wide distribution were considered as formal and those introduced in meeting abstracts, thesis or dissertations were considered as informal. However, all the conditions for formality set in the code were also taken into consideration.

THE CRETACEOUS IN SOUTHEASTERN ARIZONA AND NORTHEASTERN SONORA

Bisbee Group

In 1902, Dumble briefly described, under the name of Bisbee beds, a sequence of arenaceous and calcareous strata near the town of Bisbee in southeastern Arizona. Later, Ransome (1904) raised the Bisbee term to a group rank and divided it into four formations: Glance Conglomerate, Morita Formation, Mural Limestone and Cintura Formation; however, Ransome's lithologic descriptions were too general. Later on, many other workers contributed to the understanding of the Bisbee Group of southeastern Arizona (e.g., Stoyanow, 1949; Gilluly, 1956; Hayes and Landis, 1964; Hayes, 1970, and many others).

Lower Cretaceous strata of northeastern Sonora, were first recognized by Taliaferro (1933) in Sierra Anibacachi. He recognized the Glance Conglomerate, Morita Formation and Mural Limestone of the Bisbee Group, which unconformably overlies the Paleozoic section of that region. Taliaferro (1933) described the basal Glance Conglomerate as consisting of clasts of paleozoic and precambrian rocks, reaching a maximum thickness of 1,000 m, and gradationally overlain by the Morita Formation. In turn, the Morita Formation consists of interbedded sandstone, siltstone and shale, has an estimated thickness of 1,500 m (Jamison, 1987), and is gradationally overlain by the Mural Limestone. Taliaferro (1933) recognized the Mural Limestone as composed of a 100 m thick lower part consisting of thin-bedded shaly limestone, interbedded sandstone and calcareous shale, and an upper part consisting of a 130 m thick section of massive limestone with only minor intercalations of sandstone and shale. Warzeski (1987) divided the 260 m thick upper member of the Mural Limestone in Sierra Anibacachi and Cerro Caloso into five members which from the base upwards are: Canova, El Caloso, Angostura, La Aguja and Agua Prieta. However, these members are of local importance since they can not be recognized in neighboring localities of southeastern Arizona (Warzeski, 1987), and have not been recognized elsewhere in Sonora.

The uppermost unit of the Bisbee Group, the Cintura Formation, is exposed in the valley between Cerro Caloso and Sierra La Ceniza, southeast of the Sierra Anibacachi. There, the Cintura Formation consists of interbedded sandstone, siltstone, mudstone and some carbonaceous beds of fluvial and deltaic origin, reaching a thickness of about 700 m (Grijalva-Noriega, 1993).

The Bisbee Group was originally considered entirely as Lower Cretaceous (Ransome, 1904; Gilluly, 1956, Stoyanow, 1949; Hayes, 1970), but further work by Bilodeau and Lindberg (1983) demonstrated that the Glance ranges from Upper Jurassic to Lower Cretaceous.

Although the Bisbee Group in northeastern Sonora has not received further serious attention since Taliaferro's work, except for the work of Warzeski (1987) in the Mural Limestone, one of the authors (González-León, 1994) worked in the area focusing on the Upper Cretaceous strata and confirms the accurate recognition of the Bisbee Group formations of southeastern Ari-

zona made in northeastern Sonora by Taliaferro (1933).

Cabullona Group

Upper Cretaceous strata (Santonian to Maastrichtian) of northeastern Sonora, exposed in the Cabullona basin, were assigned by Taliaferro (1933) to the Cabullona Group, which he divided into five units: Snake Ridge Formation, Camas Sandstone, Packard Shale, Upper Red Beds, and Rhyolite Tuff.

Recent investigations in the Cabullona Basin by one of us have permitted to make a reassignment of Taliaferro's lithostratigraphic nomenclature. According to González-León (1992, 1994) the lowermost unit of the Cabullona Group is the Corral de Enmedio Formation, instead of the Snake Ridge Formation of Taliaferro, as no unit with the lithologic characteristics of the Snake Ridge is present in the Cabullona Basin. The Corral de Enmendio is disconformably overlain by the Camas Sandstone. The Packard Shale overlies the Camas and is in turn overlain by the Lomas Coloradas Formation, a name that replaces the "Upper Red Beds" of Taliaferro, as the type section of that unit was measured along the Lomas Coloradas hills of the Cabullona area (Taliaferro, 1933). The El Cemento Conglomerate is part of the Cabullona Group, being laterally equivalent to the Packard and Lomas Coloradas formations.

The uppermost unit of the Cabullona Group of Taliaferro (1933), the Rhyolite Tuff, is no longer considered as Upper Cretaceous and part of the Cabullona Group, but is considered as Tertiary instead, as it unconformably overlies the Lomas Coloradas Formation (González-León, 1994).

SIERRA DEL TIGRE

The Sierra del Tigre is located in northeastern Sonora, about 40 km northwest of the town of Bavispe and about 90 km northeast of Arizpe (Fig. 1). Lower Cretaceous strata were recognized by Imlay (1939) from the sierra at the head of Cañon Santa Rosa, but no further work has been done by any other author in that area. Imlay (1939) reported a Cretaceous section 950 m thick on top of Paleozoic rocks. The lower 516 m consists of shale, sandstone and minor limestone with an Aptian-Albian marine fauna of bivalves and ammonites. The remainder 434 meters consist of interbedded medium- to thick-bedded limestone, sandstone and minor shale. The limestone beds predominate upwards and the uppermost part of the section is a sequence of interbedded limestone, shale and sandstone. Imlay (1939) did no attempt to correlate this section with the Bisbee Group.

González-León and Jacques-Ayala (1990) correlated the sequence of Sierra del Tigre, although quite thick, to the Mural Limestone. Following these authors idea, and although more field work is needed, it is herein established that the lower 516 m of the section correspond to the lower member of the Mural, because it contains thin- to medium-bedded fossiliferous marly limestone, shale and sandstone. The upper 434 meters consisting of thick-bedded limestone and minor shale and sandstone, correspond to the upper member of the Mural Limestone of Ransome (1904) (Table 1).

SIERRA AZUL AND CERRO LA BANDERA

The northernmost known outcrops of Lower Cretaceous rocks in north-central Sonora occur in the western flank of Sierra Azul and Cerro La Bandera area. This mountain range is located about 35 km due east of the town of Imuris and approximately 55 km southwest of the city of Cananea (Fig. 1).

The Lower Cretaceous units of the Sierra Azul area were originally described by Rangin (1986) who correlated them with the Bisbee Group of southeastern Arizona and northeastern Sonora, as well as with other coeval sections elsewhere in Sonora. However, Rangin (1986) did not assign the Sierra Azul units to the Bisbee Group or to any of its composing formations, even though he postulated that the Sierra Azul succession corresponds to a domain transitional between a sedimentary and a volcanogenic, in eastern and western Sonora respectively.

The descriptions given by Rangin (1986) were used by González-León and Jacques-Ayala (1990) in their paleogeographic synthesis for the Cretaceous of Sonora which included the Sierra Azul succession but did not assign the units to any lithostratigraphic scheme either.

In a meeting abstract, Kitz and Anderson (1988) postulated that the Sierra Azul succession was a deep-water basinal equivalent of the continental to shallow water Bisbee Group of Ransome (1904) and apply to it (informally) the nomenclatural scheme of such a lithostratigraphic group. Accordingly, they recognized the Morita, Mural and Cintura formations. However, in a subsequent work McKee (1991) does not adhere to this stratigraphic practice, and developed the idea of deposition in a marine basin well below storm-wave-base, with the limestone beds and coarse siliciclastic rocks composed of shallow water constituents (including organic remains) due to re deposition into deeper water, by means of block sliding and other mass gravity processes.

However, the assignation of the units in Sierra Azul to a given nomenclature should be independent from the veracity of this hypothesis because, according to article 22(d) of the North American Stratigraphic Code (NACSN, 1983), the inferred geologic history and depositional environment of a given unit are not valid criteria for the establishment of lithostratigraphic units. In fact, one must rely solely on the lithologic characteristics of the rock bodies.

After analyzing and comparing descriptions given for the Sierra Azul sequence by Rangin (1986) and McKee (1991), we came to the conclusion that there are not any major or relevant differences with the Bisbee units of northeastern Sonora as to warrant the establishment of a new set of lithostratigraphic units. Hence, as formerly expressed by Kitz and Anderson (1988), we herein propose to utilize the Bisbee Group nomenclatural scheme for the Sierra Azul sequence (Table 1).

In the Sierra Azul area, Rangin (1986) described a 1,700 m thick Lower Cretaceous section exposed North of Santa Teresa Ranch between Cerro La Calosa and Arroyo El Cuchillo, recognizing six lithic units. This section is located within the study area of McKee (1991) who distinguished several units, numbered from 1 to 7, and which are somewhat equivalent to those of Rangin (1986). Therefore Unit 1 of McKee and the lowermost unit of Rangin are assigned to the Glance Conglomerate. Mckee's unit 2 is equivalent to unit 2 of Rangin and corresponds to the Morita Formation. McKee's units 3, 4, 5 and 6 (Rangin's subdivisions 3, 4, and 5) are in turn assigned to the Mural Limestone. Finally, the Cintura Formation corresponds to Mckee's unit 7 and to the uppermost unit of Rangin. Based on the above, brief descriptions of these units as proposed in this paper for Sierra Azul are given in Table 1

Northwestward from Sierra Azul is located the Cerro La Bandera area. There occurs a continetal conglomeratic unit, resting on Jurassic rocks and overlain by Quaternary deposits, for which Gilmont (1978) informally introduced the name Cocospera formation. Later on, Nourse (1989) correctly recognized the Cocospera formation as the conglomeratic unit underlying the Cretaceous fossiliferous beds in Sierra Azul, and postulated that, except at one locality, the contact with underlying Jurassic rocks is everywhere a fault within his study area.

Thus, Gilmont's (1978) unit lithologically is very similar to and occupies the stratigraphic position of the Glance Conglomerate, and therefore the term Cocospera formation must be abandoned and replaced by the Glance.

SANTA ANA AREA

Cretaceous rocks crop out west, south and southeast of the town of Santa Ana (Fig. 1). The first studies on the Cretaceous rocks of Santa Ana date back to 1929 when Teodoro Flores performed reconnaissance geologic work in central Sonora, followed by Burckhardt (1930) who studied some Valanginian-Hauterivian fossils collected near the town of Santa Ana.

Arellano (1956) suggested an equivalence of these rocks to the Bisbee Group of Ransome (1904) in Arizona, but it was not until 1968 when Salas informally assigned the name "Represo formation" to the these rocks. This name was later used by Morales-Montaño

(1984). Later, Rangin (1986) did not assigne these rocks to any nomenclatural scheme, but he correlated them with the Morita and Mural formations of southeastern Arizona. Later on, Navarro-Fuentes and Tellez-Duarte (1988) assigned (informally) the Santa Ana rocks to the Bisbee Group, but assigned the stratigraphic interval which corresponds to the Mural Limestone to the Represo formation. But afterwards, Navarro-Fuentes (1989) also assigned (informally) these rocks to the Bisbee Group, recognizing the Morita, Mural (instead of Represo), and Cintura formations, although he did not give any explanation at all to support his conclusion, or his reasons for this change in terminology. Similarly, Jacques-Ayala (1993) referred to the Cretaceous rocks exposed in the Santa Ana area as the Bisbee Group.

Based on its lithological characteristics, we conclude that indeed, the stratigraphic sequence exposed in the Santa Ana area should be taken as the Bisbee Group, including the Morita, Mural and Cintura formations (Table 1). Furthermore, after a careful revision of the lithologic descriptions and thicknesses (485 m) of the units described by Salas (1968) and by Navarro-Fuentes (1989), we came to the conclusion that the Represo formation only fits the characteristics of the Mural Limestone and the lowermost part of the Cintura Formation. Therefore, to avoid further confusion, the Represo name should be completely dropped off future geologic work.

On the other hand, Jacques-Ayala (1993) reports the presence of the Arroyo Sásabe Formation (a chronocorrelative of the Mural) at the southernmost exposure of Cretaceous rocks in the Santa Ana area, southwest of the Arco Verde Ranch. Here, this unit consists of shale, sandstone and minor limestone and conglomerate, and contains the foraminifer *Orbitolina*, but because this unit is lithologically dissimilar to the Arroyo Sásabe as exposed in the Sierra El Chanate, we believe that what Jacques-Ayala called Arroyo Sásabe in the Santa Ana area is only a slight facies change of the Mural, and should not be taken as the Arroyo Sásabe, to avoid further nomenclatural complications. Figure 2 shows the history of the nomenclature applied to the Cretaceous stratigraphic sequence exposed in the Santa Ana area as well as our proposed nomenclature.

Furthermore, according to Jacques-Ayala (1993), another unit, the Upper Cretaceous Pozo Duro Member of the El Chanate Formation, consisting of a pebble conglomerate in a reddish purple mudstone, lies unconformably on top of the Cintura in Cerro Pima (near Rancho El Represito). But because (1) the exposed thickness of this unit in this area is only a few meters, (2) its exposures are very poor and (3) the lithologic description given by Jacques-Ayala (1993) is too vague, we advise no to extend this name to the Santa Ana area, until further studies are performed. Instead, it should be taken as a facies change of the upper part of the Cintura Formation to avoid further stratigraphic complications.

Also, it seems that the section in Cerro La Pima, which is Navarro-Fuentes (1989) "Schoolen 2", is overturned. Therefore what Navarro-Fuentes referred to as the Cintura in Cerro La Pima is actually the Morita Formation and vice versa.

In the Santa Ana area, the Bisbee Group is exposed from Cerro La Pima to the west to Cerro El Represo to the east and to the ranches of Los Chirriones and La Carleña to the south. It varies in thickness from 1500 m in Cerro La Pima to the west, to 1900 m to the south and southeast of Santa Ana (Jacques-Ayala, 1993).

The chronoposition of the Bisbee Group in the Santa Ana area is not well constrained. According to Navarro-Fuentes (1989) and Jacques-Ayala (1993) it is Aptian-Albian, based on lithocorrelation and the presence of the foraminifer *Orbitolina texana* (Roemer) (Salas, 1968) in the stratigraphic interval corresponding to the Mural Limestone. On the other hand, Flores (1929) and Burckhardt (1930) reported the presence of Neocomian fossils, therefore the possibility of the Bisbee Group ranging from Neocomian to Albian should not be ruled out, until further chronostratigraphic work is done.

CERRO DE ORO AREA

The Cerro de Oro area is located in central Sonora, approximately 60 km northeast of Hermosillo. Several names and different chro-

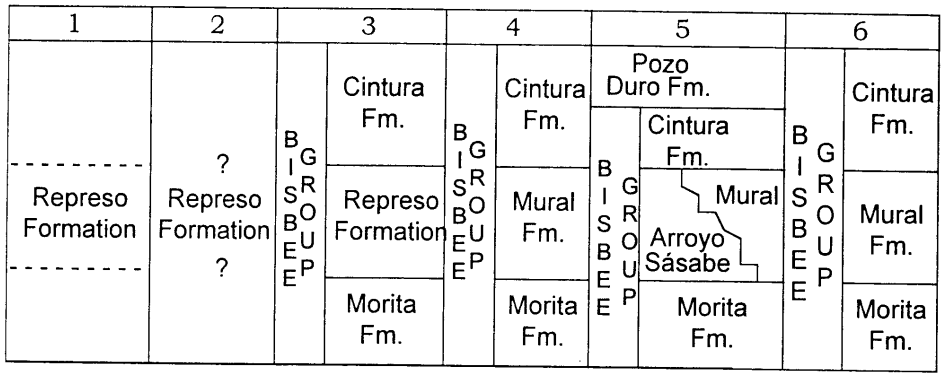

Figure 2.- History of the stratigraphic nomenclature applied to the Cretaceous units of the Santa Ana area. 1, Salas (1968); 2, Morales-Montaño (1984); 3, Navarro-Fuentes and Tellez-Duarte (1988); 4, Navarro-Fuentes (1989); 5, Jacques-Ayala (1993); 6, this work.

nopositions have been assigned to Cretaceous strata of this area, creating a problem due to the lack of an adequate lithostratigraphic framework.

González-León and Jacques-Ayala (1988) used the following formational names, from base to top: 1) Cerro de Oro Formation (Barremian-Lower Aptian); 2) Bisbee Group, including Morita Formation (Upper Aptian), Mural Limestone (Lower-middle Albian) and Cintura Formation (middle-Upper Albian); and 3) La Palma Formation (Cretaceous, post-Albian).In contrast, Castro and Morfín (1988) informally referred to the same rocks as the Cerro de Oro Group, including the following formations: a) Los Tubos (Aptian-Albian), b) Caliza Antúnez (Albian), and c) Los Valles (post-Albian-Cenomanian). The Los Tubos formation corresponds to what González-León and Jac-ques-Ayala (1988) named Cerro de Oro and Morita formations, the caliza Antúnez to the Mural Limestone and the Los Valles formation to both the Cintura and la Palma formations of González-León and Jacques-Ayala (1988).

Clearly, there is a problem with the name Cerro de Oro, since it has been applied both, to a formation (González-León and Jacques-Ayala, 1988) and to a group (Castro and Morfín, 1988). Similarly, there is a homonymy conflict for La Palma name because González-León and Jacques-Ayala (1988) used it for an Upper Cretaceous formation whereas Amaya et al. (1988) and Castro and Morfín (1988) applied it to Precambrian (?) rocks.

Bisbee Group

Following the rules and regulations established by the North American Commission on Stratigraphic Nomenclature (NACSN, 1983), and because the lithologic characteristics of the units in the Cerro de Oro area are very similar to the Bisbee Group as described in southern Arizona and northern Sonora, the name Bisbee Group should be used instead of Cerro de Oro Group. Furthermore, the term Cerro de Oro has been used more with a formational rank (e.g.: González-León and Jacques-Ayala, 1988; Jacques-Ayala et al., 1990; Grijalava-Noriega, 1991), therefore, we propose to keep this usage.

In fact, the Castro and Morfín's (1988) nomenclatural scheme must be abandoned altogether and maintained the one introduced by

González-León and Jacques-Ayala (1988) because: (1) the stratigraphic subdivisions of the latter authors make it easier to establish comparisons with other areas; (2) their scheme is based on natural lithologic unit breaks and more useful for geologic work, since an unconformity separates the Cerro de Oro Formation from the Morita and from the Upper Cretaceous La Palma Formation, a fact not recognized by Castro and Morfín (1988), who, as mentioned above, lumped them together in their Los Tubos and Los Valles units respectively; and (3) the names Morita, Mural and Cintura have precedence, by the rule of priority, over the Los Tubos, Antunez and Los Valles terms because the former were published first in the same issue. In addition, we herein propose to follow González-León and Lucas (in press) suggestion to include the Cerro de Oro Formation as part of the Bisbee Group in this area (Table 1)

La Palma Formation

As mentioned above, the "La Palma" term was formally used to refer to an Upper Cretaceous unit (González-León and Jacques-Ayala, 1988). In contrast to this usage, the La Palma term was informally used also to refer to Precambrian (?) rocks (Amaya et al., 1988; Castro and Morfín, 1988). However, the use of the term in this sense is inadequate because:

(1) it was first published in an abstract form (Amaya et al., 1988), and therefore informally published;

(2) The La Palma Formation *sensu* González-León and Jacques-Ayala (1988) was formally published first, because it appeared before in the issue where it was also published *sensu* Castro and Morfín, 1988; and

(3) applying the La Palma name to Upper Cretaceous rocks with a formational rank will not make necessary to bring another name to the stratigraphic nomenclature of Sonora. Therefore, we conclude that the use of this term should be retained, but to refer to an Upper Cretaceous unit *sensu* González-León and Jacques-Ayala (1988).

TUAPE AREA

Cretaceous rocks near the town of Tuape, are located about 150 km northeast of Hermosillo (Fig. 1), and have been studied by Rodríguez-Castañeda who in 1984 and 1988 assigned part of the succession to the Upper Jurassic without giving formational names to them. However, in 1991, Rodríguez-Castañeda proposed the Bacuchi, Tuape and Los Tanques formations to encompass the Lower Cretaceous rocks of this area. The first two units include rocks that were considered to be Jurassic in the 1984 and 1988 works of Rodríguez-Castañeda.

The Bacuchi Formation consists of limestone, shale, sandstone and conglomerate, whose age is poorly constrained. It was correlated by Rodríguez-Castañeda (1991) with the Glance Conglomerate. However, it is lithologically very similar to the Cerro de Oro Formation of González-León and Jacques-Ayala (1988) and González-León and Lucas (in press), therefore we herein propose to use Cerro de Oro Formation instead of Bacuchi. Similarly, we propose to abandon the names Tuape and Los Tanques because Rodríguez-Castañeda (1991) set forth those units to include in them a lower terrigenous unit and an upper mostly chemical one respectively, which in stratigraphic position and lithic characteristics are quite similar to the Morita and Mural formations respectively.

Further support for the abandonment of the Bacuchi, Tuape and Los Tanques names is provided by the fact that the Cerro de Oro, Morita, Mural and Cintura formations had previously been recognized by González-León and Jacques-Ayala (1988) in the Cerro de Oro area located about 100 km SSW of the town of Tuape. This means that geographically, the Rodríguez-Castañeda's units lie somewhat in between the Bisbee Group of northeastern Sonora and that of Cerro de Oro, and keeping and using the Bacuchi, Tuape and Los Tanques names may imply that they represent different units. Nevertheless, since such is not the case, this assumption may lead to confusion or erroneous considerations as to the Cretaceous geology of Sonora, and according to article 20 of the NASC, this is enough reason for the abandonment of stratigraphic units.

Thus, the Cretaceous scheme herein proposed for the Tuape region consists of the Bisbee Group with the following units in ascending order: Cerro de Oro Formation, Morita Formation and Mural Limestone (Table 1). Rocks assignable to the Glance and Cintura formations have not been reported from the Tuape region.

ARIZPE AREA

The area under consideration is located approximately 10 km northwest of the town of Arizpe, and about 150 km northeast of Hermosillo (Fig 1). Here, a sequence of about 2000 m, exposed from Sierra Los Azulitos to Cerro La Ceja, was informally assigned to two groups by González-León (1978); the Ceja group which he divided into the Temporales, El Macho and Mesa Quemada formations, and the Azulitos group which comprised the Nogalar and Sahuaro formations. These units are unconformably overlain by what González-León (1978) informally named Aguila conglomerate. Later on, González-León and Jacques-Ayala (1990) established a correspondence of the Temporales, El Macho and Mesa Quemada formations with the Morita, Mural and Cintura Formations, but they did not suggest the use of these names instead. But in fact, the lithologic characteristics of both the Azulitos and Ceja groups very much resemble the Bisbee Group as defined by Ransome (1904).

Consequently, we have arrived to the conclusion that both groups should be dropped out completely from current use, along with their corresponding formations, and be replaced by the Bisbee Group nomenclature. In addition, analyzing the lithologic descriptions of the Temporales formation of González-León (1978), we recognize, at the base of the section in the Arizpe area, a unit we believe to correspond to the Cerro de Oro Formation of González-León and Jacques-Ayala (1988), which should be included at the base of the Bisbee Group (Fig. 3).

Therefore, it is herein established that limestone beds intercalated with marly sandstone

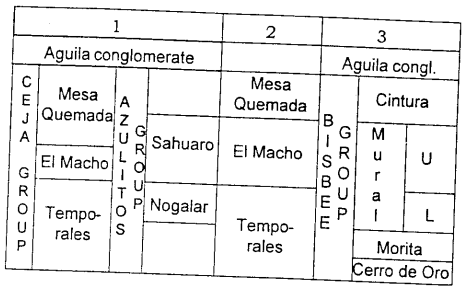

Fig. 3 - Stratigraphic nomenclature applied to the Cretaceous rocks of Arizpe area, as interpreted in this work. 1, González-León (1978); 2, González-León and Jacques-Ayala (1990); 3, this work. L= lower, U= upper.

at the base of the Temporales formation of González-León (1978) correspond to the Cerro de Oro Formation of González-León and Jacques-Ayala (1988), as exposed in the Cerro de Oro area.

Bisbee Group

It is herein established that in the Arizpe area the Bisbee Group is comprised of the Cerro de Oro, Morita, Mural and Cintura formations (Table 1). The Cerro de Oro corresponds to the lowermost 30 to 50 m of the Temporales formation of González-León (1978), the Morita corresponds to the following 250 m of the Temporales. The following units of González-León (1978) actually correspond to the Mural Limestone: the upper part of the Temporales, El Macho, Nogalar, the base of the Sahuaro and the base of the Mesa Quemada formations.The Cintura corresponds to the upper part of the Mesa Quemada (Fig. 3). The Bisbee Group in this area range from Upper Aptian to middle Albian (González-León, 1978).

It is important to note that fossil identifications including *Scabrotrigonia emoryi* and *Neithea texana* from the calcareous beds of the upper part of the Cintura, which are typical bivalves of the upper part of the Mojado

Formation in the Animas Mountains of New Mexico (S.G. Lucas, written communication to C. González-León, 1992), suggest that the upper part of the Cintura may correlate with the Mojado Formation of Zeller (1965) in southwestern New México, and thus a paleogeographic relationship between them.

Furthermore, we believe that this carbonate interval in the upper part of the Cintura could be assigned to a new lithostratigraphic unit that lithocorrelates with the Mojado Formation of New Mexico, but for the time being, it must be included in the Cintura Formation as more field work is necessary to clarify this matter.

Aguila conglomerate

González-León (1978) informally introduced the term Aguila conglomerate for a pebble conglomerate consisting of small poorly classified and rounded clasts of limestone and sandstone, poorly cemented and highly compacted, exposed on top of the Cintura Formation. Clasts of this conglomerate commonly contain orbitolinids, rudists and oysters, similar to the ones found in the Mural Limestone of the area.

The base of this conglomerate, although not exposed, was interpreted by González-León (1978) as an angular unconformity and in turn it is unconformably overlain by Tertiary volcanic rocks.

This unit is mostly covered but, according to González-León (1978) it is at least 20 m thick, and it is only exposed along the Arroyo El Aguila at the southern part of the sierra Cordón de Enmedio.

The chronoposition of the Aguila conglomerate is not certain but, on the basis of lithologic correlation with the base of the Cabullona Group of Taliaferro (1933), and its non-deformational character, González-León (1978) suggested a Maastrichtian chronoposition of this unit.

However, since this unit has not been formally established and since it needs further study, caution should be taken when using this name or trying to extend it outside the Arizpe area.

SIERRA EL CHANATE AND CERROS EL AMOL

Sierra El Chanate is located in northwestern Sonora, 25 km east-northeast of the town of Caborca and 12 km north of Highway 2 (Fig. 1). Cretaceous strata exposed in this sierra vary in thickness from 1200 to 3500 m and range from Aptian (?) to Campanian (Jacques-Ayala and Potter, 1987).

The history of the stratigraphic nomenclature applied to these strata is complicated. For instance: (1) same formational names have been applied to different stratigraphic units, (2) the stratigraphic scope of a given formation has been modified, or (3) unit ranks have been changed from formation to group rank and vice versa. Figure 4 shows the nomenclature that has been applied to the rocks of Sierra El Chanate and the stratigraphic nomenclature suggested in this work.

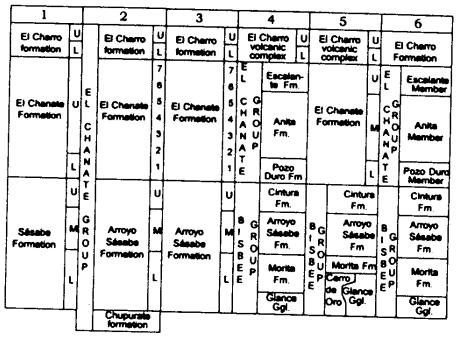

Fig. 4 - Figure 4.- History of the stratigraphic nomenclature applied to the units exposed in Sierra El Chanate by several workers: 1, Jacques-Ayala (1983); 2, Jacques-Ayala (1986); 3, Jacques-Ayala and Potter (1987) and Jacques-Ayala et al. (1988); 4, Jacques-Ayala (1989), Jacques-Ayala et al. (1990); 5, Jacques-Ayala (1993); 6, this work. L= lower, M= middle, U= upper. Numbers one through seven refer to informal members.

Following is a discussion on these units, with emphasis on the history of their stratigraphic nomenclature. The base of Lower Cretaceous rocks of this area corresponds to the Bisbee Group of Ransome (1904), which is overlain by the El Chanate Formation. Upper Cretaceous rocks have been assigned to the El Charro Formation (Jacques-Ayala, 1983), as they are lithologically different from the Upper Cretaceous Cabullona Group of northeastern Sonora.

Bisbee Group

The rocks referred to this group were first named Sásabe formation (Jacques-Ayala, 1983) and later renamed Arroyo Sásabe Formation by Jacques-Ayala (1986, 1989) and Jacques-Ayala and Potter (1987). Later on, Jacques-Ayala et al. (1990, 1992 and 1993) started using Bisbee Group to refer to these rocks and divided it into four units, from base to top: Glance Conglomerate, Morita, Arroyo Sásabe (instead of Mural) and Cintura formations (Table 1).

Worth mentioning is the fact that, Jacques-Ayala (1986) describes a sequence 400 m thick of sandstone and conglomerate below his Arroyo Sásabe Formation, the Chupurate Formation, which he also includes in the El Chanate Group (Table 1). No subsequent work mentions this unit again, and its is difficult to ascertain its correspondence or relationship with the Glance, Morita or any other formation, therefore the presence of this unit is open to debate.

Glance Conglomerate.

Originally, this unit was not observed by Jacques-Ayala in 1983 and 1986, when he begun his stratigraphic studies in this sierra, but when recognized by Jacques-Ayala and Potter (1987) at the base of the section, it was included by them in the lower member of the Arroyo Sásabe Formation. Later, Jacques-Ayala et al. (1990) and Jacques-Ayala (1992) named this unit as the Glance Conglomerate.

Although the descriptions provided by Jacques-Ayala and Potter (1987) and Jacques-Ayala (1992) are too general and we believe further study is required, this unit is lithologically very similar to the Glance Conglomerate of Ransome (1904), and therefore should be referred to as such, at least until further field studies prove otherwise.

The chronoposition of the Glance is very uncertain; nevertheless, based on stratigraphic position, Jacques-Ayala (1992) mentioned the possibility of it being as young as Aptian and as old as Upper Jurassic.

Morita Formation.

In 1983, Jacques-Ayala informally named this unit as the lower member of his Sásabe formation, which he later (Jacques-Ayala and Potter, 1987) renamed Arroyo Sásabe Formation. Later, he referred to this unit as the Morita Formation *sensu* Ransome (1904) (Jacques-Ayala et al., 1990; Jacques-Ayala, 1992). But recently, Jacques-Ayala (1993) erroneously assigned the lower 30 m of this sequence, which is shale with intercalations of limestone and sandstone, to the Cerro de Oro Formation.

Lithologically, this unit is quite similar to the Morita Formation, therefore, we agree with Jacques-Ayala and others (1990) and Jacques-Ayala (1992) that most of the lower member of their former Arroyo Sásabe Formation should be referred to as the Morita. We, on the other hand, disagree with Jacques-Ayala (1993) that the Cerro de Oro Formation is present in this area because the lithology of this formarion in Cerro de Oro area is quite different from the sequence that Jacques-Ayala assigned to his Cerro de Oro Formation in Sierra El Chanate.

Although the Morita Formation is barren of any fossils, Jacques-Ayala (1992) on the basis of stratigraphic position and a very dangerous correlation with the Cerro de Oro Formation, assigned an Aptian chronoposition to the Morita Formation.

Arroyo Sásabe Formation.

The "Sásabe" name is taken from the Sásabe creek, which runs at the northeastern side of Sierra El Chanate. Jacques-Ayala (1983) first informally referred to this unit as the middle member of his Sásabe formation which, as mentioned earlier, was later renamed Arroyo Sásabe Formation (Jacques-Ayala, 1986; Jac-

ques-Ayala and Potter, 1987) to avoid confusion with the town of Sásabe on the border with U.S.A., and divided the formation, without giving any explanation to support their proposal, into three members (Jacques-Ayala and Potter, 1987). Later on, Jacques-Ayala (1989, 1992) and Jacques-Ayala et al. (1990) restricted the Arroyo Sásabe to refer only to the middle member of the previous Arroyo Sásabe and assigned it, together with the rest of the sequence to the Bisbee Group (Glance, Morita, and Cintura formations). Although lithologically similar to the Mural Limestone of Ransome (1904), this unit could not be taken as such, because it contains more shale and sandstone and contains intervals of tuff and volcaniclastic siltstone and sandstone.Therefore, we agree with Jacques-Ayala (1992) that this unit is not the Mural Limestone.

The Arroyo Sásabe was considered as Aptian-Albian by Jacques-Ayala and Potter (1987), based on the presence of *Trigonia* and *Macraster* sp. Attempting any type of correation of the Arroyo Sásabe with other formally established formations should be cautiously done, since its chronostratigraphic position is still not well constrained. Nevertheless, based only on stratigraphic position, the Arroyo Sásabe occupies the Mural Limestone interval.

Cintura Formation.

Jacques-Ayala (1983) and later Jacques-Ayala and Potter (1987), referred to this unit as the upper member of the Sásabe and Arroyo Sásabe formations, respectively. But later in 1990 Jacques-Ayala et al. referred to it as the Cintura Formation, because its lithological characteristics are quite similar to the Cintura Formation of Ransome (1904).

Although the Cintura does not contain any age diagnostic fossils, based on stratigraphic position below the El Chanate Formation, the Cintura could be assigned to the uppermost Albian to possibly Cenomanian.

El Chanate Formation

The nomenclatural history of this unit is somewhat confusing (Fig. 4). Jacques-Ayala (1983) first referred to a unit between the Sásabe and El Charro formations, as El Chanate Formation and divided it into two informal members. Not much later, Jacques-Ayala (1986) referred to El Chanate as a group divisible into four formations: Chupurate, Arroyo Sásabe, El Chanate (here as a formation with seven informal members) and El Charro formations. In 1987, Jacques-Ayala and Potter restricted this unit to a formational rank, between the Arroyo Sásabe Formation below and El Charro Formation above. In contrast to the previous uses given to the "El Chanate", Jacques-Ayala et al. (1990) and Jacques-Ayala (1993) referred to El Chanate as a group comprised of three formations, the Pozo Duro, Anita and Escalante, which were thrown to the literature without following any stratigraphic nomenclatural regulations at all.

Rising the El Chanate unit from a formation to a group rank is not advisable as the internal stratigraphy of this unit, although quite thick, is coherent and should not be separated into formations but only into members. Therefore we propose here to maintain the formational rank for the El Chanate name and separate it into 3 formal members: Pozo Duro, Anita and El Chanate, following Jacques-Ayala et al. (1990) suggestions (Fig. 4).

According to Jacques-Ayala and Potter (1987) the chronoposition of the El Chanate is Albian to Cenomanian(?), because: (1) the presence of a marine fauna with the gastropod *Rissoa dupiniana* d'Orbigny (Albian) and the bivalve *Crassatella* sp. (Albian to Miocene) at the top of the middle member, and (2) fossil wood identified as Albian to Maastrichtian, as well as Barremian to Cenomanian angiosperms present in the upper member.

Discordant chronopositions (Albian and Turonian to Miocene) obtained from fauna from the middle part of the El Chanate Formation (Anita formation of Jacques-Ayala, 1993) is awkward, and thus suspicious. Jacques-Ayala (1993) lithocorrelated the El Chanate Formation with the Cabullona Group. We believe, however that there are not lithological similarities between both units to support such correlation, and given the obscure age of the El Chanate, a chronocorrelation between both units is only tentative. The El Chanate Formation is conse-

quently a very suspicious, partially marine unit overlying the Cintura Formation, that could be either considered an Albian, as first proposed by González-León and Jacques-Ayala (1990), or an Upper Cretaceous (Turonian to Campanian) unit.

In the neighboring area of Cerros El Amol, located just 20 km southeast of Sierra El Chanate, Jacques-Ayala et al. (1990) and García y Barragán (1992) recognized the Bisbee Group and the El Chanate Formation as in Sierra El Chanate, along with a new unit 3200 m thick, the Altar formation which overlies the El Chanate Formation in a sharp and conformable contact, and underlies the El Charro Formation. According to Jacques-Ayala et al. (1990), this unit includes the "Altar Schist", introduced by Stoyanow (1942), mentioned by Cooper and Arellano (1946) and later dated by Damon et al. (1962). It seems as well that the Altar formation is also part of the metamorphic sequence described by Hayama et al. (1984) in the vicinity of the town of Altar. According to Jacques-Ayala et al. (1990) and García y Barragán (1992), the Altar formation is divided into five members (informal).

Although Jacques-Ayala et al. (1990) do not give a possible chronoposition for the Altar Formation, in their stratigraphic columns (their figure 3), they place this unit in the Upper Cretaceous (Turonian-Coniacian). In contrast, Jacques-Ayala (1993) placed this unit (his figure 7) in the Campanian-Maastrichtian.

Nevertheless, and unfortunately in both cases, the authors did not give any explanation to support their chronoposition assignment for the Altar. Similarly García y Barragán (1992) concluded that "...the age of the lower three members of the Altar formation is Late Cretaceous, whereas the age of the upper two members is less certain: perhaps Late Cretaceous, but Jurassic or Triassic are also possibilities."

Given these uncertainties and contradictions we propose not to consider the Altar formation as a new Cretaceous lithostratigraphic unit, until further work is done to precisely date it or to at least establish its stratigraphic position with certainty.

El Charro Formation

This unit, which lies above the El Chanate Formation, was first informally described and divided in two members by Jacques-Ayala (1983). Since then, the El Charro Formation has remained as such, even though it has not been used much in the literature (Jacques-Ayala, 1983; Jacques-Ayala and Potter,1987; Willard, 1988), and in many cases, it has only been vaguely mentioned (Jacques-Ayala, 1989; Jacques-Ayala and García y Barragán, 1988; Jacques-Ayala, García y Barragán and De Jong, 1990; Jacques-Ayala et al., 1993).

Later, Jacques-Ayala, García y Barragán and De Jong (1990) and Jacques-Ayala (1993) referred to El Charro as a volcanic complex. However, this designation is erroneous because (1) the change of the El Chanate name from formational to complex rank (Jacques-Ayala, García y Barragán and De Jong, 1990) was in a guidebook and without giving any supporting evidence, which makes it an informal change; (2) according to the North American Commission on Stratigraphic Nomenclature (NACSN, 1983), the term complex is used for units (lithodemic) which do not conform with the law of superposition, a feature that is not present in the El Charro succession; (3) the internal stratigraphy of the El Charro sequence can be divided into lithostratigraphic units, which is not a characteristic of volcanic complexes; (4) it does not have internal complex stratigraphic relationships, that characterize other volcanic complexes elsewhere [e.g.,Tucson Mountains (Lipman, 1993)]; (5) the facies changes in this unit are normal features of volcanic successions. Furthermore, the introduction of this term does not result in gaining a better understanding of the geology of this region but only contributes to further complicate the stratigraphic nomenclature.

Therefore we conclude that the El Charro unit should be kept as a formation, not as a complex. However, this unit should be properly restudied following the suggestions of the North American Commission on Stratigraphic Nomenclature (NACSN, 1983).

Jacques-Ayala and Potter (1987) originally assigned El Charro Formation to the Upper Cre-

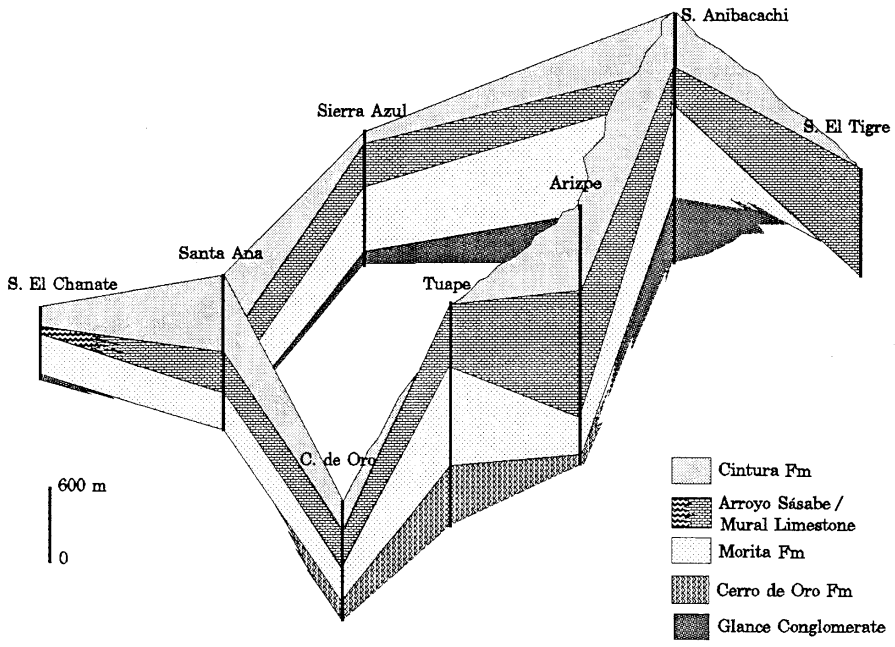

Fig. 5 - Lithocorrelation of the Bisbee Group in northern Sonora. Chronostratigraphic positions and facies relationships are not implied. Upper limits of the sequences are defined by an erosional unconformity.

taceous (?) based on its stratigraphic position. And later, Jacques-Ayala et al. (1993) gave an Ar/Ar age of 71.6 ± 0.7 to it, which places this unit in the Campanian.

PALEOGEOGRAPHIC IMPLICATIONS OF THE BISBEE GROUP

As can be seen in figure 5, the Lower Cretaceous "Bisbee" units of northern Sonora have a large geographic extension. However, deposition during "Bisbee time" was variable, as suggested by the different thickness of the stratigraphic sequences exposed in the areas under consideration in this work. The sequences in north easternmost Sonora (Cabullona, Sierra del Tigre and Arizpe) are the thickest, and become thinner to the southwest, a feature that is readily observed in the distribution of the Glance Conglomerate.

On the other hand, the presence of the Cerro de Oro Formation below the Morita reflects an early advance of the sea, but apparently only in

BISBEE GROUP	SE Arizona and NE Sonora (1)	Sierra El Tigre (2)	Sierra Azul (3)	Santa Ana (4)	Cerro de Oro (5)	Tuape (6)	Arizpe (7)	S. El Chanate (8)
Cintura	Pinkish-gray to pale-red feldspathic sandstone and grayish-red siltstone and mudstone; occasional pebble conglomerate and claystone. A few beds of impure limestone near its base. 300 to 600 m thick.	Not exposed	Red and light green siliciclastic mudstone and shale containing some sandstone, conglomerate and limestone beds. 110 m thick.	Red to purplish-red and green mudstone intercalated with gray to purplish-gray and green sandstone. 500 to 1000 m thick.	Thin- to massive-bedded brown, green, yellow, gray and purple mudstone and fine-grained sandstone, with occasional thin-bedded conglomerate lenses. 290 m thick.	Not exposed	Fine-grained sandstone and shale and sandy shale intercalated with thick-bedded limestone with abundant pelecypods, including oysters, *Inoceramus* and pectens. 800 m thick.	Red to purplish-red, thin- to medium-bedded mudstone with calcareous nodules, shale and sandstone with minor conglomerate lenses. 60 to 300 m thick.
MUR AL upper	Thick-bedded medium- to light-gray fossiliferous limestone, rich in molluscan and coral debris, as well as rudists and orbitolinids. Locally calcareous shale and siltstone intercalated in the upper part. 54 to 84 m thick.	Thick- to massive bedded oyster-rich gray limestone intercalated with thin-bedded nodular sandy limestone, dark-gray and yellowish shale and sandstone. 434 m thick.	Thick to massive-bedded limestone with rudists, corals and orbitolinids, overlain by siliciclastic mudstone, shale, and less sandstone and limestone, with ooids and gastropods 245 to 280 m thick.	Thick-bedded red to pink sandstone, shaly sandstone and green, yellow and gray shale,	Thick- to massive bedded light-gray fossiliferous limestone rich in corals and rudists, and thick-bedded bioclastic limestone with gastropods and orbitolinids. 85 to 385 m thick.	Medium- to massive-bedded light-gray to reddish-brown limestone with orbitolinids, rudists, corals, gastropods, oysters, ammonoids and braquiopods. Thickness unknown.	Calcareous shale, fine-grained sandstone, thin-bedded limestone and oyster-rich marly lime-stone; base is thick lime-stone with rudists, orbito-linids, corals, gastropods, and algae. 520 to 570 m.	**Arroyo Sásabe:** Green shale, and green tuff, volcaniclastic silt-stone and sandstone, purplish red sandstone with ostreid-bearing floatstone to bindstone, intercalated with gray vitric tuffs. 95 m thick.
lower	Thin-bedded, pale-yellowish-brown to pale-olive to greenish-gray oyster-rich limestone and sandstone, and calcareous siltstone and mudstone. 100 to 164 m thick.	Intercalations of fossili-ferous fissile grayish shale, thin-bedded light yellow sandstone and thin- to medium-bedded gray nodular limestone. 516 m thick.	Black shale with sand-stone, siltstone and a few oyster-bearing limestone. Thick-bedded limestone near its base and top with fine-shell fragments. 250 to 295 m thick.	intercalated with thick- to massive-bedded gray limestone. 100 to 650 m thick.	Thin- to medium-bedded brown mudstone intercalated with oyster-rich marly and sandy limestone and sandstone. 65 m thick.	Thin- to medium-bedded green to black fossilife-rous shale, medium to thick-bedded fossiliferous limestone, and thin to medium-bedded sandstone Thickness unknown.	Calcareous shale and sandstone with thin-bedded oyster-rich limestone and sandstone. Sandstone and shale more abundant at the top. 540 to 880 m thick.	
Morita	Pinkish-gray to pale-red feldspathic sandstone and grayish-red siltstone and mudstone; occasional pebble conglomerate and claystone, and impure lime-stone near the top. Less than 400 to 1500 m thick.	Not exposed	Reddish siliciclastic mudstone and shale with sandstone and micro-conglomerate; also layers of oyster-bearing lime-stone. Clasts derived from felsic volcanic rocks. 640 to 1000 m thick.	Red to purplish-red massive-bedded mudstone, gray to purplish-gray medium-bedded sandstone, and lenses of purplish-red to mottled conglomerate. 100 to 500 m thick.	Thin- to thick bedded gray, green and purple mudstone, shale, fine-grained sandstone and occasional lenses of thin-bedded conglomerate. 260 m thick.	Thin- to thick-bedded brown, gray and maroon sandstone, red siltstone, pink quartzarenite and interbedded brown to maroon conglomerate. 800 thick.	Thick-bedded medium- to fine-grained sandstone and shale with occasional thin-bedded microconglo-merate. Approx 250 m thick.	Red to purplish-red mudstone and shale, and fine- to medium-grained sandstone, lenses of igneous rock pebble conglomerate, and rare fossiliferous limestone. 193 to 486 m thick.
Glance	Poorly sorted and poorly rounded schist and limestone cobbles and pebbles bound in a matrix of reddish-brown sandy and silty mudstone. 25 to 75 to 1,100 m. thick	Not exposed	Pebble to cobble conglo-merate with tuffs, volcanic litharenites, siliciclastic mudstone and minor porphyritic felsic igneous rock. 40 to 50 m thick.	Not exposed	**Cerro de Oro:** Thin- to medium-bedded conglomerate, thin to thick-bedded fossiliferous limestone and thin-bedded mudstone and sandstone. 105 to 147 m thick.	**Cerro de Oro:** Thin to medium-bedded limestone, fissile shale with calcareous nodules, fine- to medium-grained sandstone and conglo-merate. 600 m thick.	**Cerro de Oro:** Thin- to medium-bedded light-gray limestone intercalated with marly sandstone in the lower part. Approx. 30 to 50 m thick.	Green to mottled green to buff conglomerate and coarse sandstone. 21m thick.

TABLE I - Generalized lithologic description of the Bisbee Group in the areas under consideration.
1 - Ransome, 1904; Hayes, 1970; 2 - Imlay, 1939; 3- Rangin, 1986; McKee, 1991; 4 - Salas, 1968; Navarro-Fuentes, 1989; and Jacques-Ayala, 1993; 5 - González-León and Jacques-Ayala, 1988; 6 - Rodríguez-Castañeda, 1988, 1991; 7 - González-León, 1978; 8 - Jacques-Ayala, 1983, 1992, 1993, and Jacques-Ayala and Potter, 1987.

central Sonora (Arizpe, Tuape and Cerro de Oro areas); maximum thickness of the Cerro de Oro in the Tuape area could correspond to the center of the Basin during the Cerro de Oro time and possibly during at least the beginning of the Morita time, or it could correspond to an area of more rapid subsidence. Such center must have shifted towards the northeast, later during the rest of the Bisbee deposition, attaining a maximum during Mural time in the areas of Arizpe and Sierra del Tigre.

Furthermore, the members of the Mural vary considerably in thickness, which is a feature that reflects the variations in deposition along the "Bisbee basin" (Table 1, Fig. 5). As shown in Table 1, the Mural Limestone is divisible into two members in northern Sonora, except for the Mural exposed in the Santa Ana area, where it is thinner and not divisible into members. This may reflect a slight change in sedimentation during Mural time from northeast to west-southwest, and may also be related to the drastic facies change in lithology and thickness that gave way to the deposition to the northwest in Sierra El Chanate of the Arroyo Sásabe Formation, which represents a marine lagoonal environment paleogeographically located close to the Alisitos volcanic arc.

CONCLUSIONS

Conspicuously over wide areas, the Lower Cretaceous succession of Sonora is divisible into three parts: a lower mostly terrigenous sequence, a medial carbonate, and an upper terrigenous one. This allowed us to recognize the Bisbee Group in all the sections considered in this study, although some variations do occur. The formational content of the Bisbee Group, as originally described by Ransome (1903) in south easternmost Arizona is found in northern and northeastern Sonora, and is most easily recognized in Sierra Anibacachi and Cerro Caloso in the northeastermost part of the state.

Thus, the exposed Lower Cretaceous strata of Sierra El Tigre is assigned to the Mural Limestone, whereas the succession of Sierra Azul and Cerro La Bandera areas is broken down and assigned to the Glance, Morita, Mural and Cintura formations. Elsewhere, the Glance Conglomerate is only exposed in the Sierra El Chanate area.

In Cerro de Oro, Tuape and Arizpe areas, the stratigraphic position of the Glance below the Morita Formation is taken up by the Cerro de Oro Formation, which apparently attains its maximum thickness in the Tuape area (Fig. 5). Rocks referable to this interval are not exposed in Santa Ana, and therefore, it is unknown whether the Glance or the Cerro de Oro (or none) forms the base of the Lower Cretaceous section there.

Except for Sierra El Tigre, where only the Mural Limestone is present, the Morita Formation is found in all the areas considered in this study, although it shows some variations in thickness (Fig. 5) and lithological content. In the Chanate area, the Arroyo Sásabe Formation overlies the Morita, whereas elsewhere, the Mural Limestone is present instead, with slight thickness and facies changes. On the other hand, the uppermost unit of the Bisbee Group, the Cintura Formation, is not present in the Tuape area and at Sierra El Tigre (Fig. 5).

Of the areas considered, Upper Cretaceous units are only exposed in Cabullona, Arizpe, Cerro de Oro and El Chanate, and due to their contrasting lithological content and/or the scarcity of stratigraphic data, the nomenclatural schemes proposed by earlier workers are maintained. Thus, the Cabullona Group, consisting of the Corral de Enmedio, Camas, Packard, Lomas Coloradas, and the Cemento (laterally equivalent to the latter two units) formations occurs only in Cabullona, whereas in Arizpe the Upper Cretaceous is represented by the Aguila conglomerate for which more field work is needed. La Palma Formation encompass the Upper Cretaceous rocks of the Cerro de Oro area

The rank of the El Chanate Group, set up by Jacques-Ayala (1983, 1986, 1993) and Jacques-Ayala et al. (1987, 1990) in the Sierra El Chanate area, is lowered to formation, composed of the Pozo Duro, Anita and Escalante Members. On the other hand, their El Charro formation needs to be revised. Furthermore, the Altar formation recognized by Jacques-Ayala et al. (1990) and García y Barragán (1992) in Cerros El Amol is not considered as pertaining to the

Upper Cretaceous, due to the ambiguous and seemingly contradictory geologic information now available.

Finally, the paleogeographic distribution of the Bisbee Group during Early Cretaceous time was variable, including thickness variations and facies changes during Morita and Mural times, which are recorded by the Cerro de Oro and Arroyo Sásabe formations. Furthermore, the Lower Cretaceous units differ markedly from the Upper Cretaceous ones, in that they posses a more restricted geographic extent, as well as a contrasting lithologic character. Obviously, this reflects a drastic paleogeographic change between the Early and Late Cretaceous time in this part of the continent, that may be related to the mid-Cretaceous tectonic event proposed by several workers (Rangin, 1977, 1986; Calmus and Radelli, 1987).

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