Revista Mexicana de Ciencias Geológicas, volumen 14, número 1, 1997, p. 38-49.
Universidad Nacional Autónoma de México, Instituto de Geología, México, D.F.

MICROFACIES OF A LOWER CRETACEOUS MARINE SUCCESSION IN CERRO LAS CONCHAS, SONORA, MEXICO

*Rogelio Monreal-Saavedra**

ABSTRACT

The upper Aptian-middle Albian marine sequence exposed in the Cerro Las Conchas is clearly upside down, being the middle Albian rocks in the topographic base of the sequence, while the upper Aptian is in the upper part of the section. The microfacies analysis of this succession showed that the environments of deposition were variable, and represent sedimentation in a shallow sea varying from inner- to outer-neritic water depths. Although the succession was mostly deposited in a shallow-water neritic environment, several minor sea-level changes are recorded which are part of three transgression-regression cycles.

The Cerro Las Conchas succession, although geographically widely separated, is correlated with the U-Bar Formation in the Big Hatchet Mountains of southwestern New Mexico, as their lithologies and fauna present are quite similar. Also, the Las Conchas sequence corresponds to the same facies belts as the U-Bar Formation in New Mexico and the Mural Limestone in southeastern Arizona, but they were probably located along the opposite (southern) margin of the basin.

Key words: Stratigraphy, microfacies, Aptian, Albian, U-Bar Formation, Bisbee Basin, Arivechi, Sonora.

RESUMEN

La secuencia marina del Aptiano superior-Albiano medio expuesta en el cerro Las Conchas está evidentemente invertida, estando las rocas del Albiano medio en la base de la sección, mientras que el Aptiano superior se encuentra en la parte superior de la secuencia. El análisis de las microfacies de esta secuencia muestra que los ambientes de depósito fueron variables, y representa la sedimentación en un mar somero con profundidades que varían de nerítico interior a exterior. También, un número de microfacies presentes en diferentes intervalos en la parte inferior de la secuencia es característico de lagunas y construcciones biogénicas. Además, el análisis de los ambientes deposicionales representados por esta secuencia muestra que, aun cuando la sucesión fue principalmente depositada en un mar somero, existieron varios cambios de nivel del mar que son parte de tres ciclos de transgresión-regresión.

La sección estudiada es correlacionable, aunque geográficamente separada muchos kilómetros, con la Formación U-Bar del suroeste de Nuevo México. Además, la secuencia del cerro Las Conchas y la Formación U-Bar están estrechamente relacionadas, ya que la secuencia en el área de Las Conchas corresponde al mismo cinturón de facies que originó la Formacion U-Bar en Nuevo México y la Caliza Mural en el sureste de Arizona, pero localizado probablemente cerca del límite opuesto (meridional) de la cuenca.

Palabras clave: Estratigrafía, microfacies, Aptiano, Albiano, Formación U-Bar, cuenca Bisbee, Arivechi, Sonora.

INTRODUCTION

The Lower Cretaceous rocks of eastern Sonora provide important clues to the understanding of facies distribution, sedimentary environments and regional paleogeography of the Bisbee Basin. The southwesternmost known exposure of Lower Cretaceous marine sedimentary strata is found in the cerro Las Conchas area near Arivechi, Sonora.

The area under study is located about 5 km to the east-southeast of the town of Arivechi, which is located about 15 km south of the town of Sahuaripa, Sonora. The Lower Cretaceous stratigraphic section here studied is located just south of "Las Conchas", nearby the dirt road Arivechi-Tarachi, about 2 km to the southwest of the highest peak of cerro Las Conchas, and about 1 km south of cerro Peñasco Blanco (Figure 1).

**Universidad de Sonora, Departamento de Geología, Rosales y Bld. Luis Encinas, Hermosillo, Sonora, México. E-mail: monreal@aurora.geologia.uson.mx.*

The cerro Las Conchas area has been under study since Remond (1866) collected fauna from this locality. After Remond, several workers have performed either paleontological, stratigraphical, structural, or geological mapping studies (Gabb, 1869; King, 1939; Martínez and Palafox, 1985; Almazán-Vázquez and Palafox, 1985; Palafox and Martínez, 1985; Minjares *et al.*, 1985; Pubellier, 1987; Almazán-Vázquez and Fernández, 1988; Almazán-Vázquez, 1990; Fernández and Almazán-Vázquez, 1991). None of these authors has dealt with the facies and/or sedimentary environments of the Lower Cretaceous marine sequence.

The purpose of this study was to perform a microfacies analysis and to define the succession of sedimentary environments and sea-level fluctuations represented by the Lower Cretaceous marine carbonate sequence exposed in the cerro Las Conchas. This analysis allows the paleogeographic relationship of this sequence with the rest of the Lower Cretaceous successions exposed in northern Sonora to be modeled.

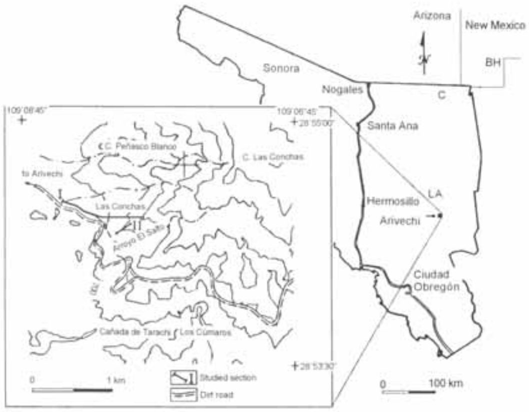

Figure l. Location map of the state of Sonora showing the sections studied in the cerro Las Conchas. BH: Big Hatchet Mountains, C: Cabullona area, L: Lampazos area.

GEOLOGICAL SETTING

The Arivechi region is characterized by a variety of rock types and ages that include: (a) sedimentary rocks of undifferentiated Paleozoic, Mississippian, Permian, Cretaceous, and Miocene age; (b) volcanosedimentary rocks of Jurassic and Late Cretaceous age; (c) Eocene igneous intrusive rocks; and (d) igneous extrusive rocks of Oligocene, Miocene, and Quaternary age (Almazán-Vázquez, 1990; Fernández and Almazán-Vázquez, 1991; Palafox and Martínez, 1985; Radelli, 1995, personal communication).

The rocks of the Arivechi region have undergone compressional and extensional tectonism, as most of the rocks exposed are folded, faulted and intruded by igneous rocks. Many of the sedimentary and volcanosedimentary rocks are metrically and decametrically folded, and several thrust and normal faults cross the area. Also, nappes of Mississippian and Permian rocks are thrust over Jurassic and Cretaceous strata (Almazán-Vázquez, 1990; Fernández and Almazán-Vázquez, 1991; Palafox and Martínez, 1985; Radelli, 1995).

LITHOSTRATIGRAPHY

The Lower Cretaceous carbonate succession exposed in the Arivechi area is upside down (see the Chronostratigraphic Position and Correlation section of this paper). This sequence was studied along two sections, located on the western slope of cerro Las Conchas:

SECTION I

This section runs from north of the watering place for cattle called "Las Conchas", to the hills north of the Arroyo El Salto (Figure 1). Section I was separated into four field lithic units (Figure 2):

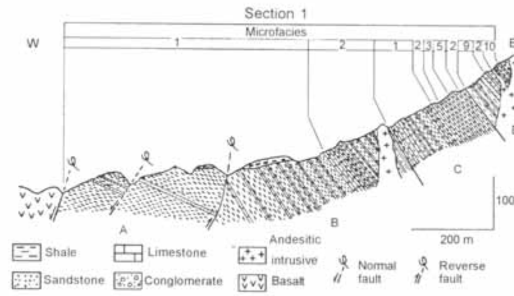

Figure 2. Schematic field profile of Section I, cerro Las Conchas, showing the field units (capital letters) and microfacies present (in numerals). *A*, Unit A; *B*, Unit B; *C*, Unit C; *D*, Unit D.

Unit A

This unit is mainly shale with irregular alternations of sandstone and thin bedded nodular fossiliferous limestone. The shale is thick bedded, sometimes sandy, pervasively fractured, dark gray to black, weathers medium gray, and contains abundant pelecypods (including *Pecten* and *Protocardium*) and gastropods (including *Turritella*). Limestone is thin bedded, nodular, dark gray and weathers light gray to light tan. Sandstone is medium to thick bedded, medium gray and weathers light gray to light tan. Unit A is about 50-m thick, its base is not exposed and the contact with unit B above is transitional. Right along Section I, the contact is a reverse fault.

Unit B

Irregular alternations of shale, limestone and sandstone comprise this unit. Shale is thin bedded, fissile, fossiliferous (including abundant *Turritella*), medium gray and weathers light gray to light tan. The unit displays a structural fabric, with pencil cleavage and microfolding present. Limestone is thin bedded, nodular, medium gray and weathers light gray to light tan and becomes more abundant towards the top of the unit. Unit B is approximately 250-m thick and the contact with unit C, although covered, is probably transitional.

Unit C

This unit is composed of irregular alternations of fossiliferous (including mollusks, corals and echinoderms) limestone and shale. Limestone is thin to medium bedded, nodular, mollusk-bearing (including *Turritella*), medium to dark gray and dark tan, weathers light to medium gray and medium tan, and is occasionally sandy. Shale is thin bedded, fissile, medium gray and weathers light tan. Unit C is approximately 200 m thick and the contact with unit D, although covered, is probably transitional.

Unit D

The uppermost unit is made up of irregular alternations of sandstone, siltstone and shale with occasional intercalations of limestone (at the base) and conglomerate. Sandstone and shale beds are medium bedded, dark gray, weather tan and dark brown, and contain ammonites. Limestone is thin to medium bedded, nodular, dark gray, weathers medium gray and dark brown and contains oyster and small pelecypod fragments. Clasts in the conglomerate beds are rounded, 2 mm to 8 cm in diameter, and are made up of orthoquarzite and sandstone. Since this unit is mostly covered and is intruded by several andesitic dikes and sills which are exposed at the top of the hill, its thickness is not known; nonetheless, about 80 m of this unit are exposed along this section.

SECTION II

This section is located between Section I and the Arroyo El Salto (Figure 1). Section II was separated into four field lithic units (Figure 3):

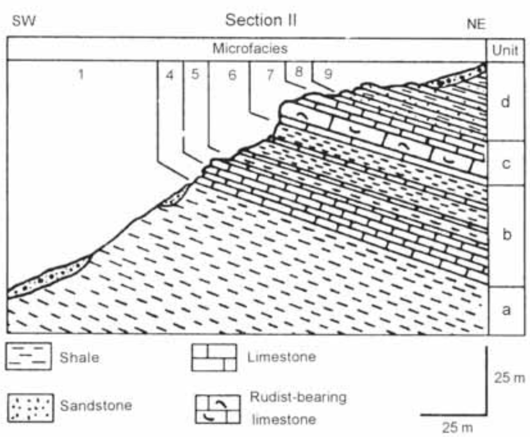

Figure 3. Schematic field profile of Section II in cerro Las Conchas, showing the field lithic units (lowercase letters) and microfacies (in numerals) present. *a*, unit a; *b*, unit b; *c*, unit c; *d*, unit d.

Unit a

This unit is an irregular alternation of thin-bedded fossiliferous shale and very thin-bedded nodular limestone with abundant pelecypods (including *Trigonia*) and gastropods. The base is not exposed and the top is in sharp but conformable contact with unit b. The exposed thickness of unit a is approximately 50 m.

Unit b

This unit is composed of irregular alternations of thin- to medium-bedded, occasionally nodular limestone, sandy limestone, shale and minor calcareous sandstone; shale content increases towards the top. Unit b is rich in pelecypods (including oysters and rudists) and gastropods. Colors vary from light- to dark-gray and weather light- to greenish-tan. The top of unit b is mostly covered and the contact with unit c is sharp but conformable. The approximate thickness of unit b is about 40 m.

Unit c

This unit is an interval of thick- to massive-bedded rudist-bearing (mostly caprinids) medium-gray limestone which is covered by a thin- to medium-bedded somewhat nodular dark-gray orbitolinid-rich limestone. Pérez-Ramos (1988) identified the caprinids as being *Caprotina* sp. and *Caprinuloidea lenki* (Boehm). Unit c weathers light gray and light greenish gray. The contact with unit d is sharp but conformable. Unit c is about 15-m thick.

Unit d

Capping this sequence is an interval of thin- to medium-bedded dark-gray sandstone intercalated with shale and minor amounts of limestone beds. The unit weathers light tan and the top of this unit was not observed because it is covered.

Unit a corresponds to the top of Unit B of section I and units b and c are facies changes of Unit C, unit d most probably corresponds to the base of Unit D of Section I.

MICROFACIES ANALYSIS

MICROFACIES

The 44 samples collected were thin sectioned and prepared for study using standard petrographic procedures. The microfacies analysis was performed using techniques according to the methods of Flugel (1982), Carozzi (1989) and as applied by Longoria and Monreal (1991). Classification of carbonates was done using Dunham's (1962) and Embry and Klovan's (1972) textural scheme, and Folk's (1959, 1962) petrographic scheme. The relative abundance of grain types was established based on the following criteria: A (abundant) for more than 25 grains of a given type; F (frequent) for 16 to 25 grains; S (scarce) for 11 to 15; R (rare) for 6 to 10; and T (trace) for 1 to 5 grains. Tables 1 and 2 show the textural and allochem content of each collected sample.

The carbonate sequence exposed in the cerro Las Conchas area, is herein divided into 10 microfacies, based on textural characteristics and allochem content (Tables 1 and 2). The microfacies were named with numerals and they are stratigraphically young as their number decreases, except for microfacies 4, 6, 7, and 8, which are a package of rocks developed laterally (exposed in section II) as a facies change of facies 5 of section I. Field Unit A of Section I is divisible into one

Table 1. Textural characteristics and allochem content of the microfacies present in Section I of cerro Las Conchas. A: abundant, F: frequent, S: scarce, R: rare, T: traces.

Microfacies		1												2			1			2	3	5	2	9	2	10
Field Unit		A									B						C							D		
Sample No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Texture	Mudstone		x							x	x			x	x	x	x	x	x							
	Wackestone											x								x					x	
	Floatstone	x					x	x	x				x								x		x			x
	Packstone	x																				x				
Siliciclastic				x	x	x																		x		
Allochem content	Intraclasts											R										S			A	
	Ooids											S														
	Pellets								S			T														
	Calcisphaerulids							T						T	S	S	T				S		S			
	Calpionellids														S	S									A	
	Sponges																			A		R				
	Echinoderms						F					R				S					S		S			S
	Spines															T	F	T	F	T	S		F			
	Crinoids														R											
	Planktonic														T				?		T				T	
	Brachiopods										T		S												T	
	Foram. Planktonic										T				T	R				T					A	
	Benthic									T					T	T									T	T
	Miliolids	T																			R					
	Other	R										T				R					F					
	Ostracods	T	T					T		T	R	T		R	A	A	A	S	T	S	F				A	
	Mollusks			T																						
	Bivalves	A	T				A	F		T	R	F	S		T		T				T	S	S			R
	Gastropods	A	T		F		F	S	S	R	S		T			T					R	A	S			
	Cephalopods	S														S					F	S	S			A
	Green algae																					T				
Terrigenous particles								T	R		T	R														A

microfacies, Unit B into two, Unit C into five and Unit D into three microfacies (Figure 2 and Table 1). Field unit a of Section II is divisible into one microfacies, unit b into three, unit c into two and unit d into one microfacies (Figure 3 and Table 2).

A description of the microfacies, in which the Lower Cretaceous marine sequence of cerro Las Conchas is divided, is as follows, from top to bottom:

Microfacies 1

This interval is characterized by mudstone, sublitharenite, calcareous mudstone (fossiliferous micrites), wackestone (biomicrites) and floatstone (biomicrudites). Main allochems present in this microfacies are bivalve and gastropod fragments (including *Turritella*) with trace quantities of arenaceous and planktonic foraminifera (Figure 4, *A*) and ostracod, brachiopod and echinoderm spine fragments. Many of the floatstone samples showed coalescive neomorphism in the form of microsparite and pseudosparite. Terrigenous angular quartz particles are present at some intervals.

This microfacies represents deposition in a shallow-water middle-neritic environment with a high influx of terrigenous sediments.

Microfacies 2

Limestone beds are mudstone, wackestone and floatstone (fossiliferous micrites, biomicrites and biomicrudites) with

Table 2. Textural charactericties and allochem content of the microfacies present in Section II of cerro Las Conchas. A: abundant, F: frequent, S: scarce, R: rare, T: traces.

Microfacies		1						4			5	6		7			8	9		
Field Unit		a						b						c				d		
Sample No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Texture	Mudstone					x	x		x				x							x
	Wackestone											x				x	x			
	Floatstone	x	x	x	x			x						x	x	x	x			
	Packstone										x									
Siliciclastic										x								x	x	
Allochem content	Intraclasts							R		T	A			R		A	A			
	Ooids									R										
	Pellets										F					A	A			
	Calpionellids																T			
	Radiolarians																			S
	Corals																A			
	Echinoderms				R		R				F									R
	Spines					R	T	T			S									
	Crinoids					T											F			
	Planktonic					?	?													
	Brachiopods									T										
	Foram. Planktonic					T											R			S
	Miliolids														R	A				
	Orbitolinids			T											A	R				
	Other	T	T										T	R		A	T			
	Ostracods	R	R		R	F	T					T					T			
	Mollusks					T				T		F								
	Bivalves	A	F	R	A		?	A	R		A			A		A				
	Gastropods	F	S	A					T		A					R				
	Red Algae										T									
	Green Algae										S			S						
Terrigenous particles		R	S	A			T				A	A	S							A

mollusk and ostracod fragments (Plate 1, *B* and *E*), less frequent calcisphaerulids (Figure 4, *D*) and calpionellids (*Colomiella*, Figure 4, *C*) and varying amounts of echinoderm fragments and spines. In addition, present in inconspicuous abundance, are planktonic and benthic foraminifera, planktonic crinoids, bivalve, gastropod and cephalopod fragments. The upper part showed abundant sponge spicule fragments. Also, coalescive neomorphism is present at some intervals.

This microfacies represents deposition in a shallow-water outer-neritic environment, with a variable supply of terrigenous grains.

Microfacies 3

This microfacies is composed of floatstone (biomicrudites) with varying amounts of allochems, which in order of abundance include: ostracod and mollusk fragments, arenaceous foraminifera, echinoderm plates and spines, calcisphaerulids (*Pithonella*?), miliolids (Figure 5, *B*), planktonic crinoids, and planktonic foraminifera (Figure 5, *C*). Abundant coalescive neomorphism is present.

Microfacies 3 represents deposition in a shallow-water middle-neritic environment with an incipient development of

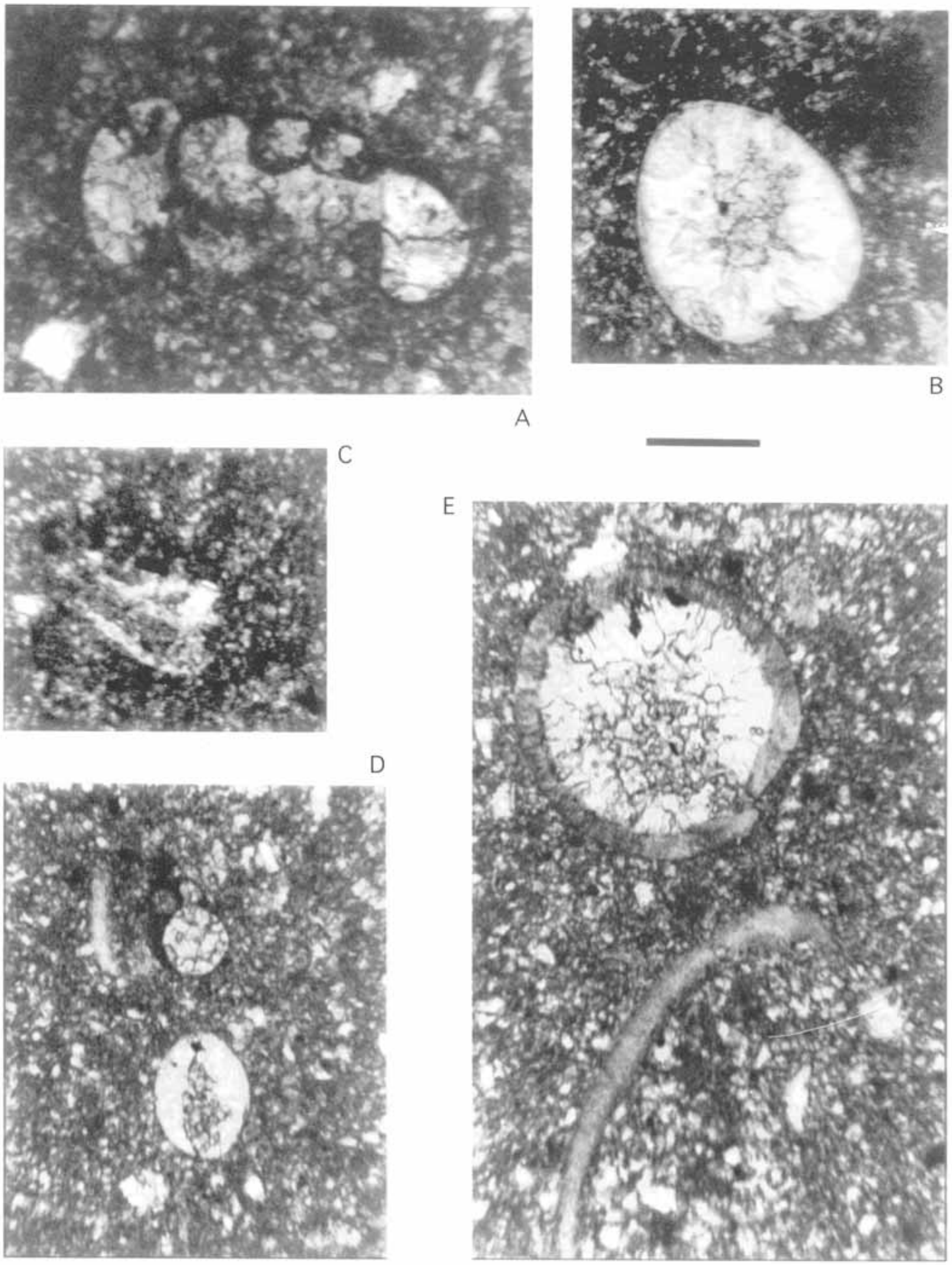

Figure 4. Microfossils of the stratigraphic section studied in the Las Conchas area, Section I. (*A*) Planktonic foraminifera, Microfacies 1. (*B*) Ostracod, Microfacies 2. (*C*) The calpionellid *Colomiella*, Microfacies 2. (*D*) Calcisphaeres (*Pithonella ovalis*?), Microfacies 2. (*E*) Ostracods, Microfacies 2. Bar length = 100 micrometers.

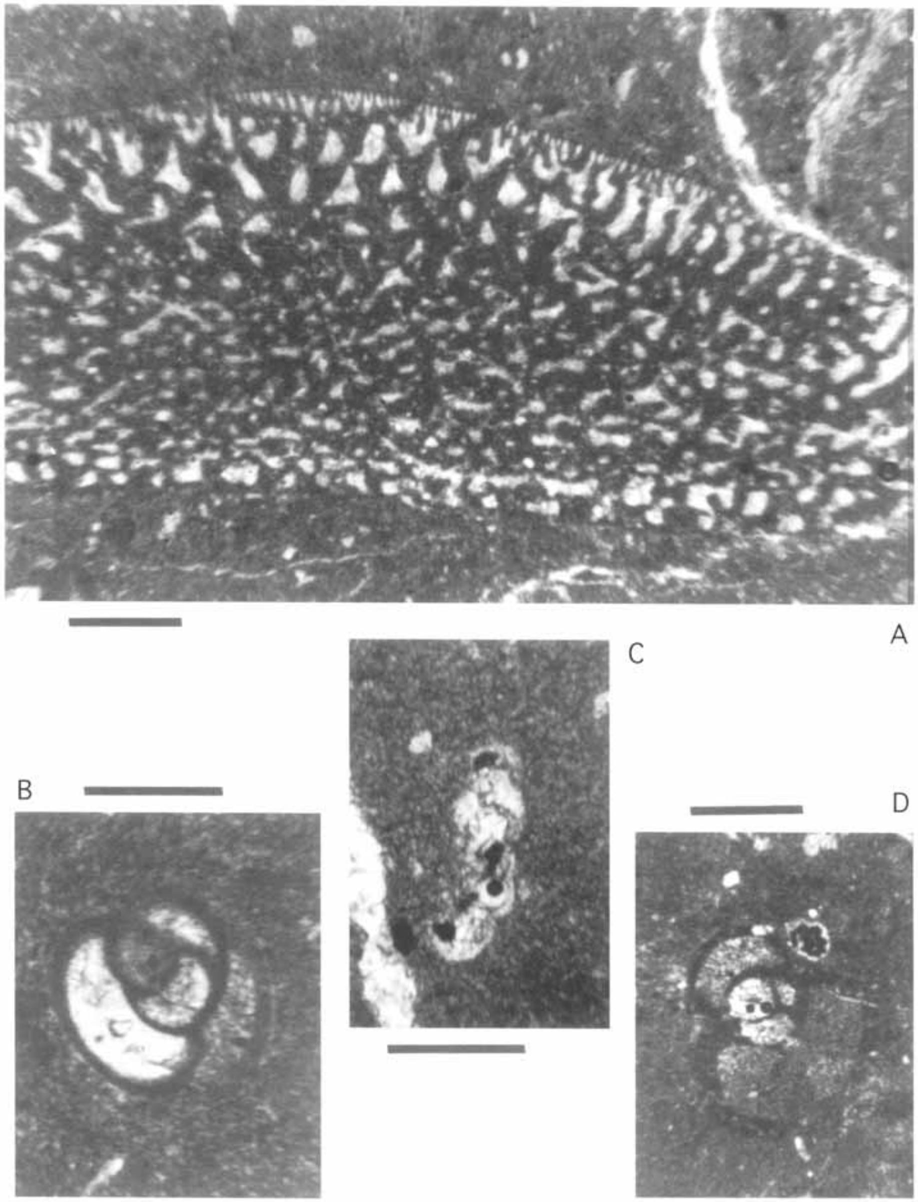

Figure 5. Microfossils of the stratigraphic section studied in the Las Conchas area. (*A*) *Orbitolina texana*?, Microfacies 7, Section II, bar length = 300 micrometers. (*B*) Miliolid, Microfacies 3, Section I, bar length = 100 micrometers. (*C*) Planktonic foraminifera, Microfacies 3, Section I, bar length = 100 micrometers. (*D*) Textularid foraminifera, Microfacies 3, Section I, bar length = 300 micrometers.

lagoonal conditions, as suggested by the presence of minor quantities of miliolid foraminifera.

Microfacies 4

This microfacies includes mudstone and floatstone (biointramicrites, biointramicrosparite and biointramicrudites) with abundant intraclasts and rare occurrences of ooids, abundant bivalve fragments and traces of gastropods, brachiopods and echinoderm spines. This interval contains abundant coalescive neomorphism, as some micrite is recrystallized to microsparite (20-50%).

Microfacies 4 represents deposition in a shallow-water middle neritic environment, with influence or proximity to shoal conditions, and with a high influx of terrigenous sediments.

Microfacies 5

Packstone (biointrapelsparites and biointrapelpseudo-sparites) with abundant intraclasts, pseudopeloids, mollusk fragments and echinoderm plates and spines, with lesser amounts of green algae and sponge spicules, comprises this microfacies. Large terrigenous quartz grains are present as well as late cement "B", and coalescive neomorphism including microsparite and pseudosparite.

This microfacies represents deposition in a shallow-water middle-neritic environment with development of biostromes, and with only a very slight influence of terrigenous sediments.

Microfacies 6

Limestone beds in this microfacies are mudstone and wackestone (fossiliferous micrites, and biomicrudites) with only mollusk (oyster) fragments and traces of ostracodes. The mudstones contain abundant terrigenous quartz grains and abundant coalescive neomorphism, with around 70% of the micrite matrix recrystallized to microsparite.

This microfacies represents deposition in a shallow-water middle-neritic environment, with a very high influx of terrigenous sediments.

Microfacies 7

Floatstone (biointrapelmicrudites) with abundant intraclasts and pseudopellets, gastropod and bivalve fragments (including rudists), orbitolinids (Figure 5, *A*), other arenaceous foraminifera and miliolids make up this microfacies.

Microfacies 7 represents deposition in a shallow-water middle neritic environment with development of rudist biostromes and bioherms to form a barrier and consequent lagoonal conditions, and with no influx of terrigenous sediments.

Microfacies 8

This microfacies contains wackestone and floatstone (biointrapelmicrites and biointrapelmicrudites) with abundant intraclasts, pseudopeloids and coral (reworked) fragments. Other components in lesser quantities include crinoid fragments and the planktonic foraminifer *Ticinella gorvachica* (identified by Longoria and Monreal, in press) (Figure 6, *A*, *C* and *D*), some of which are reworked. It also contains trace quantities of ostracods (Figure 6, *B*) and the calpionellid *Colomiella* (identified by Longoria and Monreal, in press) (Figure 6, *B*).

Microfacies 8 represents deposition in outer-neritic waters and with no influx of terrigenous sediments. In addition, the presence of planktonic fauna, including foraminifera and the abundance of intraclasts, suggests deposition at a basin margin.

Microfacies 9

This interval is characterized by thin- to medium-bedded fine-grained sandstone and siltstone. Sandstone beds are lithic graywackes and litharenites with silt-size subangular to subrounded grains of quartz and rock fragments. Limestone beds are micrites (biomicrites) with only scarce amounts of calcified radiolaria and planktonic foraminifera, and minor occurrences of echinoderm fragments. Angular silt-size quartz grains are abundant.

This microfacies represents deposition in an outer neritic to slope environment with a very high influx of terrigenous sediments and absence of conditions favorable for production of carbonate facies, probably as a result of a sea-level high stand.

Microfacies 10

Limestone in this microfacies is floatstone (biomicrudites) with abundant cephalopod and bivalve fragments, and lesser amounts of echinoderm fragments and benthic foraminifera. Abundant terrigenous quartz grains are present.

This microfacies represents deposition in a shallow-water middle-neritic environment with high influx of terrigenous sediments.

SEDIMENTARY ENVIRONMENTS AND SEA-LEVEL FLUCTUATIONS

Since the Standard Microfacies (SMF) types of Flugel (1982) is an idealized model, and to avoid confusion with the nine facies belts considered by Flugel, which may not be present in the Las Conchas section, a particular model that fits the Las Conchas section has been devised.

The Aptian-Albian sequence studied in this work represents deposition in a shallow sea, varying from inner- to outer-neritic water depths (Figure 7) and the microfacies analysis of this sequence also shows that the environments of

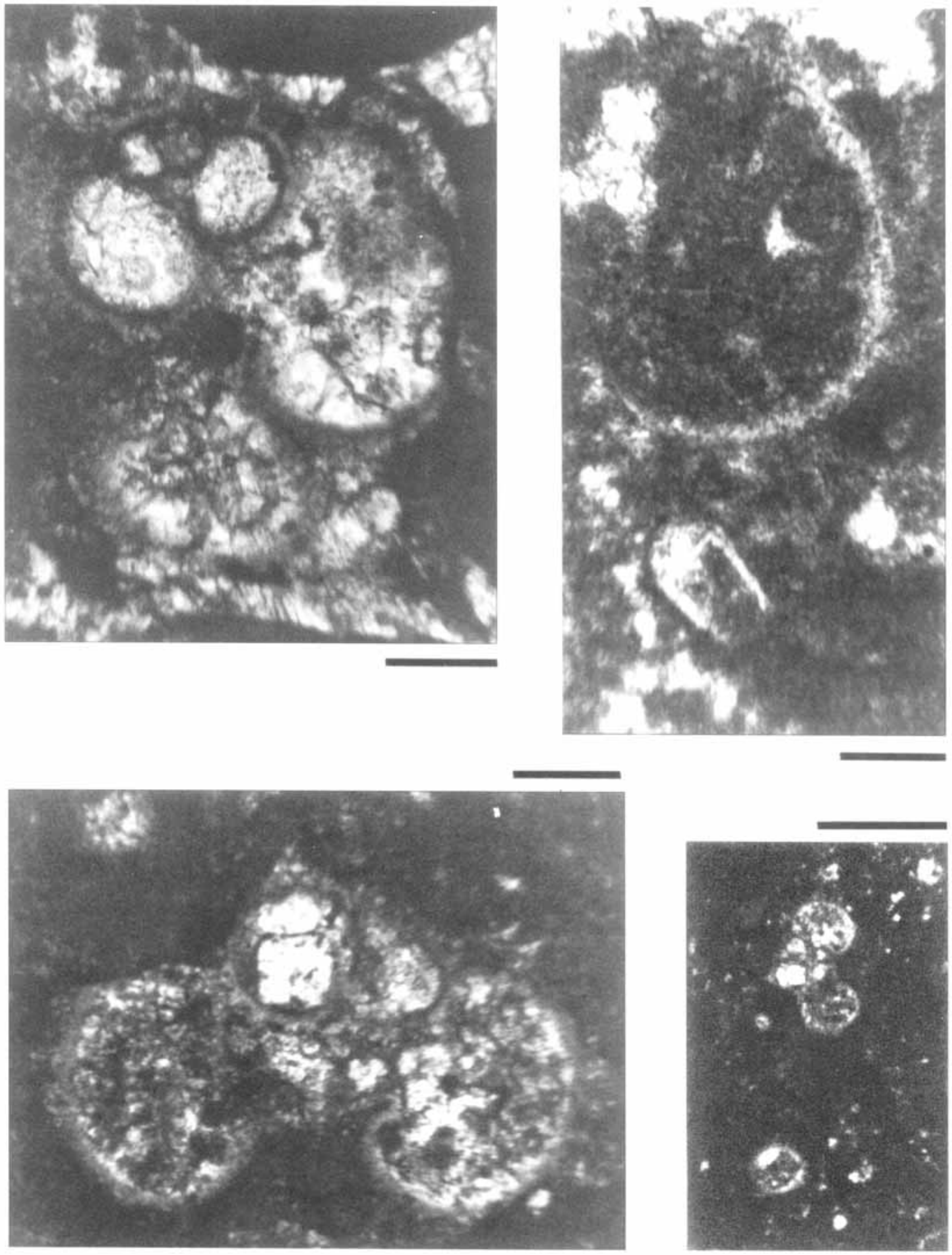

Figure 6. Microfossils of stratigraphic section studied in the Las Conchas area, Microfacies 8, Section II. (*A*) Planktonic foraminifera (*Ticinella gorvachica*), bar length = 100 micrometers. (*B*) Ostracod and calpionellid (*Colomiella*), bar length = 100 micrometers. (*C*) Planktonic foraminifera (*Ticinella* sp.), bar length = 100 micrometers. (*D*) Planktonic foraminifera (*Ticinella* sp.), bar length = 400 micrometers.

Age	Field Unit Section I	Field Unit Section II	Microfacies	Terrigenous Influx
Lower-Middle Albian	A	-	1	high
	B	a	1	high
Upper Aptian	B	-	2	high
	C	-	1	high
	C	-	2	variable
	C	-	3	absent
	-	b	4	high
	C	b	5	low
	-	b	6	high
	-	c	7	absent
	-	c	8	absent
	C	-	2	absent
	D	d	9	very high
	D	-	2	high
	D	-	10	high

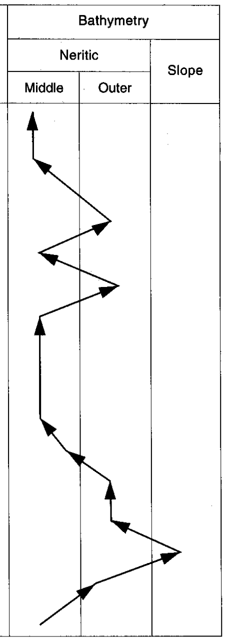

Figure 7. Bathymetric changes represented by the microfacies of the Aptian-Albian section exposed in cerro Las Conchas, Sonora.

deposition were variable. Also, some microfacies, which are present at different intervals in the upper part of the section, are characteristic of lagoons, biostromes and bioherm buildups.

In addition, the microfacies analysis shows that the influx of terrigenous sediments was variable, ranging from a low to a very high influx (Figure 7): microfacies 3, 7 and 8 are evidences of carbonate deposition with no terrigenous influx; microfacies 5 records a slight terrigenous influence; microfacies 1, 2, 4, 6 and 10 record deposition with a high terrigenous influx; and microfacies 8 represents a facies in which carbonate deposition is completely absent.

The analysis of the depositional environments represented by the Las Conchas section shows that although the succession was mostly deposited in a shallow-water neritic sea, except for microfacies 9 which was probably deposited in a basin margin (outer neritic to slope), several minor sea-level changes are recorded, which are included in three transgression-regression cycles (Figure 7).

CHRONOSTRATIGRAPHIC POSITION AND CORRELATION

The stratigraphic sequence studied in this work has been previously assigned to: (a) the Lower Cretaceous by Palafox and Martínez (1985), based on the presence of *Orbitolina texana* Roemer; (b) the Aptian-Albian by Almazán-Vázquez and Palafox (1985), based on the presence of *Orbitolina texana* Roemer, *Pinna equivillana*, *Pecten* (*Neithea*) *texanus* Roemer, *Caprinuloidea* sp. cf. *lenki* (Bohm) and *Casiope zebra* (Gabb); and (c) the upper Aptian-middle Albian by Pubellier (1987), based on the presence of *Engonoceras*, *Epistreptophyllum* and *Orbitolina texana*. Nonetheless, it was not previously established that this sequence is overturned. This statement is based on the following:

1. The following fauna is present in the topographically lowermost part of the sequence (Almazán-Vázquez, 1990; 1996, personal communication), unit A and lower part of unit B of Section I of this study (Figure 2): *Ludbrookia arivechensis* (Heilprin) that ranges from lower to upper Albian (Scott, 1977), *Granocardium* (*Granocardium*) *sabulosum* (Gabb) that ranges from middle to basal upper Albian, *Protocardium* (*Protocardium*) *granuliferum* (Gabb) that ranges from middle Albian to lower Cenomanian (Scott, 1986). This fauna, then, is evidence for a middle Albian age for this part of the sequence.
2. In contrast, the calpionellid genus *Colomiella* and the foraminifer *Ticinella gorvachica*, present in the upper topographic part of the section, uppermost part of unit B and unit C of Section I of this study (Figure 2), suggest an uppermost Aptian stratigraphic position.
3. Also, as stated by Pérez-Ramos (1996, oral communication), the rudistids found in the Arivechi area are "pointing upwards", that is, their growth position is upside down. Thus, it is clear that the section in the cerro Las Conchas is upside down.

Although previous workers (Martínez and Palafox, 1985; Palafox and Martínez, 1985; Minjares *et al.*, 1985; Pubellier, 1987) established a correlation of the Lower Cretaceous rocks exposed in the Arivechi area with the Bisbee Group of Arizona, it was not until the works of Almazán-Vázquez and Fernández (1988), Almazán-Vázquez (1990) and Fernández and Almazán-Vázquez (1991), when the Cretaceous rocks of the Arivechi area were referred to as the Morita, Mural and Cintura Formations of the Bisbee Group.

This work includes only part of the Lower Cretaceous sequence exposed in the Arivechi area, and corresponds to what Palafox and Martínez (1985) referred to as the middle and upper units of their informally established Arivechi group, and to what Almazán-Vázquez and Fernández (1988) and Almazán-Vázquez and Palafox (1985) referred to as the Morita and Mural Formations. In contrast to the previous nomenclatural assignments, this section, even though part of it may resemble the upper Mural Limestone of southeastern Arizona, is herein correlated to the upper Aptian to middle Albian U-Bar Formation in the Big Hatchet Mountains of New Mexico. The Las Conchas section may possibly be a facies related to the Oyster Limestone and the Limestone-Shale members proposed by Zeller (1965) for the U-Bar. This conclusion is based on lithologic resemblance with this formation as exposed in southwestern New Mexico, and following the suggestions for stratigraphic procedures set in the International Stratigraphic Guide (Salvador, 1994), which states that lithocorrelation should be based on physical characteristics of the rocks, and that identification of a lithostratigraphic unit by means of its fossil content is using only inferred evidence of lithologic properties and is not based directly on lithologic criteria. Although it may seem strange to correlate the Las Conchas section with a far away succession and not with closer ones (*i. e.*, units in the Lampazos area), it is the usefulness of correlations to do such, especially for paleogeographic studies.

A lithologic correlation of the Las Conchas section with the units in the Lampazos area is not possible, since the physical characteristics of the Espinazo del Diablo and Nogal Formations, although somewhat similar in lithology, are stratigraphically and paleontologically different from the units studied in this work, but the Arivechi sequence does resemble the U-Bar Formation of New Mexico.

Furthermore, facies changes and time transgressive attributes have been widely established for many stratigraphic units elsewhere. Warzeski (1987) correlates the upper Aptian-lower Albian Mural Limestone of SE Arizona and NE Sonora with the upper Aptian-middle Albian U-Bar Formation of SW New Mexico, implying then, that the same facies of the Mural Limestone are younger in SW New Mexico, although referred to with a different nomenclature.

Nevertheless, it is important to consider the fauna present in the Arivechi area: of the nearly 60 species that have been reported from the Las Conchas section (Almazán-Vázquez and Palafox, 1985; Almazán-Vázquez, 1990; Pérez-Ramos, 1988), only 10 correspond to the 71 species reported for the Lampazos area by González-León (1988) and Scott and González-León (1991). On the other hand, 10 of the 30 to 40 species reported by Lasky (1947) and Zeller (1965) from southwestern New Mexico and Gilluly (1956) from southeastern Arizona and northeastern Sonora, are also reported from the Las Conchas section, especially *Turritella seriatum-granulata* Roemer, *Lunatia pedernalis* (Roemer), *Serpula* sp., *Pecten* (*Neithea*) *texanus* Roemer, and *Engonoceras serpentium* (Cragin), which were also reported by Zeller (1965) in New Mexico. Furthermore, the microfauna reported by Warzeski (1987), Scott and Warzeski (1993) and Monreal (1989) for the Mural in northeastern Sonora and from the U-Bar Formation of New Mexico (Weise, 1982; Warzeski, 1987) is strikingly similar to the microfauna recognized in this work, namely planktonic foraminifera, calpionellids, calcisphaeres, ostracods and planktonic crinoids.

In addition, the rudistids reported from the Las Conchas section by Pérez-Ramos (1988), which are caprinids and caprotinids are also reported by Zeller (1965) from the U-Bar Formation. Also, *Caprinuloidea lenki* is present in Arivechi and the bioherm facies of the Mural Limestone in the Cerro de Oro area, northeast of Hermosillo. Furthermore, none of the rudistid fauna from Las Conchas is present in Lampazos, in northeastern Sonora or in southeastern Arizona.

PALEOGEOGRAPHIC IMPLICATIONS AND CONCLUSIONS

The Lower Cretaceous sequence exposed in the cerro Las Conchas is lithologically and facieswide related to the U-Bar Formation of southwestern New Mexico, and thus it is also related to the Mural Limestone sequence of SE Arizona and NE Sonora, but since no facies analysis had been performed in the cerro Las Conchas section, the direct facies/paleogeography relationships among these rocks could not had been previously established.

The Arivechi section ranges in age from late Aptian to middle Albian, and therefore it seems to be more condensed, because at least the time of deposition of this section is longer than the Mural's, and although deposition during Mural time was variable along the margins of the Bisbee Basin, as evidenced by the variations in thickness and lithologic character of the different Mural sequences in northern Sonora (Monreal *et al.*, 1994), it can be established that the Mural Limestone, the U-Bar Formation and the Arivechi section are paleogeographically related. This affinity then rises two questions to consider: (1) what is the paleogeographic relationship between these sequences? and (2) what is the relationship between the Arivechi sequence to the Lower Cretaceous succession exposed in the Lampazos area, located only about 50 km to the north of Arivechi?

In the Arivechi area, the Aptian-Albian section is nearly 600-m thick, the base and top of the sequence are not exposed and thus its real thickness is unknown. The Mural Limestone succession in northern Sonora varies considerably in thickness and lithological character, a feature which is a consequence of facies changes along the margins of the Bisbee Basin. Monreal and collaborators (1994) have demonstrated that the Mural Limestone succession thickens towards the east of Sonora, being the Arizpe sequence the thickest in northern Sonora (from 1,060 to 1,450 m thick). But in New Mexico, the U-Bar Formation is 1,091 m (3,500 ft) thick, thicker than the Mural in the other localities where it is exposed. This would mean that the depocenter of the Bisbee Basin could have been near Arizpe during late Aptian-early Albian and then moved westwards, and switch to southwestern New Mexico during middle Albian.

During late Aptian-late Albian times in the Lampazos area, deposition took place in middle-neritic to pelagic environments, and the stratigraphy and facies present are closely related to the main body of the Chihuahua trough; this suggests a paleogeographic affinity between the Lampazos succession and the northeast Mexico facies belts (Longoria and Monreal, in press). In contrast, the Arivechi sequence was deposited in shallower water depths and related to the Bisbee Basin facies of SE Arizona and SW New Mexico. This relationship between strikingly different stratigraphic sequences supports the idea of paleogeographic juxtapositions in the Lower Cretaceous of Sonora (Monreal, 1995).

Unfortunately, the Arivechi sequence is the southernmost known Lower Cretaceous sedimentary section in Sonora, and until other Lower Cretaceous sequences exposed in southernmost Sonora are discovered and studied in detail, the southern limit and the latest marine facies of the Bisbee Basin will not be constrained. Nonetheless, since the Mural succession of the cerro Las Conchas is similar in lithology and facies to the SW New Mexico succession, and both represent deposition in middle- to outer-neritic environments, it can be established that the Las Conchas succession corresponds to the same facies belts, but probably located along the opposite (southern) side of the Bisbee Basin developed from late Aptian to middle Albian.

Furthermore, the relationships among tectonism during time of deposition of the Lower Cretaceous succession, tectonism involved during time of deformation and the timing and mechanisms for facies juxtapositions still need to be established.

ACKNOWLEDGMENTS

This work was supported by a grant (No. 1455-T9207) from Consejo Nacional de Ciencia y Tecnología (CONACYT) while at the Centro de Estudios Superiores del Estado de Sonora. Also, I thank Dr. Carlos González-León from the ERNO of the Instituto de Geología, UNAM, Dr. William Bilodeau from the Department of Geology at California Lutheran University, and an anonymous reviewer for their helpful comments and suggestions that notably improved this manuscript. I also thank Dr. Luigi Radelli from the University of Sonora and Dr. José F. Longoria from the Florida International University for their insightful comments.

BIBLIOGRAPHICAL REFERENCES

Almazán-Vázquez, Emilio, 1990, Fauna Aptiano-Albiano del cerro Las Conchas, Sonora centro-oriental, *in* Meiburg, Peter, ed., Contribuciones al Cretácico de México y América Central: Linares, N.L., Universidad de Nuevo León, Facultad de Ciencias de la Tierra, Actas, no. 4, p. 153-173.

Almazán-Vázquez, Emilio, and Fernández, M.A., 1988, Estratigrafía de la hoja Arivechi (H12-D56): Universidad Nacional Autónoma de México, Instituto de Geología, Simposio sobre geología y minería de Sonora, 2, Hermosillo, Sonora, Resúmenes, p. 2-3 (abstract).

Almazán-Vázquez, Emilio, and Palafox, J.J., 1985, Bioestratigrafía del Cretácico Temprano del cerro Las Conchas al oriente de Arivechi, Sonora: Hermosillo, Sonora, Universidad de Sonora, Boletín del Departamento de Geología, v. 2 (Segunda época), p. 25-29.

Carozzi, A.V., 1989, Carbonate rock depositional models—a microfacies approach: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, *in* Ham, W.E., ed., Classification of carbonate rocks: American Association of Petroleum Geologists, Memoir 1, p. 108-121.

Embry, A.F., and Klovan, J.E., 1972, Absolute water depth limits of Late Devonian paleoecological zones: Geologische Rundschau, v. 61, no. 2, p. 672-686.

Fernández, M.A, and Almazán-Vázquez, Emilio, 1991, Geología de la carta Arivechi (H12D56): Hermosillo, Sonora, Dirección General de Fomento Minero, Secretaría de Fomento Industrial y Comercio del Estado de Sonora, mapa.

Flugel, Erik, 1982, Microfacies analysis of limestones: Heidelberg, Springer-Verlag, 633 p.

Folk, R.L., 1959, Practical petrographic classification of limestones: American Association of Petroleum Geologists Bulletin, v. 43, p. 1-38.

———1962, Spectral subdivision of limestone types: American Association of Petroleum Geologists Memoir 1, p. 62-84.

Gabb, W.M., 1869, Cretaceous and Tertiary fossils of California in northern Mexico: California Geological Survey, Paleontology, v. 2, 280 p.

Gilluly, James, 1956, General geology of central Cochise, Colorado, Arizona: U.S. Geological Survey, Professional Paper 281, 169 p.

González-León, C.M., 1988, Estratigrafía y geología estructural de las rocas sedimentarias cretácicas del área de Lampazos, Sonora: Universidad Nacional Autónoma de México, Instituto de Geología, Revista, v. 7, no. 2, p. 148-162.

King, R.E., 1939, Geological reconnaissance in northern Sierra Madre Occidental of Mexico: Geological Society of America Bulletin, p. 1625-1722.

Lasky, S.G., 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U.S. Geological Survey Professional Paper 208, 101 p.

Longoria, J.F., and Monreal, Rogelio, 1991, Lithostratigraphy, microfacies, and depositional environments of the Mesozoic of Sierra La Nieve, Coahuila, northeast Mexico: Revista de la Sociedad Geológica de España, v. 4, nos. 1 and 2, p. 7-31.

———in press, The Aptian-Albian succession in east-central Sonora, Mexico—stratigraphic and structural significance.

Martínez, J.A., and Palafox, J.J., 1985, Geología del área de Arivechi, Sonora: Hermosillo, Sonora, Universidad de Sonora, Departamento de Geología, professional thesis, 91 p. (unpublished).

Minjares, Ismael; Palafox, J.J.; Torres, Yolanda; Martínez, J.A.; Rodríguez, Bernardo; and Villalobos, Roberto, 1985, Consideraciones respecto a la estratigrafía y estructura del área de Sahuaripa-Arivechi: Hermosillo, Sonora, Universidad de Sonora, Boletín del Departamento de Geología, v. 2 (Segunda época), p. 90-105.

Monreal, Rogelio, 1989, Regional stratigraphic studies of the Lower Cretaceous in northern Mexico and the southern United States: Richardson, Texas, University of Texas at Dallas, Ph. D. dissertation, 371 p. (unpublished).

———1995, Las facies marinas (Aptiano-Albiano) del Grupo Bisbee y cronocorrelativas en Sonora: Hermosillo, Sonora, Boletín del Departamento de Geología, v. 12, no. 1, p. 65-78.

Monreal, Rogelio; Valenzuela, Manuel; and González-León, C.M., 1994, A revision of the stratigraphic nomenclature for the Cretaceous of northern Sonora, and some paleogeographic implications: Hermosillo, Sonora, Universidad de Sonora, Boletín del Departamento de Geología, v. 11, no. 1, p. 171-190.

Palafox, J.J., and Martínez, J.A., 1985, Estratigrafía del área de Arivechi, Sonora: Hermosillo, Sonora, Universidad de Sonora, Boletín del Departamento de Geología, v. 2, nos. 1 and 2, p. 30-59.

Pérez-Ramos, Olivia, 1988, Estudio estratigráfico de algunos rudistas de Sonora: Hermosillo, Sonora, Universidad de Sonora, Boletín del Departamento de Geología, v. 5, nos. 1 and 2, p. 41-51.

Pubellier, Manuel, 1987, Relations entre domaines cordillerain et Mésogéen au nord du Mexique—Étude géologique de la Vallée de Sahuaripa, Sonora central: Paris, Université de Paris 6, Ph. D. dissertation, 219 p. (unpublished).

Radelli, Luigi, 1995, Scheelite deposits of central Sonora, Mexico: Hermosillo, Sonora, Universidad de Sonora, Boletín del Departamento de Geología, v. 2, nos. 1 and 2, p. 65-73.

Remond, Auguste, 1866, Notice of the geological explorations in northern Mexico: California Academy of Sciences Proceedings, v. 3, p. 244-257.

Salvador, Amos, ed., 1994, International stratigraphic guide (2nd ed.): Boulder, Colo., International Union of Geological Sciences and Geological Society of America, 214 p.

Scott, R.W., 1977, Paleobiology of Lower Cretaceous carditid bivalves, North America: Journal of Paleontology, v. 51, no. 6, p. 1150-1160.

———1986, Paleobiology of Early Cretaceous Protocardiids, Caribbean Province: Journal of Paleontology, v. 60, no. 6, p. 1186-1211.

Scott, R.W., and González-León, C.M., 1991, Paleontology and biostratigraphy of Cretaceous rocks, Lampazos area, Sonora, Mexico, in Pérez-Segura, Efrén, and Jacques-Ayala, César, eds., Studies of Sonoran Geology: Geological Society of America Special Paper 254, p. 51-67.

Scott, R.W., and Warzeski, E.R., 1993, An Aptian-Albian shelf ramp, Arizona and Sonora, *in* Simo, J.A.; Scott, R.W.; and Masse, J.P., eds., Cretaceous carbonate platforms: American Association of Petroleum Geologists Memoir, v. 56, p. 71-79.

Warzeski, E.R., 1987, Revised stratigraphy of the Mural Limestone—a Lower Cretaceous carbonate shelf in Arizona and Sonora, *in* Dickinson, W.R., and Klute, M.A., eds., Mesozoic rocks of southern Arizona and adjacent areas: Arizona Geological Society Digest, v. 18, p. 335-363.

Weise, J.R., 1982, Stratigraphy, lithofacies, and biofacies of the U-Bar Formation (Aptian-Albian) of the Big Hatchet Mountains, Hidalgo County, New Mexico: El Paso, Texas, University of Texas at El Paso, Ph. D. dissertation, 341 p. (unpublished).

Zeller, R.A., Jr., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir, v. 16, 128 p.

Manuscript received: September 4, 1995.
Corrected manuscript received: January 31, 1997.
Manuscript accepted: April 16, 1997.

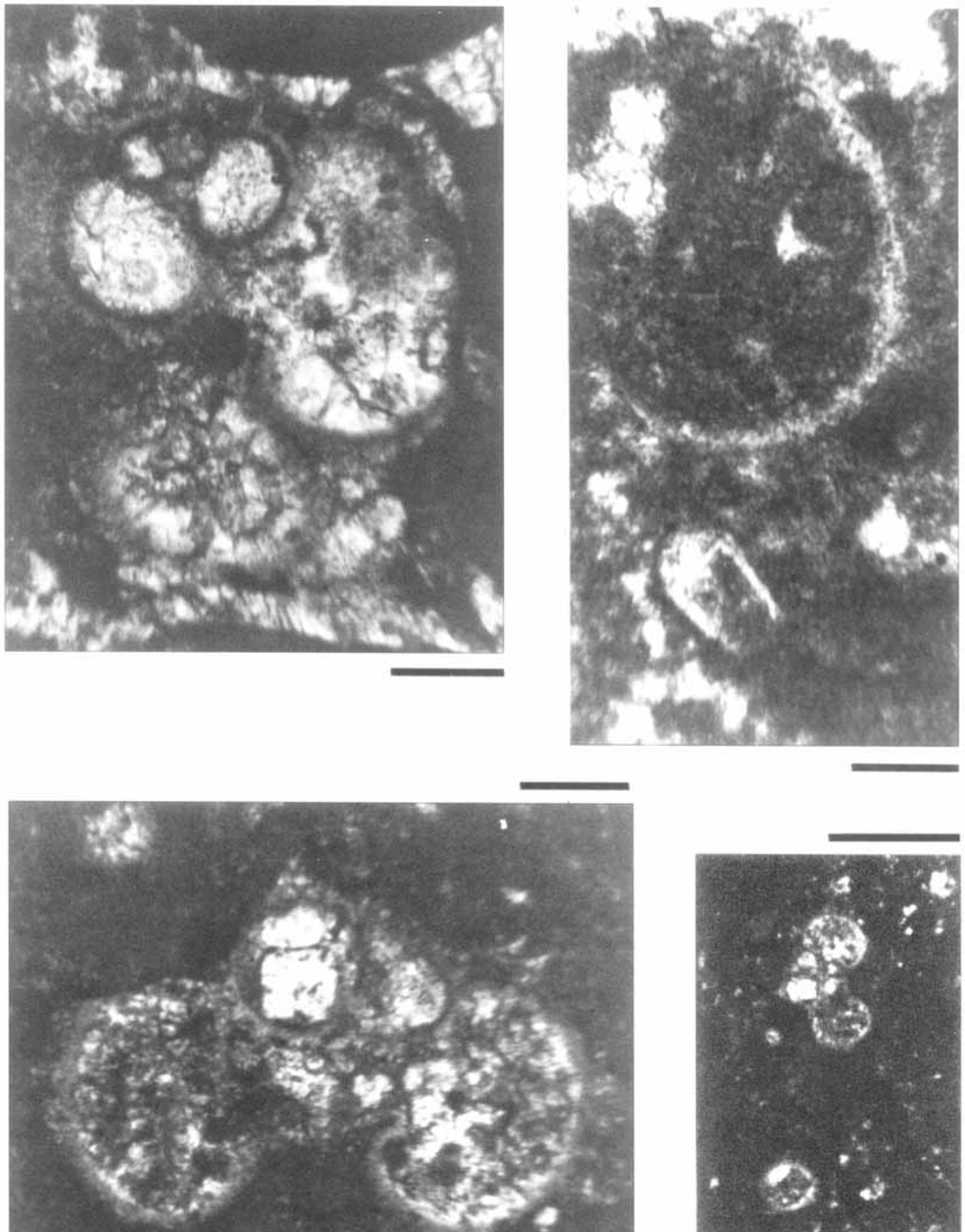

Figure 6. Microfossils of stratigraphic section studied in the Las Conchas area, Microfacies 8, Section II. (*A*) Planktonic foraminifera (*Ticinella gorvachica*), bar length = 100 micrometers. (*B*) Ostracod and calpionellid (*Colomiella*), bar length = 100 micrometers. (*C*) Planktonic foraminifera (*Ticinella* sp.), bar length = 100 micrometers. (*D*) Planktonic foraminifera (*Ticinella* sp.), bar length = 400 micrometers.