Evolution of Cupido and Coahuila carbonate platforms, Early Cretaceous, northeastern Mexico

Christoph Lehmann* *Department of Earth Sciences, University of California, Riverside, California 92521*

David A. Osleger
Isabel P. Montañez *Department of Geology, University of California, Davis, California 95616*

William Sliter[†] *U.S. Geological Survey, Menlo Park, California 94025*

Annie Arnaud-Vanneau *Institut Dolomieu, rue Maurice Gignoux, 38031 Grenoble cedex, France*

Jay Banner *Department of Geological Sciences, University of Texas, Austin 78712-1101*

ABSTRACT

The Cupido and Coahuila platforms of northeastern Mexico are part of the extensive carbonate platform system that rimmed the ancestral Gulf of Mexico during Barremian to Albian time. Exposures of Cupido and Coahuila lithofacies in several mountain ranges spanning an ~80 000 km^2 area reveal information about platform morphology and composition, paleoenvironmental relations, and the chronology of platform evolution. New biostratigraphic data, integrated with carbon and strontium isotope stratigraphy, significantly improve chronostratigraphic relations across the region. These data substantially change previous age assignments of several formations and force a revision of the longstanding stratigraphy in the region. The revised stratigraphy and enhanced time control, combined with regional facies associations, allow the construction of cross sections, isopach maps, and time-slice paleogeographic maps that collectively document platform morphology and evolution.

The orientation of the Cupido (Barremian-Aptian) shelf margin was controlled by the emergent Coahuila basement block to the northwest. The south-facing margin is a high-energy grainstone shoal, whereas the margin facing the ancestral Gulf of Mexico to the east is a discontinuous rudist-coral reef. A broad shelf lagoon developed in the lee of the Cupido margin, where as much as 660 m of cyclic peritidal deposits accumulated. During middle to late Aptian time, a major phase of flooding forced a retrograde backstep of the Cupido platform, shifting the locus of shallow-marine sedimentation northwestward toward the Coahuila block. This diachronous flooding event records both the demise of the Cupido shelf and the consequent initiation of the Coahuila ramp.

The backstepped Coahuila ramp (Aptian-Albian) consisted of a shallow shoal margin separating an interior evaporitic lagoon from a low-energy, muddy deep ramp. More than 500 m of cyclic carbonates and evaporites accumulated in the evaporitic lagoon during early to middle Albian time. Restriction of the platform interior dissipated by middle to late Albian time with the deposition of peloidal, miliolid-rich packstones and grainstones of the Aurora Formation. The Coahuila platform was drowned during latest Albian to early Cenomanian time, and the deep-water laminites of the Cuesta del Cura Formation were deposited.

This study fills in a substantial gap in the Cretaceous paleogeography of the eastern Gulf of Mexico coast, improving regional correlations with adjacent hydrocarbon-rich platforms. The enhanced temporal relations and chronology of events recorded in the Cupido and Coahuila platforms significantly improve global correlations with coeval, economically important platforms worldwide, perhaps contributing to the determination of global versus regional controls on carbonate platform evolution during middle Cretaceous time.

INTRODUCTION

Lower Cretaceous epicontinental carbonates provide reservoirs for enormous volumes of hydrocarbons along the Gulf of Mexico coast and in the Middle East. Some of the largest carbonate platforms developed in northeastern Mexico and Texas, specifically during Barremian to Albian time, when carbonate platforms reached their maximum extent around the Gulf of Mexico coast (Scott, 1990; Wilson and Ward, 1993). For this reason, Cretaceous carbonate platforms of Texas and eastern Mexico have been the focus of numerous regional studies (e.g., Coogan et al., 1972; Enos, 1974; Wilson, 1975; Bebout and Loucks, 1974; Scott, 1990; Minero, 1991; Enos and Stephens, 1993). Recent research on the Cupido and Coahuila platforms has focused on spectacular outcrops in the Sierra Madre Oriental near Monterrey and Saltillo (Wilson and Pialli, 1977; Conklin and Moore, 1977; Goldhammer et al., 1991; Wilson and Ward, 1993). These important studies have documented the composition and orientation of the Cupido reefal platform margin and have established the character of the peritidal facies belt immediately behind the margin. However, critical questions remain about the vast interior of the Cupido platform and its paleogeographic and genetic relationship with the younger Coahuila platform. Furthermore, the current stratigraphic framework in the

*Present address: BP Amoco Exploration and Production, 501 WestLake Park Boulevard, Houston, Texas 77079-2696; e-mail: lehmanct@bp.com.
[†]Deceased.

Data Repository item 9956 contains additional material related to this article.

GSA Bulletin; July 1999; v. 111; no. 7; p. 1010–1029; 12 figures.

study area is marked by equivocal age assignments, and thus there may be miscorrelations.

To attain a more complete regional understanding of these two platforms, we focused on remote and relatively uninvestigated exposures to the west and northwest in the Sierra de Parras and above the Coahuila basement block. The objectives of this study were to (1) document paleogeographic and large-scale facies relationships across northeastern Mexico for Barremian to Albian strata, (2) obtain new biostratigraphic and chemostratigraphic information to refine chronostratigraphic relationships, and (3) use these data to interpret the evolutionary development of these Lower Cretaceous platforms.

The results of this study have important implications for our understanding of the Early Cretaceous evolution of the Gulf of Mexico coast region. First, the new biostratigraphic data, integrated with carbon and strontium isotope stratigraphy, dictate a substantial revision of the longstanding stratigraphic framework in the study area. In addition, this study fills in a substantial hole in the data for the Cretaceous paleogeography of the eastern Gulf of Mexico coast, improving regional correlations with adjacent hydrocarbon-rich platforms to the south in eastern Mexico (Valles–Golden Lane) and to the north in Texas (Sligo-Comanche). Perhaps most important, the high-resolution chronology of the evolution of the Cupido and Coahuila platforms can be compared to coeval platforms worldwide to search for connections and distinctions, contributing to an enhanced understanding of global versus regional controls on carbonate platform development.

PALEOTECTONIC EVOLUTION AND GEOLOGIC SETTING

The distribution of Lower Cretaceous carbonate platforms in northeastern Mexico (Fig. 1) is closely linked to the opening of the Gulf of Mexico (Anderson and Schmidt, 1983; Winker and Buffler, 1988; Wilson, 1990). Late Triassic to Middle Jurassic extensional rifting and strike-slip faulting produced a mosaic of fault blocks (Wilson, 1990; Coahuila, Picachos, Tamaulipas) and intervening grabens in which lacustrine and alluvial-fan redbeds, evaporites, and clastic strata accumulated (Ovianki, 1974; Padilla y Sanchez, 1982; Salvador, 1987; Wilson, 1990; Michalzik, 1991; Michalzik and Schumann, 1994). The Coahuila basement block (Fig. 1) is composed of granite and granodiorite of Permian-Triassic age intruded into Permian orogenic sediments and appears to have been a peninsular extension of the early Mesozoic craton (Wilson et al., 1984; Wilson, 1990). The block is bounded on the north by the left-lateral San Marcos fault (McKee et al., 1990), and on the south by the left-lateral Torreon-Monterrey lineament (parallel with the trend of the Sonora-Mojave megashear) (Anderson and Schmidt, 1983). The Sonora-Mojave megashear is inferred to have extended to the east, bisecting the Tamaulipas block and the Picachos block (Wilson, 1990). Left-lateral shear zones are interpreted to have been major intracontinental transform faults that were active during Late Triassic to Middle Jurassic time, but were likely inactive during carbonate deposition in Barremian through Albian time (Wilson, 1990; Goldhammer and Wilson, 1991).

During Late Jurassic time, sea-floor spreading started in the Gulf of Mexico (Buffler and Sawyer, 1985; Winker and Buffler, 1988), and nearshore siliciclastic and carbonate deposits (La Gloria and Zuloaga Formations) accumulated near basement highs, passing into offshore carbonate shoals and outer-ramp muds (Zuloaga Formation; Meyer and Ward, 1984; Johnson, 1991). Evaporites and mudstones of the Olvido Formation were deposited conformably on the Zuloaga Formation during continuous flooding. These initial marine carbonate deposits were terminated with deposition of siliciclastics and lime mudstones of the La Casita Formation during Late Jurassic and earliest Cretaceous time (Fortunato and Ward, 1982).

The rift phase of the Gulf of Mexico was completed by the beginning of Cretaceous time, and the region underwent cooling and continuous subsidence throughout Early Cretaceous time (Goldhammer et al., 1991). During this time, more than 2000 m of shelfal carbonates were deposited around the ancestral Gulf of Mexico. In northeastern Mexico, the Barremian to Aptian Cupido platform accumulated between the Coahuila basement block and a coral-rudist reefal margin (Figs. 1 and 2; Conklin and Moore, 1977; Wilson and Pialli, 1977; Selvius and Wilson, 1985; Goldhammer et al., 1991). The Cupido margin rimmed the Gulf of Mexico coast from southern Louisiana through Texas (Sligo Formation) and southward beyond Monterrey into the Sierra Madre Oriental, where it abruptly bends westward (Fig. 1) along the northern front of the Sierra de Parras (the western Sierra Madre Oriental; Fig. 3) (Wilson, 1990; Wilson and Ward, 1993). Based on paleogeographic relations, the Coahuila basement block apparently controlled the orientation of the Cupido reef trend. Peritidal sediments accumulated in a shallow shelf lagoon in the lee of the Cupido rudist platform margin, while hemipelagic lime mudstones (Lower Tamaulipas Formation) were deposited on the surrounding deeper water shelf (Fig. 2). The Cupido-Sligo platform was drowned during deposition of argillaceous carbonates and shales of the middle to upper Aptian La Peña and Pearsall Formations (Smith and Bloxsom, 1974; Loucks, 1977; Tinker, 1985; Goldhammer et al., 1991).

The second major episode of carbonate platform evolution in the region, the Coahuila platform (Acatita-Aurora Formations; Fig. 2), developed on top of the Coahuila basement block during Aptian through Albian time. The Coahuila platform margin manifests a significant backstep from the preceding Cupido margin, a result of long-term sea-level rise through Early Cretaceous time that culminated during Cenomanian time (Haq et al., 1988). Deeper water carbonates of the Upper Tamaulipas Formation were deposited on the more rapidly subsiding portions of the platform surrounding the Coahuila block. The Coahuila platform was ultimately drowned during latest Albian–earliest Cenomanian time, as recorded by diachronous deposition of thinly interbedded cherty lime mudstones and argillaceous rhythmites of the Sombreretillo and Cuesta del Cura Formations (Fig. 2; Bishop, 1972; Ice, 1981; Longoria and Monreal, 1991). Deposition of pelagic mudstones, shales, and coarser siliciclastic strata of younger Cretaceous formations indicates the transition to foreland basin sedimentation and the beginning of Laramide orogenesis.

METHODS AND DATABASE

There were 37 sections totaling 17 000 m logged on a decimeter scale throughout the >80 000 km^2 study area (Fig. 3). Most sections were measured on the Coahuila block (9 sections) and in the northern part of the Sierra de Parras (14 sections), where Lower Cretaceous restricted evaporite interior, shallow shelf-lagoon, and high-energy shoal-margin deposits are exposed. There were 14 sections of deep-platform facies measured in the southern part of the Sierra de Parras, in the Sierra Madre Oriental near Saltillo and Monterrey, and in isolated mountain ranges east of the Sierra de Paila. Hand samples for petrographic study of individual lithofacies were collected at 10–20 m intervals at selected platform-margin and platform-interior sections and at 5–10 m intervals at selected deep-platform sections.

Biostratigraphic zonation for the Barremian-Albian of northeastern Mexico (Fig. 4) was established on the basis of planktonic foraminifers (e.g., Longoria and Gamper, 1977; Ice and McNulty, 1980; Ross and McNulty, 1981; Longoria, 1984), nannoconids and colomiellids (Bonet, 1956; Trejo, 1960, 1975), ammonites (Böse and Cavins, 1927; Imlay, 1944a, 1944b; Young, 1974, 1977, 1978; Stinnesbeck, 1991), and rudists (Coogan, 1977, Young, 1984). Additional biostratigraphic data were collected in this study from the Sierra Madre Oriental near Monterrey and Saltillo, the Sierra de Parras, and ranges to the north overlying the Coahuila basement block.

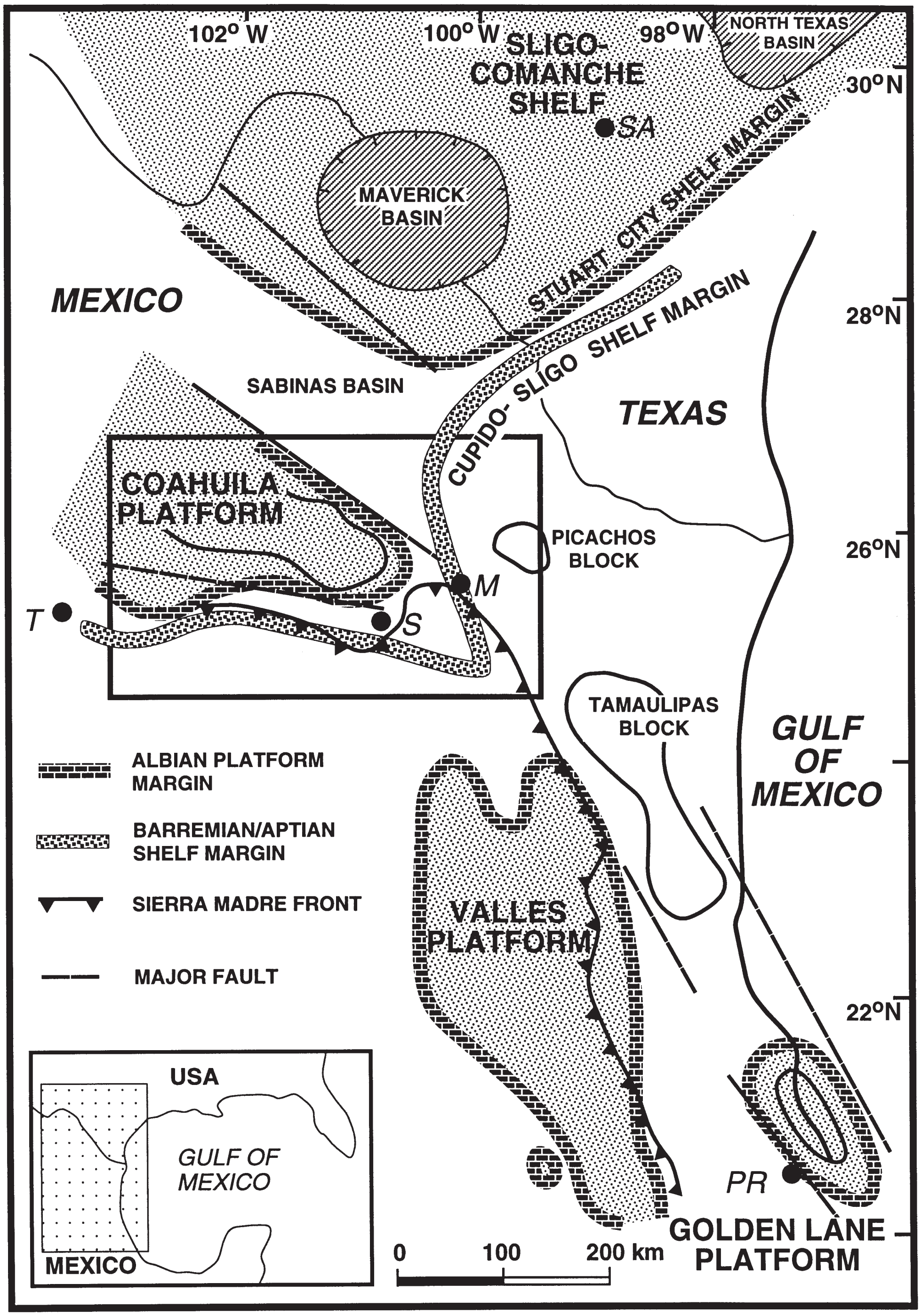


Figure 1. Tectonic map of northeastern Mexico and south Texas showing distribution of Barremian-Aptian and Aptian-Albian carbonate platforms (modified after Wilson and Ward, 1993, and Lehmann et al., 1998). Shaded areas show the Albian platforms only. Solid thin line within Coahuila platform is interpreted edge of Permian-Triassic granodioritic basement (Coahuila block). Rectangle outlines the study area. M—Monterrey, PR—Poza Rica, S—Saltillo, SA—San Antonio, T—Torreon.

Thin sections of select samples from three stratigraphic sections were screened petrographically using transmitted light and cathodoluminescence to identify: (1) least-altered rudists, (2) lime grainstones in which marine cements compose >90% of all cements, and (3) syndepositional dolomites that predate compaction, preserve fabric, and exhibit minimal petrographic evidence for recrystallization. Microsamples (1–5 mg) of these three components were drilled from ultrasonically cleaned, thick sections (500 µm thick) or polished billets using a binocular microscope, a hand-held dental drill, and 250–500 µm faceted bits.

Two splits of microsamples were used for stable isotope and Sr isotope analyses. Oxygen and car-

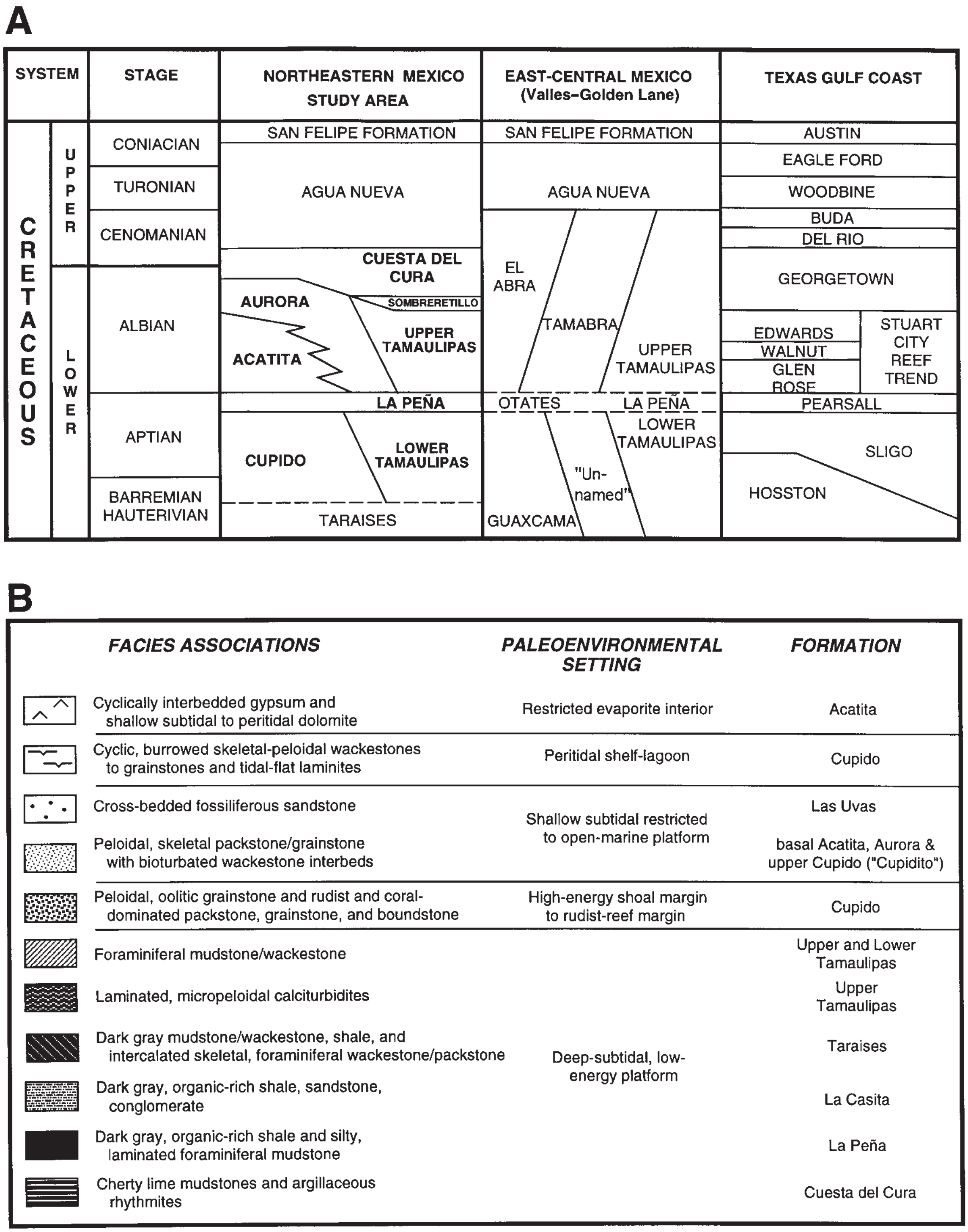


Figure 2. (A) Correlation chart for the Lower Cretaceous of Mexico and Texas (modified from Wilson and Ward, 1993). Units discussed in this study are in bold. (B) Patterns used in all associated figures for facies associations and corresponding paleoenvironmental settings and formations.

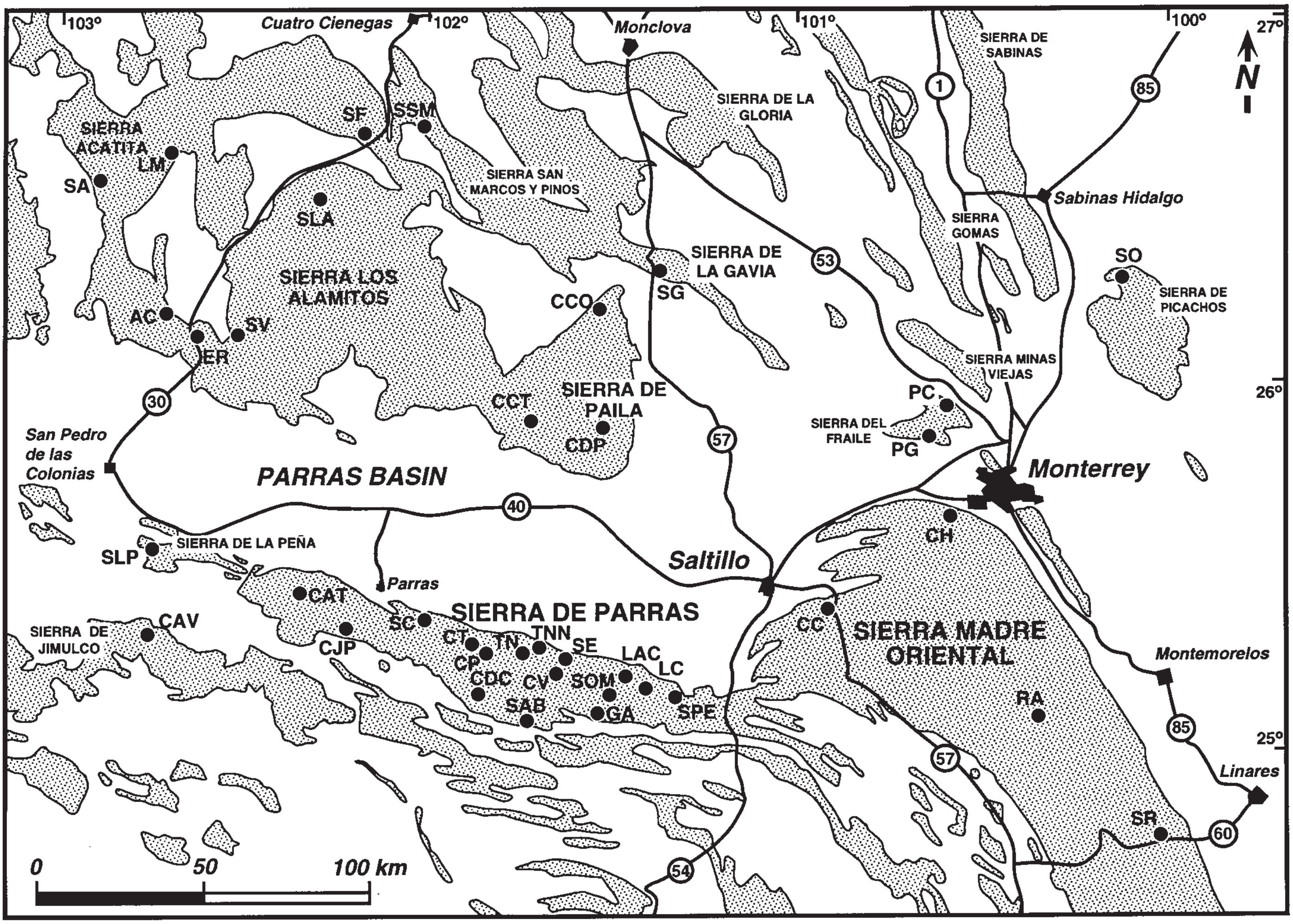


Figure 3. Location map of measured sections and mountain ranges with Lower Cretaceous exposures (modified from Lehmann et al., 1998). Sections are indicated by filled circles. Ranges comprising the Coahuila block include the Sierra Acatita, Sierra Los Alamitos, and Sierra de Paila. AC—Agua Chico, CAT—Cañon Taraises, CAV—Cañon Viobora, CC—Cañon del Chorro, CCO—Casa Colorado, CCT—Cañon Corazon del Toro, CDC—Cañon de Cobra, CDP— Cañon de los Perdidos, CH—Cañon de Huasteca, CJP—Cañon de Juan Perez, CP—Cerro Prieto, CT—Cerro de Tunal, CV—Chile Verde, ER—El Roya, GA—Garambullo, LAC—La Casita, LC—La Concordia, LM—Las Margaritas, PC—Potrero Chico, PG—Potrero Garcia, RA—Rayones, SA—west side Sierra Acatita, SAB—Sabinilla, SC—west side Sierra Cabrera, SE—Sierra Escondida, SF—Sierra La Fragua, SG—Sierra de La Gavia, SLA—north side Sierra Los Alamitos, SLP—Sierra de la Peña, SO—Sombreretillo, SOM—Sombrero, SPE—Sierra de Parras, east side, SSM—Sierra San Marcos y Pinos, SR—Cañon de Santa Rosa, SV—Sierra Venado, TN—Tanque Nuevo, TNN—Tanque Nuevo, north.

bon isotope analyses were conducted at the University of Texas, Austin, and the University of California, Davis, following procedures outlined in Gao et al. (1995) and Bemis et al. (1998)[1]. External precision (1σ) was better than ±0.08‰ and ±0.05‰ for $\delta^{18}O$ and $\delta^{13}C$, respectively. Strontium isotope analyses were conducted at the University of Texas following procedures outlined in Banner and Kaufman (1994). In order to avoid contamination by radiogenic ^{87}Sr from associated noncarbonate phases during sample dissolution, all samples were pretreated three times for 30 min in 0.2 M ultrapure ammonium acetate buffered to a pH of 8 to remove exchangeable Sr from noncarbonate phases prior to dissolution in 4% (calcites) or 8% (dolomites) ultrapure acetic acid (cf. Montañez et al., 1996). Procedural blanks for Sr, including the pretreatment and column chemistry, ranged from 5 to 26 pg, and were negligible for the samples analyzed. The $^{87}Sr/^{86}Sr$ data are corrected for fractionation to $^{87}Sr/^{86}Sr = 0.1194$ using an exponential relationship. Repeated analyses of NBS-SRM 987 standard yielded a mean $^{87}Sr/^{86}Sr$ value of 0.710203 ± 24 (1 σ; n = 3) by data acquisition in static multicollection mode during the early part of this study, and 0.710259 ± 8 (1 σ; n = 10) by data acquisition in dynamic multicollection mode during the later part of this study. To facilitate comparison of $^{87}Sr/^{86}Sr$ results with recently published composite-seawater Sr isotope curves for Early to middle Cretaceous time, all data presented and discussed in this paper have been renormalized to a $^{87}Sr/^{86}Sr$ value of 0.710250 for NBS-SRM 987. Subsamples from different marine components within each of two thick sections yielded $^{87}Sr/^{86}Sr$ values with similar variability as the repeated analysis of the SRM standard.

[1]GSA Data Repository item 9956, data table, is available on the Web at http://www.geosociety.org/pubs/ftpyrs.htm. Requests may also be sent to Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301; e-mail: editing@geosociety.org.

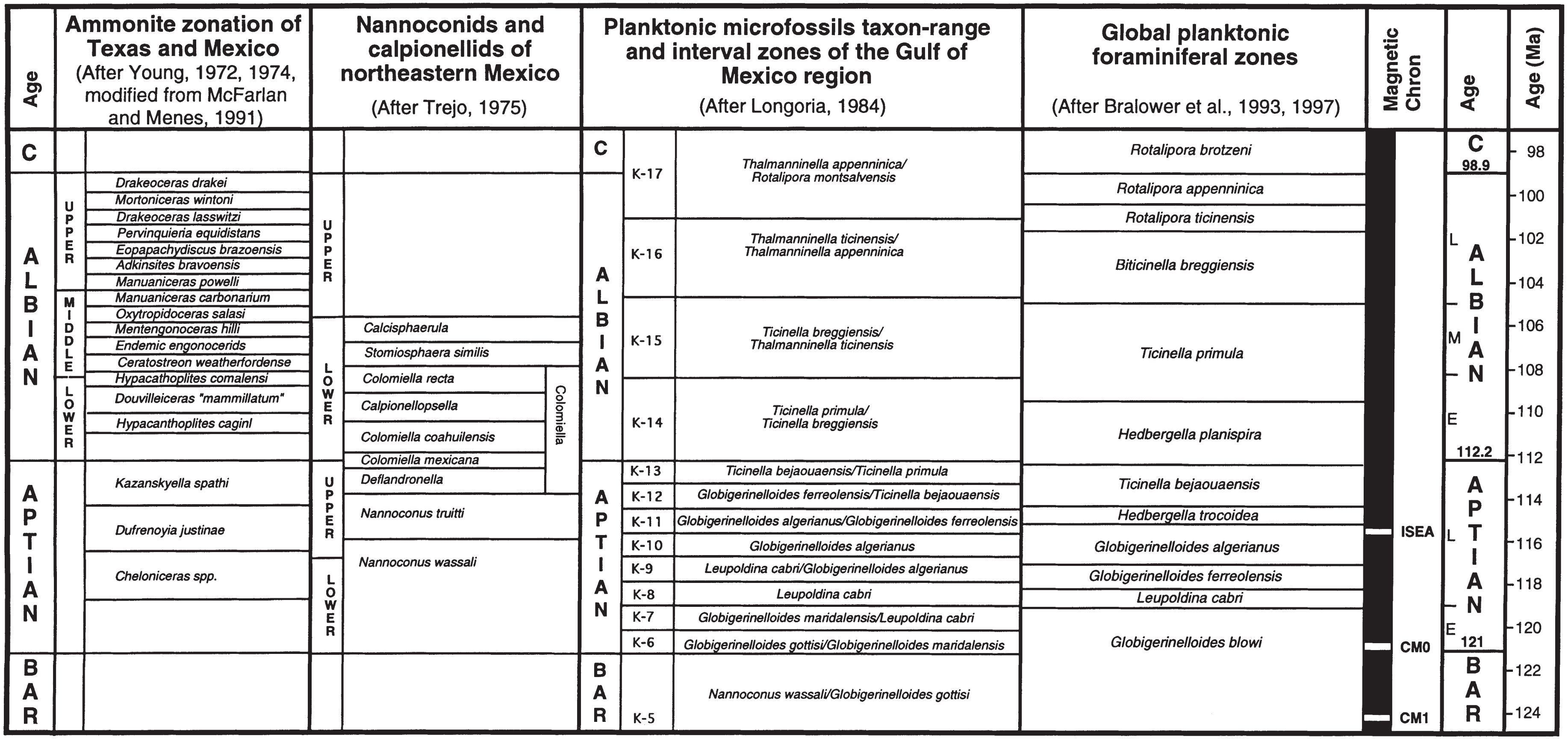


Figure 4. Biostratigraphic correlation chart for the Barremian to Albian of Texas and northern Mexico compared with the global planktonic foraminiferal zones. Dark vertical band is the magnetic chronology with short-term reversals in white and absolute ages from Gradstein et al. (1995). See Bralower et al. (1997) for details on how the global planktonic foraminiferal zones from Bralower et al. (1993) were calibrated to the Gradstein et al. (1995) time scale. Note that planktonic foraminifera taxon range and interval zones of Longoria (1984) are divided into equal time units within the stages. This explains differences between the biozones of Longoria and the global planktonic foraminiferal zones of Bralower et al. (1993, 1997). The La Peña Formation is within the *Dufrenoyia justinae* ammonite zone and *Globigerinelloides algerianus* planktonic foraminifera zone.

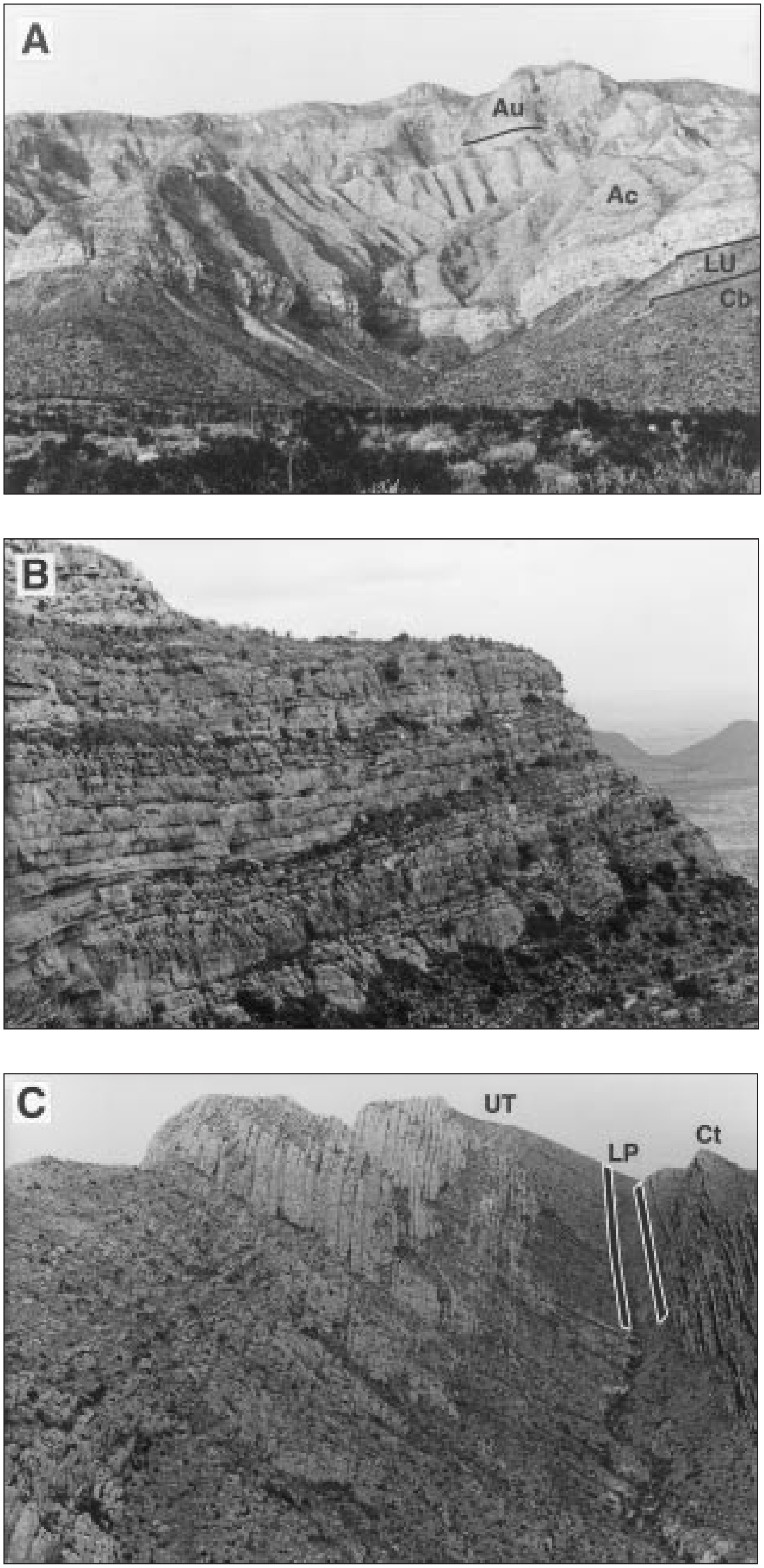


Figure 5. (A) Evaporitic, peritidal, and shallow-subtidal facies on Coahuila block, Sierra Acatita. Light colored strata are primarily evaporitic rocks of the Acatita Formation. Cb—Coahuila granodioritic basement; LU—Las Uvas Formation; Ac—Acatita Formation; Au—Aurora Formation. (B) Peritidal facies of the Cupido Formation, Tanque Nuevo. Lighter, thicker bedded strata are primarily subtidal facies and darker, thinner bedded strata are primarily tidal-flat facies. (C) Shallow to deep subtidal facies, Sierra de la Gavia. Ct—"Cupidito" facies of Cupido Formation; LP—La Peña Formation; UT—Upper Tamaulipas Formation.

FACIES ASSOCIATIONS

Barremian to Albian platform carbonates and evaporites of the study area form genetic associations of lithofacies that define five paleoenvironmental settings: restricted evaporite interior, peritidal to shallow subtidal shelf lagoon, shallow subtidal restricted to open-marine platform, high-energy shoal margin that changes along strike to a rudist-reef margin, and deep subtidal, low-energy platform (Fig. 2B).

Restricted Evaporite Interior Facies

Restricted evaporite interior facies (Acatita Formation) are located above the Coahuila block in the Sierra de Paila, Sierra Los Alamitos, and Sierra Acatita (Fig. 3). The Acatita Formation (Humphrey and Diaz, 1956) reaches a thickness of more than 500 m and consists of cyclic, interbedded carbonates and evaporites.

Gypsiferous dolomudstone with intercalated massive gypsum beds forms the dominant lithofacies within the restricted evaporite interior (Fig. 5A). These lithofacies are interbedded with bioturbated dolowackestone that typically coarsens upward to peloid-miliolid-orbitolinid dolopackstone and grainstone that may exhibit low-angle cross-lamination. Traction-deposited mechanical laminites and cryptalgal laminites may overlie the packstone-grainstone lithofacies. Cyclic arrangements of these lithofacies are interpreted to shallow upward from evaporites to carbonates (Lehmann et al., 1998). Evaporitic lithofacies are interpreted to have been deposited in a restricted, hypersaline lagoon rimmed by an elevated high-energy shoal margin that episodically migrated over the lagoon. Exposures of platform-margin facies coeval with the Acatita evaporitic facies are limited to two sections (Casa Colorado, Cañon de los Perdidos); remaining evidence of the margin is presumed to be buried beneath Upper Cretaceous strata of the Parras basin.

Peritidal to Shallow Subtidal Shelf-Lagoon Facies

Peritidal shelf-lagoon facies are exposed in the northern Sierra de Parras and in mountain ranges and potreros near Monterrey. These facies form the bulk of the Cupido Formation and have been studied in detail around Monterrey (Conklin and Moore, 1977; Wilson and Pialli, 1977; Selvius and Wilson, 1985; Goldhammer et al., 1991). Peritidal deposits of the Cupido reach a thickness of as much as 660 m and are systematically arranged into upward-fining cycles similar to those that characterize many shallow carbonate platforms (Fig. 5B). Components that are distinctive of these Cretaceous examples are caprinid and requienid rudists and *Chondrodonta* bivalves; otherwise these peritidal cycles are essentially identical to most others throughout the stratigraphic record. Similar meter-scale Cretaceous cycles have been described from the Cupido platform in the Sierra Madre Oriental near Monterrey (Goldhammer et al., 1991), the Valles platform of east-central Mexico (Minero, 1988, 1991), and the Gavrovo platform of northwestern Greece (Grötsch, 1996).

Two brecciated intervals occur within the peritidal shelf-lagoon lithofacies of the Sierra de Parras and are best developed at Tanque Nuevo where they are exposed along ~2 km of continuous outcrop (Fig. 3). Intraclast breccias are composed of subangular clasts of mudstone and tidal-flat laminites ranging from 0.1 to 0.5 m in diameter, floating in a grainy dolomitized matrix. The thickness of the brecciated horizons varies along the outcrop from 0.5 to 10 m. At Tanque Nuevo, the clast size and thickness of the breccia increase to the north toward the shelf interior.

Shallow Subtidal Restricted to Open-Marine Platform

Shallow subtidal platform facies crop out in mountain ranges centered on top of the Coahuila block (best exposed in the Sierra Acatita) and several localities in the Sierra de Parras and other ranges of the Sierra Madre Oriental. Genetically related lithofacies in this association indicate deposition in a spectrum of shallow subtidal environments from the shoreline to near fair-weather wave base. The presence or absence of certain skeletal components suggests variable restricted to open-marine conditions. Shallow-subtidal platform facies compose the Las Uvas Formation, the lower portion of the Acatita Formation, the Aurora Formation, and the upper portion of the Cupido Formation throughout the study area (Cupidito of Wilson and Pialli, 1977; unit F of Conklin and Moore, 1977).

The Cupidito unit was introduced by Wilson and Pialli (1977) as an informal transgressive unit below the La Peña shales in the Sierra de Fraile. Near Monterrey, the Cupidito unit varies significantly in thickness from 100 m to a few meters (Goldhammer et al., 1991). The thickness of the Cupidito unit in the Sierra de Parras ranges between 190 and 300 m, and consists of subtidal-dominated peritidal cycles (Fig. 5C). Peloid-miliolid-ooid grainstones to wackestones with caprinid and requienid rudists are the dominant shallow-subtidal lithofacies within these cycles. Cryptalgal laminites and fenestral mudstones rarely cap cycles, in contrast to the dominance of peritidal cycles in underlying facies of the Cupido Formation. The dominantly subtidal lithofacies of the Cupidito unit indicate a gradual upward deepening that continues through the La Peña shales; the Cupidito unit is interpreted to record a retrogradational backstep of the Cupido platform.

The Las Uvas carbonate-rich sandstone (0–15 m) unconformably overlies remnants of Permian flysch on the eastern side of the Sierra Acatita or onlaps granodioritic basement on the western side (Fig. 5A). The coarse fossiliferous sandstone is cross-bedded in places and contains clasts of the underlying granodioritic basement and Permian flysch, as well as carbonate interbeds with bivalve and brachiopod fragments. The Las Uvas sandstone is interpreted to be a transgressive shoreline deposit formed during initial flooding of the Coahuila basement block (Humphrey and Diaz, 1956).

Peloidal, skeletal packstones and grainstones of the basal part of the Acatita Formation (60–130 m thick) were deposited either directly on top of Coahuila basement or above the Las Uvas sandstone (Fig. 5A). The packstones and grainstones exhibit low-angle cross-bedding and contain miliolids, orbitolinids, shell fragments, corals, and caprinid and requienid rudists. Thick-bedded to massive, bioturbated wackestones and packstones are commonly interbedded within the coarser, skeletal-rich lithofacies. The basal Acatita Formation is interpreted to have formed in shallow subtidal, generally open-marine conditions during the initial stages of flooding of the Coahuila block.

The Aurora Formation (to 260 m thick) consists dominantly of massive, cross-bedded, peloid-miliolid packstone and grainstone (Fig. 5A). Throughout the Aurora succession, thin interbeds of bioturbated wackestone containing requienid rudists and ostracodes form subtle rhythmic alternations with the peloid-miliolid packstones and grainstones. Tidal-flat lithofacies rarely form cycle caps. The Aurora Formation is interpreted to record restricted, shallow-subtidal environments centered above the Coahuila block.

High-Energy Shoal Margin to Rudist-Reef Margin

The Aptian (Cupido) shelf margin is variable along strike. From the Sierra de Jimulco through the northern part of the Sierra de Parras and continuing eastward into the Sierra Madre Oriental (Figs. 1 and 3), the south-facing shelf margin is composed of a narrow fringe of high-energy grainstone shoal deposits. This south-facing margin makes an abrupt bend northward and changes into reefal rudist-coralline facies along the gulfward side of the platform (Wilson, 1975; Conklin and Moore, 1977; Wilson and Pialli, 1977; Wilson et al., 1984; Goldhammer et al., 1991; this study).

The grainstone shoal margin in the northern

Sierra de Parras is composed dominantly of peloids and ooids, but contains subordinate layers (1–5 m thick) of caprinid and requienid rudists. Shoal architecture consists of large-scale, progradational, sigmoidal clinoforms dipping as much as 25° to the south-southwest. The thickness of the grainstone shoal deposits varies significantly over relatively short distances (15 km), from ~60 m at La Casita to ~400 m at Chile Verde (Fig. 3).

The rudist-reef margin with intercalated lenses of grainstones extending north through Monterrey was extensively investigated; workers identified massive rudist and coral-dominated packstones, grainstones, and boundstones with stromatoporoids and abundant marine cements (biostromal shelf-margin unit C of Conklin and Moore, 1977). The reef margin attains its maximum thickness (250 m) at Potrero Chico. The contiguous shoal and reef margins of the Cupido platform formed a physical barrier separating a peritidal shelf-lagoon to the north and west from a deep-water, low-energy shelf to the south and east (Lower Tamaulipas Formation).

Deep Subtidal, Low-Energy Platform Facies

Facies of the deep subtidal, low-energy shelf are exposed everywhere throughout the study area except over the Coahuila block. Genetically related lithofacies in this association indicate deposition of periplatform and pelagic sediments below storm wave base on a low-energy muddy shelf. These facies compose the Taraises, La Peña, and Lower and Upper Tamaulipas Formations (Fig. 2).

The Taraises Formation consists of dark gray mudstone and wackestone, shale, and intercalated skeletal, foraminiferal wackestone and packstone. Wackestones contain planktonic and benthonic foraminifers, calcispheres, nannofossils, echinoid fragments, and subordinate rudist and brachiopod fragments.

The La Peña Formation ranges in thickness from 10 to 30 m in the Sierra de Parras to as much as 200 m seaward of the Cupido shelf margin (Fig. 5C; Conklin and Moore, 1977; Wilson and Pialli, 1977; Tinker, 1985). It consists of dark gray, organic-rich shale and silty, laminated foraminiferal mudstone. The shales contain middle to late Aptian ammonites (*Dufrenoyia* sp.) and rounded phosphorite clasts to 0.5 cm in diameter. Intercalated thin beds of lime mudstone contain continuous chert layers and small, recrystallized foraminifera, calcispheres, nannofossils, and radiolarians.

The Lower and Upper Tamaulipas Formations are separated by the La Peña Formation and consist of homogeneous, foraminiferal mudstone and wackestone and laminated, micropeloidal calciturbidites. The mudstone and wackestone are commonly bioturbated and contain planktonic foraminifers, nannofossils, calcispheres, ostracodes, colomiellids, echinoid fragments, and peloids. In the Sierra Madre Oriental near Monterrey, regularly spaced dolomitic firmgrounds and hardgrounds are common sedimentary features in the Upper Tamaulipas Formation. The laminated calciturbidite facies of the Upper Tamaulipas Formation are confined to sections in the southern part of the Sierra de Parras, consist entirely of well-sorted micropeloids, and exhibit C and D units of Bouma sequences. Intercalated with the calciturbidites are intraclast breccias and convolute-bedded mudstones. Breccias are mud supported and are composed of subangular to subrounded intraclasts of foraminiferal mudstone and wackestone floating in a mudstone matrix. Syndepositionally deformed mudstones exhibit Z folds that indicate a south-dipping paleoslope, which, together with the breccias and microturbidites, suggests a local steepening of the deep shelf in the southern Sierra de Parras during Upper Tamaulipas Formation deposition.

PREVIOUS WORK, AGE CONTROL, AND REVISED STRATIGRAPHY

Initial regional studies in northeastern Mexico were performed by Burrows (1909), Haarmann (1913), and Böse (1921). Böse (1923) recognized that Permian strata on top of the Coahuila granodioritic basement block are overlain by what he reported as Aptian deposits and concluded that a landmass existed during early Mesozoic time. Subsequent work by Kellum et al. (1936) and Kelly (1936) confirmed Böse's observations and the name "Coahuila peninsula" was established for this ancient landmass. Further investigations and mapping established the stratigraphic nomenclature of the study area (Imlay, 1936, 1937, 1938, 1944a, 1944b; Kellum et al., 1936; Kelly, 1936; Humphrey, 1949; Humphrey and Diaz, 1956). Subsequent studies that were carried out in the Sierra Madre Oriental and in mountain ranges to the north built upon the earlier stratigraphic framework (e.g., de Cserna, 1956; Bishop, 1966, 1970, 1972; Krutak, 1967; Garza, 1973; Smith and Bloxsom, 1974; Charleston, 1974; Ekdale et al., 1976; Conklin and Moore, 1977; Longoria and Gamper, 1977; Wilson and Pialli, 1977; Elliot, 1979; Ross, 1979, 1981; Longoria, 1984; Wilson et al., 1984; Cantú Chapa et al., 1985; Tinker, 1985; Goldhammer et al., 1991; Longoria and Monreal, 1991; and Wilson and Ward, 1993).

This study corroborates and expands upon many of the stratigraphic observations of the Sierra Madre Oriental made by these workers. However, integration of new biostratigraphic data with isotope chemostratigraphy provides improved stratigraphic resolution for key localities in the Sierra de Parras and mountain ranges to the north overlying the Coahuila basement block. These new data require a significant refinement of the previously established stratigraphic framework that has been entrenched in the literature for more than 60 yr (Imlay, 1936, 1937; Humphrey and Diaz, 1956; Wilson and Ward, 1993). Our argument for these revisions is spelled out in the following two sections.

Sierra de Parras

Lower Cretaceous shallow-water carbonates in the Sierra de Parras have been historically regarded as the Aurora Formation of Albian age (Fig. 6; Imlay 1936, 1937; Humphrey and Diaz, 1956; Wilson and Ward, 1993). The Aurora Formation was first defined in northern Chihuahua (Burrows, 1909) and described as massive rudist limestones correlative to the Glen Rose, Fredericksburg, and Washita "divisions" of Texas (King and Adkins, 1946). Böse and Cavins (1927, p. 86) described Lower Cretaceous rocks in the mountain ranges north of Monterrey and recognized "Albian" reef facies "practically all over northern Mexico containing everywhere Caprinidae and Rudistidae." They reported that this rudist-bearing facies extended from the Sierra Madre Oriental around Monterrey westward through the Sierra de Parras to the Sierra de Jimulco (Fig. 3). Imlay (1936, 1937) subsequently described and mapped rudist-bearing limestones and overlying shales and lime mudstones in the Sierra de Parras as the "Albian" Aurora Formation (Fig. 6). Underlying shales and lime mudstones were designated by Imlay as the Aptian La Peña Formation. Massive lime mudstones below the La Peña shales in the Sierra de Parras were regarded as deep-water facies of the Cupido Formation, coeval with shallow subtidal and peritidal deposits in the Sierra Madre Oriental near Monterrey (Imlay, 1937). Since then this stratigraphy has been applied in the Sierra de Parras by many other workers (e.g., de Cserna 1956; Humphrey and Diaz, 1956; Wilson and Ward, 1993).

Our investigations in the Sierra de Parras document a shaly interval from 10 to 30 m thick separating shallow-water carbonates (middle "Aurora" of previous workers) from hemipelagic lime mudstones (upper "Aurora") (Figs. 3 and 6; Cañon Taraises, west-side Sierra Cabrera, Tanque Nuevo, Sierra Escondida). These shales contain the planktonic foraminifer *Globigerinelloides algerianus*, which defines a narrow total range zone in middle Aptian time (Fig. 4; Sliter, 1989), along with *Dufrenoyia* sp., a diagnostic ammonite for middle to upper Aptian time (Young, 1977; Ross and

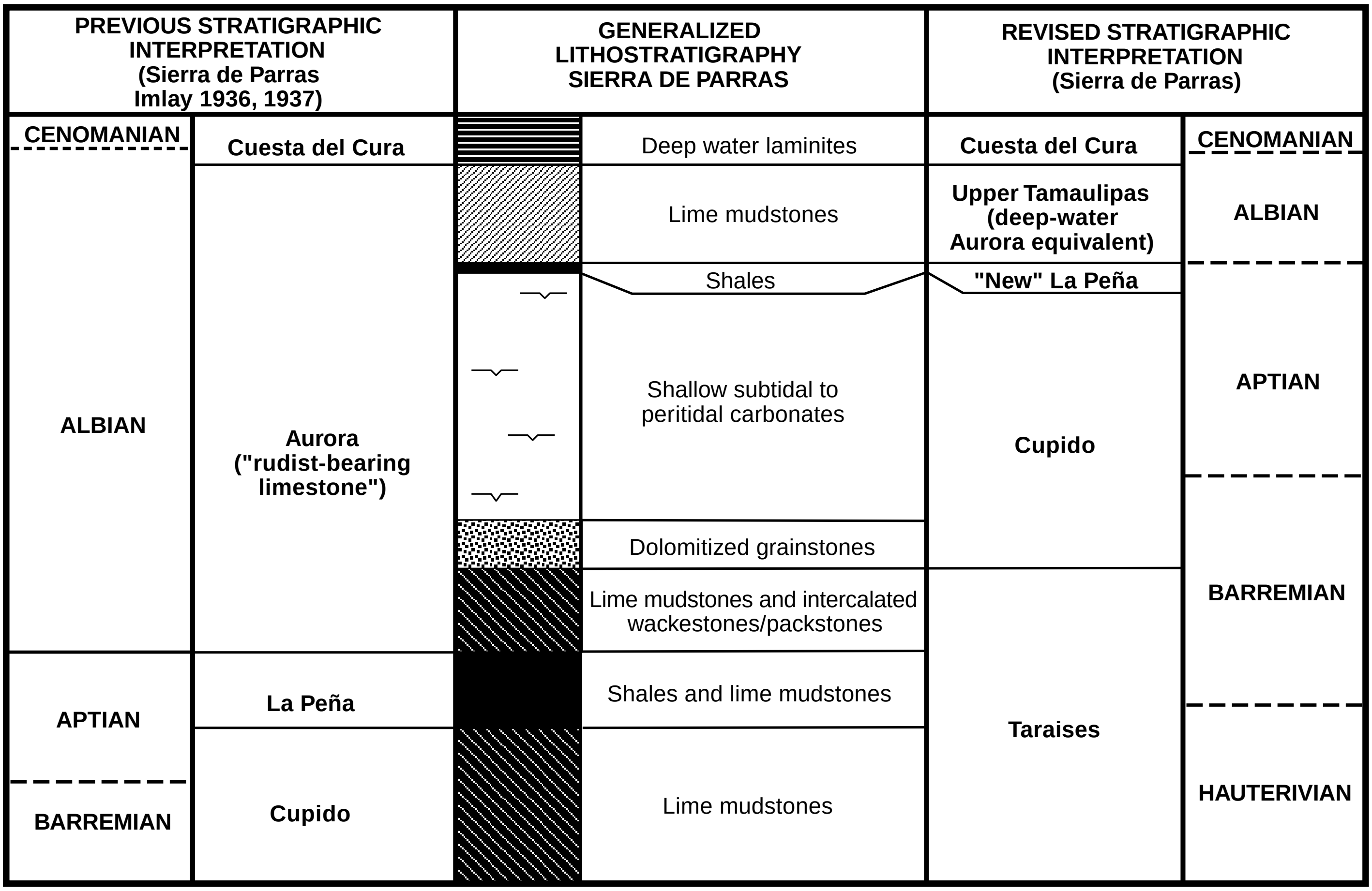


Figure 6. Generalized lithostratigraphy in the Sierra de Parras with previous stratigraphic interpretation by Imlay (1936, 1937) contrasted with the revised stratigraphic interpretation of this study. See Figure 2B for symbols.

McNulty, 1981; Tinker, 1985). *G. algerianus* and *Dufrenoyia* sp. are also found in the shales of the La Peña Formation to the east in the Sierra Madre Oriental near Saltillo and Monterrey. This newly identified shale in the Sierra de Parras ("new" La Peña; Fig. 6) is apparently correlative with the La Peña Formation in the Sierra Madre Oriental near Saltillo and Monterrey and indicates that the underlying shallow-water carbonates must correspond to the Cupido Formation rather than to the Albian "Aurora" as previously accepted. Moreover, below the newly redefined Cupido Formation in the Sierra de Parras, the occurrence of a Barremian ammonite (*Eodesmoceras* sp.; Keith Young, 1997, personal commun., Tanque Neuvo) and late Barremian to early Aptian benthonic foraminifers, including *Neotrocholina* sp. and primitive forms of *Vercorsella* sp. (La Concordia and Sierra de Parras, east side), indicates that the lime mudstones and shales formerly included in the Aptian La Peña and Cupido Formations should be included with the Taraises Formation, a diachronous, shaly, deep-water unit (Fig. 6).

A late Barremian to early Aptian rather than a late Aptian to early Albian age assignment for mudstones and shales below the newly defined Cupido Formation in the Sierra de Parras is further corroborated by the $^{87}Sr/^{86}Sr$ values of diagenetically least-altered limestones (Sierra Escondida section in Fig. 7). The $^{87}Sr/^{86}Sr$ values of micrites from this interval (average of 0.70751; range of 0.70742–0.70760) are similar to or slightly higher than published late Barremian to earliest Aptian seawater $^{87}Sr/^{86}Sr$ values of 0.70743–0.70751 (Jones et al., 1994; values renormalized to $^{87}Sr/^{86}Sr$ value of 0.710250 for NBS-SRM 987; Jenkyns et al., 1995; Bralower et al., 1997). The $^{87}Sr/^{86}Sr$ values for the Sierra Escondida samples are more widely spread than the range of values that defines the Cretaceous seawater Sr isotope curve. This difference is interpreted to reflect the effects of mixing of small to moderate amounts of diagenetic cements with marine cement during microsampling.

Lime mudstones overlying the redefined La Peña shale in the Sierra de Parras (Fig. 6) contain the foraminifers *Favusella scitula*, *F. washitensis*, *Hedbergella trocoidea*, and *Hedbergella* sp., the colomiellids *Colomiella recta* and *C. mexicana*, and ostracodes such as *Microcalamoides diversus*, suggesting a late Aptian to Albian age. The lower to middle Albian planktonic foraminifer *Ticinella primula* is found close to the contact with the overlying Cuesta del Cura Formation (Longoria and Gamper, 1977). Therefore, the mudstones overlying the redefined La Peña shale in the Sierra de Parras span late Aptian to middle Albian time and are correlative with the deep-water Upper Tamaulipas Formation (Fig. 6).

These new biostratigraphic and isotopic data radically change the accepted stratigraphic framework of the Sierra de Parras. The revised stratigraphy hinges on the recognition of Aptian La Peña shales higher in the stratigraphic section than previously mapped. The results of this study indicate that the Aurora Formation is restricted to Albian shallow-water carbonates overlying the Coahuila block to the northwest, significantly reducing the paleogeographic extent of the Aurora (Coahuila) platform. A similar interpretation that the Coahuila platform margin is buried in the Parras basin was made by Garza (1973).

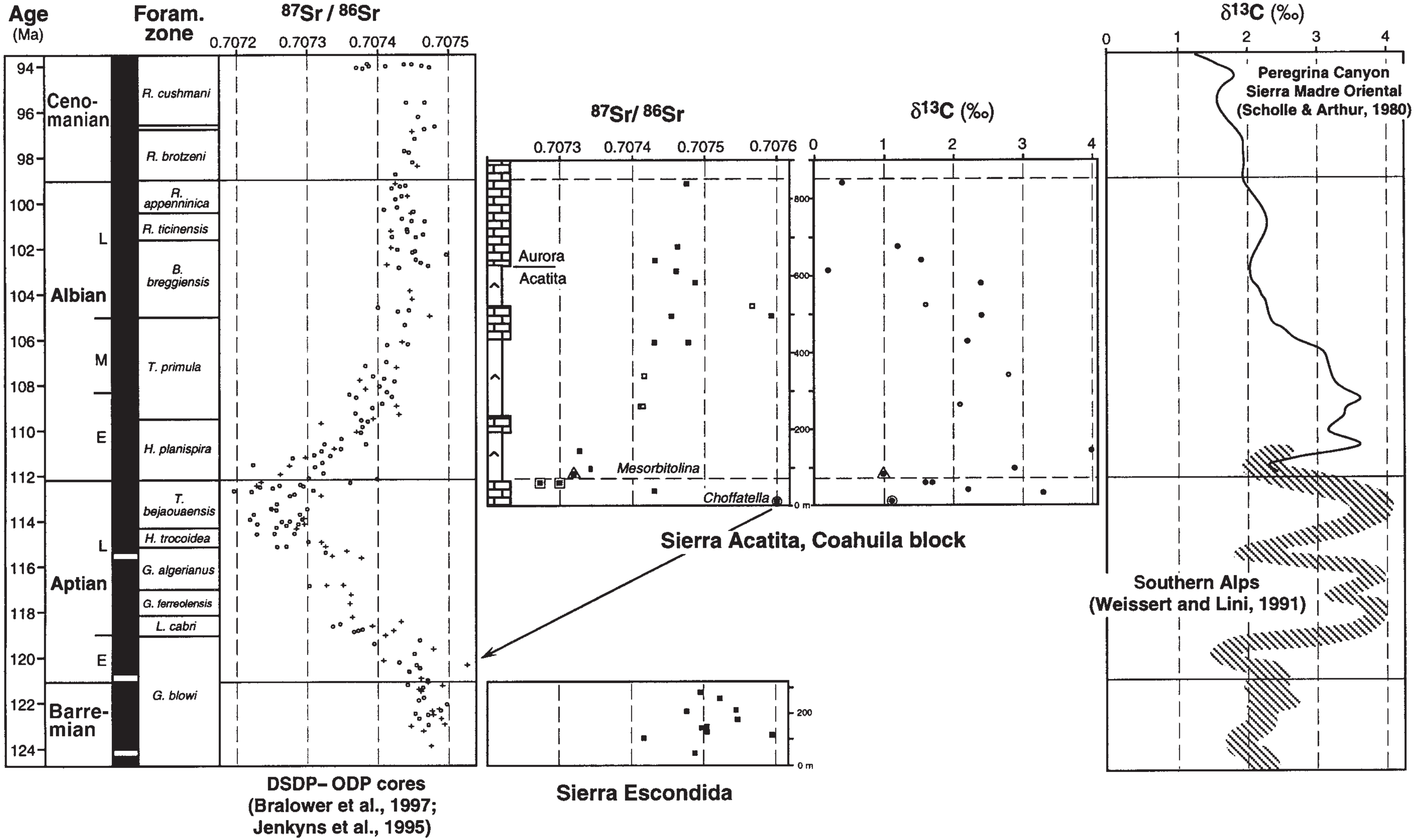


Figure 7. The $^{87}Sr/^{86}Sr$ and δ13C values of carbonates from two sections in study area of northeastern Mexico correlated with composite seawater Sr isotope curves of Bralower et al. (1997) and Jenkyns et al. (1995) and hemipelagic and pelagic $\delta^{13}C$ curves of Weissert and Lini (1991) and Scholle and Arthur (1980). Composite Sr curve of Bralower et al. (1997) (circles) derived from several Deep Sea Drilling Project–Ocean Drilling Program (DSDP–ODP) cores. Sr data of Jenkyns et al. (1995) (crosses) were derived from Resolution guyot. Absolute ages are from Gradstein et al. (1995). Same global planktonic foraminiferal zones and magnetic chronology as in Figure 4. Limestones analyzed in this study are shown by closed symbols; dolomites are shown by open symbols. Generalized stratigraphy of alternating carbonates and evaporites in the Sierra Acatita section is shown on left of Sr plot. Dashed horizontal lines in the data plots from this study show inferred stage boundaries. Alignment of published Sr and C isotope curves with data from this study is based upon all available biostratigraphic zonation and comparison of absolute values and trends in Sr and C isotopes. Shaded data points are referred to specifically in text. Arrow shows projected correlation of lowest data point with early Aptian values on Sr isotope curve.

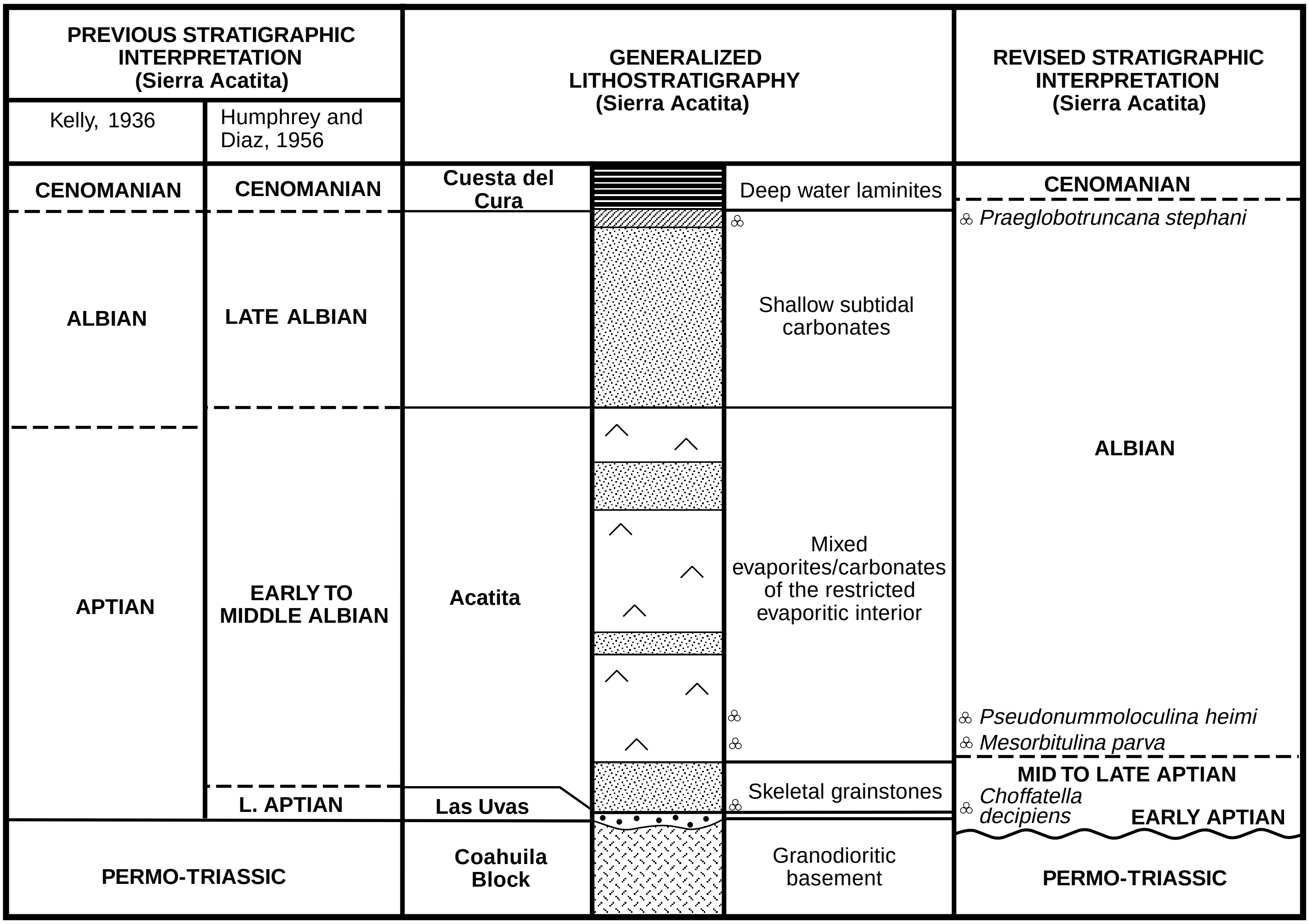


Figure 8. Generalized lithostratigraphy in the Sierra Acatita contrasting the stratigraphic interpretations of Kelly (1936) and Humphrey and Diaz (1956) with the revised stratigraphic interpretation of this study.

Coahuila Block

The correlation of Barremian-Albian carbonates in the Sierra de Parras with evaporites and carbonates on top of the Coahuila block is difficult because lateral transitions are buried within the intervening Parras basin (Fig. 3). In addition, unequivocal La Peña shales with their time-diagnostic fauna do not crop out on the Coahuila block. Further complications arise due to extensive dolomitization of carbonates interbedded with evaporites, resulting in poor fossil preservation. Consequently, previous age determinations of strata overlying Coahuila basement are equivocal and poorly constrained. New biostratigraphic and isotopic data collected in this study, however, permit a refinement of age estimates and a new stratigraphic model. Before explaining this model, a brief description of the lithostratigraphy and previous stratigraphic work on the Coahuila block is necessary (Fig. 8).

Sandstones directly overlying basement on the Coahuila block in the Sierra Acatita (0–15 m thick) were defined as the Las Uvas Formation by Humphrey and Diaz (1956). Overlying the Las Uvas Formation is the Acatita Formation, consisting of a basal, massive skeletal limestone (60–100 m thick) that passes upward into an ~500-m-thick succession of alternating evaporites and dolomites (Kelly, 1936; Humphrey and Diaz, 1956; Perkins, 1960; Wilbert, 1976; Wilson and Ward, 1993). Overlying the Acatita Formation are 190–260 m of massive shallow-water limestones containing miliolids and rudists (Aurora Formation). Deeper water facies of the Cuesta del Cura Formation overlie the Aurora deposits.

Kelly (1936) correlated the Acatita with the evaporitic Cuchillo Formation of northern Chihuahua (Burrows, 1909; King and Adkins, 1946) based on "lithologic similarities" and stratigraphic position below Aurora facies. He collected ammonites from Las Uvas sandstones in the Sierra Acatita (which he called "Lower Cuchillo Formation") that were preserved "as molds, making specific identification difficult or undeterminable" and stated that "provisional identification" of the late Aptian ammonite *Dufrenoyia justinae* was made by a student (p. 1024). He argued, despite the equivocal identification, that "the boundary between the Aptian and the Albian lies somewhere in the upper Cuchillo" (Acatita) (Kelly, 1936, p. 1027).

Humphrey and Diaz (1956) assumed the identification of *D. justinae* by Kelly (1936) to be correct, and thus a late Aptian age for the Las Uvas. They interpreted these sandstones as a nearshore equivalent to the La Peña Formation and inferred overlying evaporitic facies of the Acatita Formation to be Albian in age. Furthermore, Perkins (1960), working in the Sierra de Tlahualilo west of the Sierra Acatita, correlated the upper part of the Aurora Formation with the upper Albian Fredericksburg and Washita Groups in Texas.

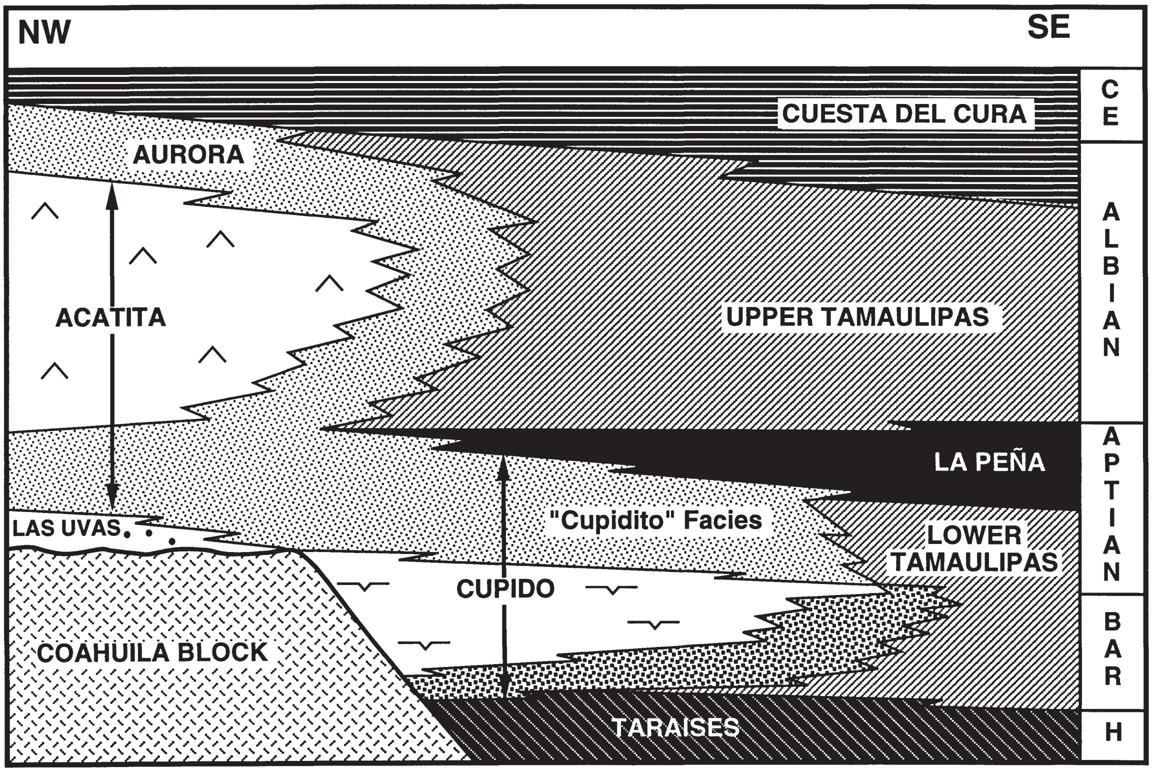


Figure 9. Chronostratigraphic interpretation for the Barremian to Albian strata of this study (modified from Lehmann et al., 1998). Note that the Las Uvas Formation and the overlying carbonates of the Lower Acatita Formation are coeval with the upper transgressive part of the Cupido Formation ("Cupidito"). Chart illustrates temporal relationships between the Coahuila block to the northwest and the Sierra de Parras to the south-southeast. See Figure 2B for symbols.

Both interpretations combined suggest that evaporites and carbonates of the Acatita Formation are early Albian in age and thus correlative with the Glen Rose Formation in Texas.

These interpretations do not provide a clear age assignment of the carbonates and evaporites deposited on top of the Coahuila block. Our revised stratigraphic interpretation, based on newly acquired biostratigraphic data combined with stratigraphic trends in carbon and strontium isotopes, significantly modifies the existing age assignments (Fig. 8). The most important difference is that the Las Uvas Formation and the massive skeletal limestone of the basal Acatita Formation are interpreted to be early to late Aptian in age (rather than late Aptian to early Albian). This interpretation is based on the presence of large miliolids and orbitolinids, especially the occurrence of *Choffatella decipiens*, at the base of the massive carbonates of the lower Acatita Formation and the top of the Las Uvas Formation (west-side Sierra Acatita and Agua Chico), suggesting a latest Barremian to early Aptian age. Furthermore, carbonate interbeds within the lowermost Acatita evaporites, which directly overlie the massive skeletal limestones, contain an orbitolinid and miliolid facies association including *Mesorbitolina parva* and *Pseudonummoloculina heimi* (west side Sierra Acatita, El Rayo), suggesting an Albian age.

The new age assignments for the lower Acatita Formation on the Coahuila block are further constrained by the $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ values of limestones and dolomites from the Sierra Acatita section (Fig. 7). The least diagenetically altered limestone samples from the basal massive skeletal limestones of the Acatita and carbonate interbeds within the lowermost Acatita evaporites exhibit a large range in $\delta^{13}C$ values over a relatively thin (~70 m) stratigraphic interval. A similar range and magnitude of shifts in $\delta^{13}C$ values of Tethyan pelagic and hemipelagic limestones define three global carbon isotope excursions during Aptian and earliest Albian time (Scholle and Arthur, 1980; Weissert and Lini, 1991; Föllmi et al., 1994). A rudist from the base of the Acatita Formation (data point within shaded circle in Fig. 7) has a low $\delta^{13}C$ value (1.1‰) and an $^{87}Sr/^{86}Sr$ value (0.70760) that is higher than any mid-Cretaceous primary marine value. This single $^{87}Sr/^{86}Sr$ value is closer to Barremian and earliest Aptian marine $^{87}Sr/^{86}Sr$ values than to middle Aptian through middle Albian values (shown by arrow). This Sr age assignment, coupled with the occurrence of *Choffatella decipiens* in the stratigraphically lowest sample, suggests that the low $\delta^{13}C$ value correlates with the more negative $\delta^{13}C$ values of the earliest Aptian (upper *Globigerinelloides blowi* zone). Combined chemostratigraphic and biostratigraphic relationships support a latest Barremian to earliest Aptian age for the basal Acatita Formation on the Coahuila block.

Stratigraphically younger samples from the massive skeletal limestone in the lower Acatita Formation record decreasing $^{87}Sr/^{86}Sr$ values. Two components of a grainstone (rudist and marine cement) from the top of the limestone (data points within shaded squares on Fig. 7) have the lowest $^{87}Sr/^{86}Sr$ values (0.70727 and 0.70731) of all carbonates analyzed in this study. These $^{87}Sr/^{86}Sr$ values and those of stratigraphically younger samples are characteristic of marine $^{87}Sr/^{86}Sr$ values that define the latest Aptian (*Hedbergella trocoidea* and *Ticinella bejaouaensis* zones) to very earliest Albian "trough" in the composite seawater Sr isotope curves of Bralower et al. (1997) and Jenkyns et al. (1995). This age estimate supports a post-middle Aptian age for the top of the massive skeletal limestones in the lower Acatita Formation and suggests that most of the

Aptian is recorded in the basal 70 m of the Acatita Formation in the Sierra Acatita section.

A limestone interbed from the lowermost evaporites in the Acatita Formation (data point within shaded triangle on Fig. 7) has the lowest $\delta^{13}C$ value (1.0‰) for this stratigraphic interval, but an overlapping to slightly higher $^{87}Sr/^{86}Sr$ value (0.70732) than immediately underlying carbonates. Rudists from directly overlying carbonate interbeds show a significant shift toward more positive $\delta^{13}C$ values (2.88‰–3.99‰) while maintaining near constant $^{87}Sr/^{86}Sr$ values (0.70734 and 0.70733). These combined isotopic trends, along with the cooccurrence of benthonic foraminifers *Mesorbitolina parva* and *Pseudonummoloculina heimi*, suggest that the $\delta^{13}C$ values of lowermost Acatita evaporites record the peak of the latest Aptian through earliest Albian negative isotope excursion and the subsequent early Albian positive excursion. In addition, increasing $^{87}Sr/^{86}Sr$ values from overlying carbonates record the early to middle Albian rise of the composite seawater Sr isotope curve (Fig. 7). These chemostratigraphic relationships imply that the Aptian-Albian boundary occurs near the base of the Acatita evaporites immediately overlying the massive skeletal limestones (Figs. 7 and 8).

The new age assignments suggest that marine incursions onto the Coahuila block occurred earlier than previously suggested and permit the construction of a chronostratigraphic diagram that illustrates the genetic relationships between the Cupido and Coahuila platforms (Fig. 9). A deepening trend within the middle to late Aptian part of the upper Cupido (Cupidito of Wilson and Pialli, 1977; Goldhammer et al., 1991) is likely coeval with the Las Uvas Formation and massive skeletal limestones of the lower Acatita Formation. Deposits contemporaneous with the late Aptian La Peña shales are inferred to be preserved as a condensed and reworked interval within the transition between massive carbonates and evaporites of the lower Acatita Formation. However, this condensed interval was not recognized in our measured sections.

Incipient drowning of the Coahuila carbonate platform is recorded in the upper Aurora Formation by as much as 20 m of foraminiferal mudstone and wackestone that grade up into cherty, deeper water calcisphere wackestones of the Cuesta del Cura Formation (Fig. 8). The mudstone and wackestone underlying the Cuesta del Cura at Cañon Corazon del Toro (Fig. 3) contain the planktonic foraminifer *Praeglobotruncana stephani.* The foraminifers *Ticinella primula* and *T. madecassiana* occur in similar muddy carbonates overlying shallow-water facies of the Aurora Formation in the Sierra de la Peña (Fig. 3). Both *Ticinella* forms extend up to the *Rotalipora appenninica* zone, whereas *P. stephani* extends from the *R. appenninica* zone through the Cenomanian strata (Sliter, 1989). Cooccurrence of these foraminifers in comparable stratigraphic intervals in the two sections suggests that diachronous termination of shallow-water deposition on the Coahuila platform began during middle Albian time and was complete by latest Albian time *(R. appenninica* zone; Fig. 4). These relative ages indicate that the Coahuila shallow-water platform backstepped in concert with onlap of Cuesta del Cura deep-water facies, the diachroneity of which was recognized by Ice and McNulty (1980).

Carbon and strontium isotope values and trends of least-altered rudists, limestones, and syndepositional dolomites throughout the upper Acatita and Aurora carbonates from the Coahuila block are similar to Albian through early Cenomanian portions of Tethyan pelagic $\delta^{13}C$ curves and the seawater Sr isotope curve (Fig. 7). Although the $\delta^{13}C$ values do not provide unequivocal time constraints, the $^{87}Sr/^{86}Sr$ values of the upper Acatita and Aurora Formations are characteristic of middle Albian to early Cenomanian seawater values. Based on the integrated biostratigraphic and isotopic data, we infer that the termination of carbonate deposition on the Coahuila platform corresponds with the worldwide drowning of carbonate platforms during the *Rotalipora appenninica* (latest Albian) time interval (Grötsch et al., 1993; Vahrenkamp et al., 1993; Sliter, 1995).

PALEOGEOGRAPHY AND PLATFORM MORPHOLOGY

The revised stratigraphy and age control, combined with platform facies associations, allow the construction of cross sections, isopach maps, and time-slice paleogeographic maps that collectively help to document platform morphology and evolution. All measured section data that were used to construct cross sections such as Figure 10 (see also Lehmann, 1997) were integrated with the chronostratigraphic interpretation (Fig. 9) to generate isopach maps (Fig. 11) and time-slice paleogeographic maps (Fig. 12). A west-east cross section extending from the western part of the Sierra de Parras to the Sierra de Picachos illustrates the facies relationships of Lower Cretaceous strata, excluding those of the Coahuila block (Fig. 10). This cross section shows that thick accumulations of shallow-water carbonates of the Cupido platform extend for >250 km from the shelf margin near Monterrey to the edge of the Coahuila block. Above the La Peña shales, only deep-ramp facies of the Upper Tamaulipas Formation are exposed along the profile, reflecting the significant backstep of the Coahuila platform margin.

The Coahuila block was exposed during Barremian time and controlled the orientation of the Cupido shelf margin (Figs. 1 and 12A). The morphology and composition of the shelf margin, however, are variable in relief, slope angle, and lithofacies. This study documents that the southern Cupido platform in the Sierra de Parras has the morphology of a shelf with a low-relief, barrier shoal margin. In contrast, the shelf margin toward the east near Monterrey is dominated by rudist reefs with stromatoporoids and corals (Wilson, 1975; Conklin and Moore, 1977; Goldhammer et al., 1991). This paleodepositional variability along the same platform margin suggests that intrinsic controls such as the windward-leeward orientation of the platform margin relative to dominant current, wave, and wind patterns may exert a critical control on margin composition and architecture. The reefal Cupido margin flanking the eastern edge of the platform faced the open Gulf of Mexico and likely underwent conditions of strong wave energy and high rates of biologic productivity, comparable to many modern east-facing reef margins (e.g., Bahamas, Belize, Great Barrier Reef). The southern shoal margin of the Cupido platform, oriented perpendicular to the open gulf, may have been dominated by longshore currents and suppressed wave and wind energy, resulting in the south to southwest migration of sand shoals and general absence of organic buildups. Minero (1991) documented similar characteristics to the variable Cupido shelf margin in facies of the mid-Cretaceous El Abra Formation, deposited in protected-island versus open paleoenvironments along the windward eastern margin of the Valles platform to the south.

A broad, flat-topped, peritidal shelf-lagoon formed in the lee of the southern and eastern Cupido margins, extending to the edge of the Coahuila block where carbonates became mixed with siltstones and sandstones derived from the exposed basement (Fig. 10). Isopachs of the Taraises, Cupido, and Lower Tamaulipas Formations (Fig. 11A) define the trend of the Cupido shelf margin (maximum thicknesses) and document tapering of a Cupido wedge toward the Coahuila block.

During early to middle Aptian time (Fig. 12B), the initial phases of flooding forced a retrograde backstep of the Cupido platform, gradually transforming the earlier reef- and shoal-rimmed shelf into a homoclinal ramp (Cupidito facies). An isolated rudist pinnacle reef in the Cupidito was described by Conklin and Moore (1977) from a locality in Potrero Oballos north of the study area; we interpret this reef to reflect an attempt to keep up with incipient drowning. Shallow subtidal deposits of the Cupidito covered an area from the edge of the Coahuila block to the Cupido margin before passing seaward into muddy facies of the Lower Tamaulipas Formation (Fig. 10).

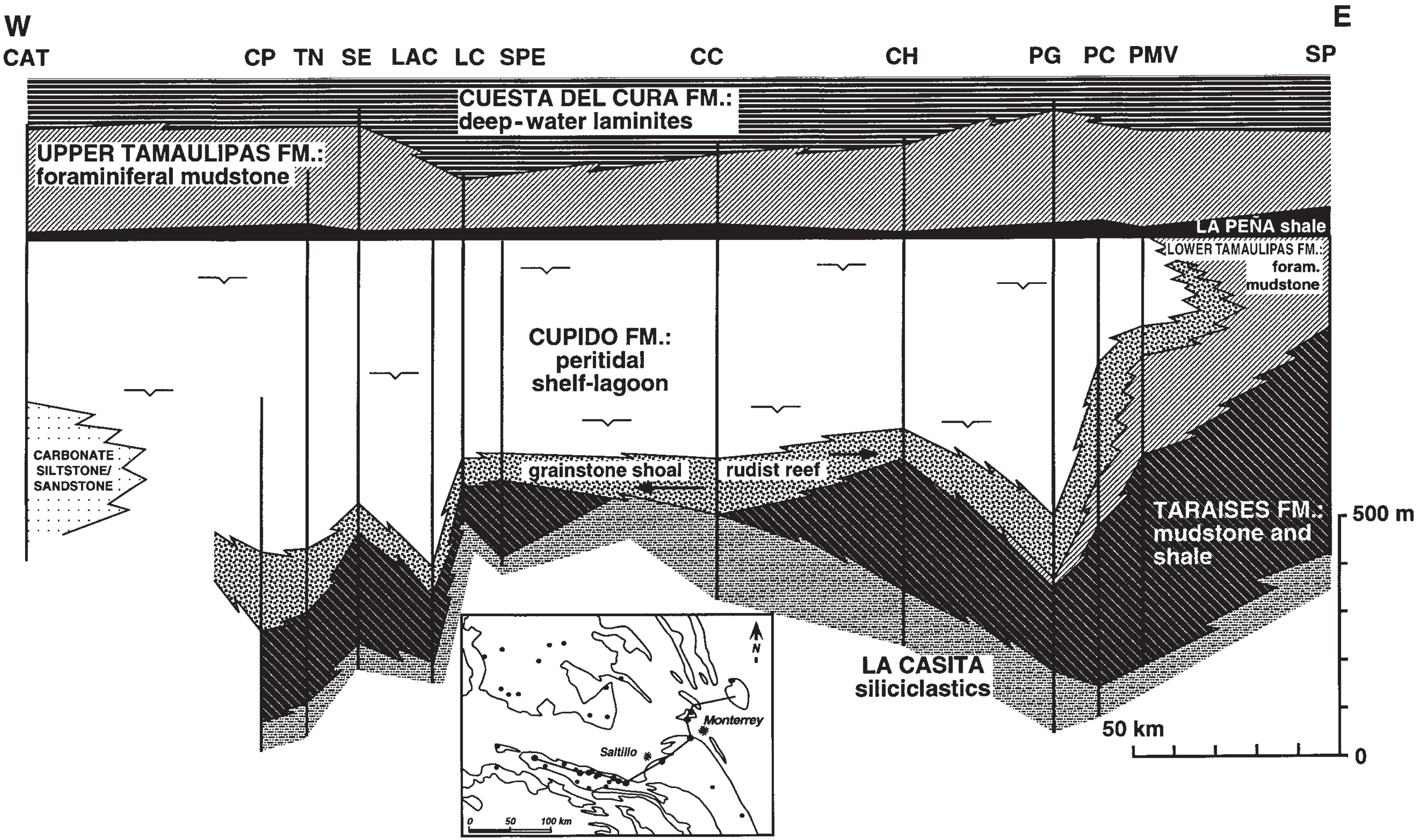
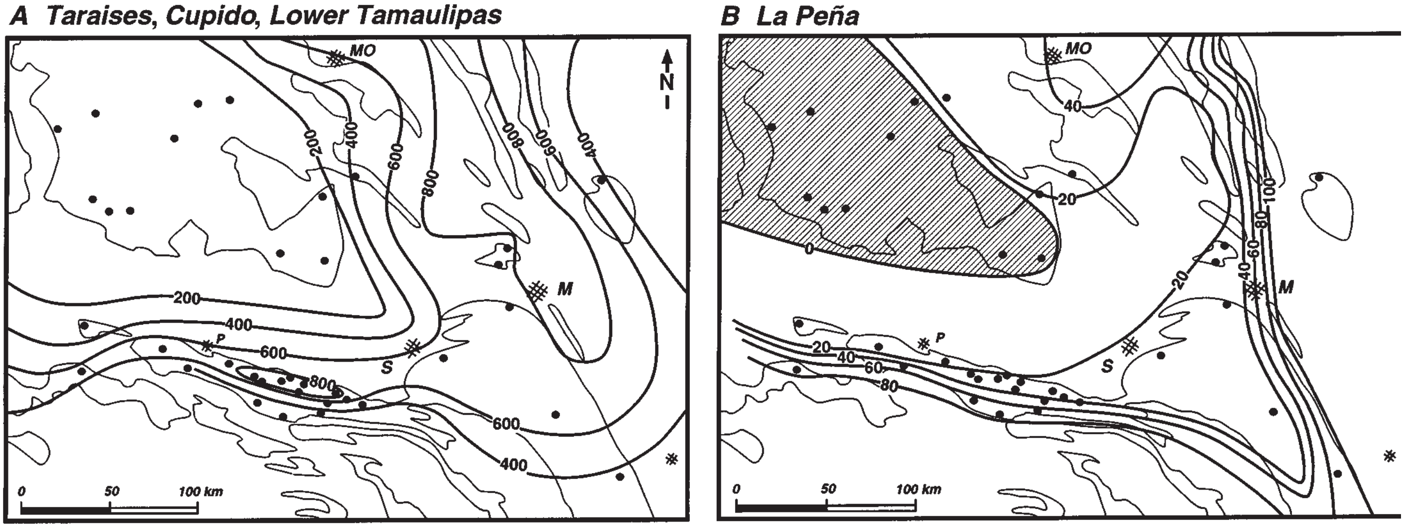


Figure 10. West-east cross section of Lower Cretaceous formations from the western edge of the Sierra de Parras (CAT) to the Sierra de Picachos (SP) using the La Peña Formation as datum. Section abbreviations as in Figure 3. The La Peña Formation is mostly covered at La Casita (LAC), La Concordia (LC), and Sierra de Parras, east side (SPE), so we estimate thicknesses at these localities on the cross section. Stratigraphic data near Monterrey and Sierra de Picachos for the La Peña and underlying formations were compiled from Bishop (1966, 1970, 1972), Charleston (1974), Conklin and Moore (1977), Wilson and Pialli (1977), Wilson (1981), Selvius (1982), Wilson et al. (1984), Selvius and Wilson (1985), Tinker (1985), Goldhammer et al. (1991), and this study. The cross section is parallel to depositional strike from Canõn Taraises to Potrero Chico, then perpendicular to strike for the Cupido shelf margin from Potrero Chico (PC) to Potrero Minas Viejas (PMV) and to the Sierra de Picachos (SP). The Cupido shelf margin changes in composition from a high-energy grainstone shoal west of Cañon del Chorro (CC) to a rudist reef margin to the east. Note the thick accumulations of peritidal shelf-lagoon facies of the Cupido Formation in the western part of the Sierra de Parras. Only deep ramp deposits of the Coahuila platform are shown in this cross section (Upper Tamaulipas Formation). Same location map as shown in Figure 3.



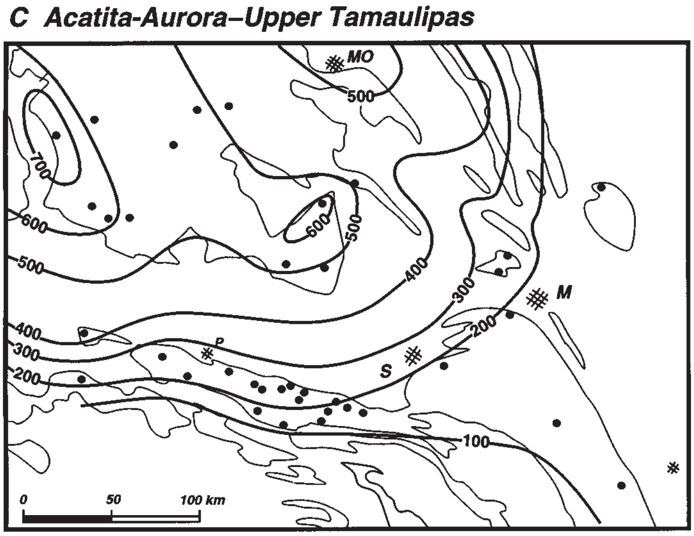


Figure 11. Isopach maps (not palinspastically corrected) of three lithostratigraphic intervals comprising the Cupido and Coahuila platforms. Thickness data were acquired from Humphrey and Diaz (1956), Charleston (1974), Conklin and Moore (1977), Wilson and Pialli (1977), Elliot (1979), Tinker (1985), and this study. (A) Thin deposits on the Coahuila block are updip equivalents to the uppermost "Cupidito" facies of the Cupido Formation (Las Uvas and lower Acatita Formations). (B) Shales and lime mudstones of the La Peña Formation do not extend up onto the Coahuila block (shaded interior of 0 m contour), but a thin interval of carbonate and perhaps evaporite strata of the lower Acatita is interpreted to be coeval with the La Peña Formation on the block. (C) Two thickest accumulations on the Coahuila block represent evaporitic subbasins centered over the Sierra Acatita (west) and Cañon Corazon del Torro (east). Same area as shown in Figure 3. Light lines are outline of the mountain ranges shown in Figure 3. MO—Monclova, M—Monterrey, S—Saltillo, P—Parras.

On the Coahuila block, deposition of the basal carbonate-rich sandstone (Las Uvas) and overlying skeletal packstone-grainstone (lower Acatita) marks the beginning of Early Cretaceous carbonate platform development in that area. The Las Uvas Formation represents transgressive shoreline deposition preserved in topographic lows on the irregular basement surface. Overlying pure carbonates of the lowermost Acatita Formation reflect the complete marine inundation of the Coahuila block and the establishment of a carbonate-generating biota.

During middle to late Aptian time (Fig. 12C), deposition of shales and laminated foraminiferal mudstones of the La Peña Formation marked the peak of flooding and termination of the Cupido platform. The Cupido platform termination coincides with a major episode of shallow platform demise throughout the peri-Tethyan region (Föllmi et al., 1994). Small, rounded phosphorite clasts within the La Peña shale suggest reworking within the La Peña and are a common feature of drowning events (Föllmi, 1989). In the area overlying the Coahuila block, this flooding interval should be marked by a condensed and reworked interval within the transition from carbonates to evaporites in the lower Acatita Formation (Figs. 9 and 11B). Significant unconformities are probable in the Aptian lower Acatita Formation, based on extremely slow accumulation rates of 7.5–12.5 m/m.y. (60–100 m of accumulation over ~8 m.y.). The diachronous Cupidito–La Peña flooding event records both the demise of the Cupido shelf and the initiation of the Coahuila ramp. This transition occurred simply by the landward migration of the locus of shallow-marine sedimentation back toward the Coahuila block during the Cupidito–La Peña backstep (Fig. 9).

After the La Peña flooding, carbonate platform development resumed (Fig. 12D) with the margin of the Coahuila ramp backstepped to the northwest ~100 km relative to the Aptian Cupido margin near Monterrey. Evaporites of the Acatita Formation formed in the interior of the Coahuila carbonate platform; variable thicknesses of the evaporites throughout the region (200–500 m; the greatest thicknesses are centered over the Sierra Acatita and Cañon Corazon del Torro; Fig. 11C) suggest differing degrees of restriction behind the ramp margin barrier. The ramp margin that isolated the Coahuila interior lagoon from open-marine conditions is only exposed at two locations on the Coahuila block, but the presence of skeletal packstone and grainstone

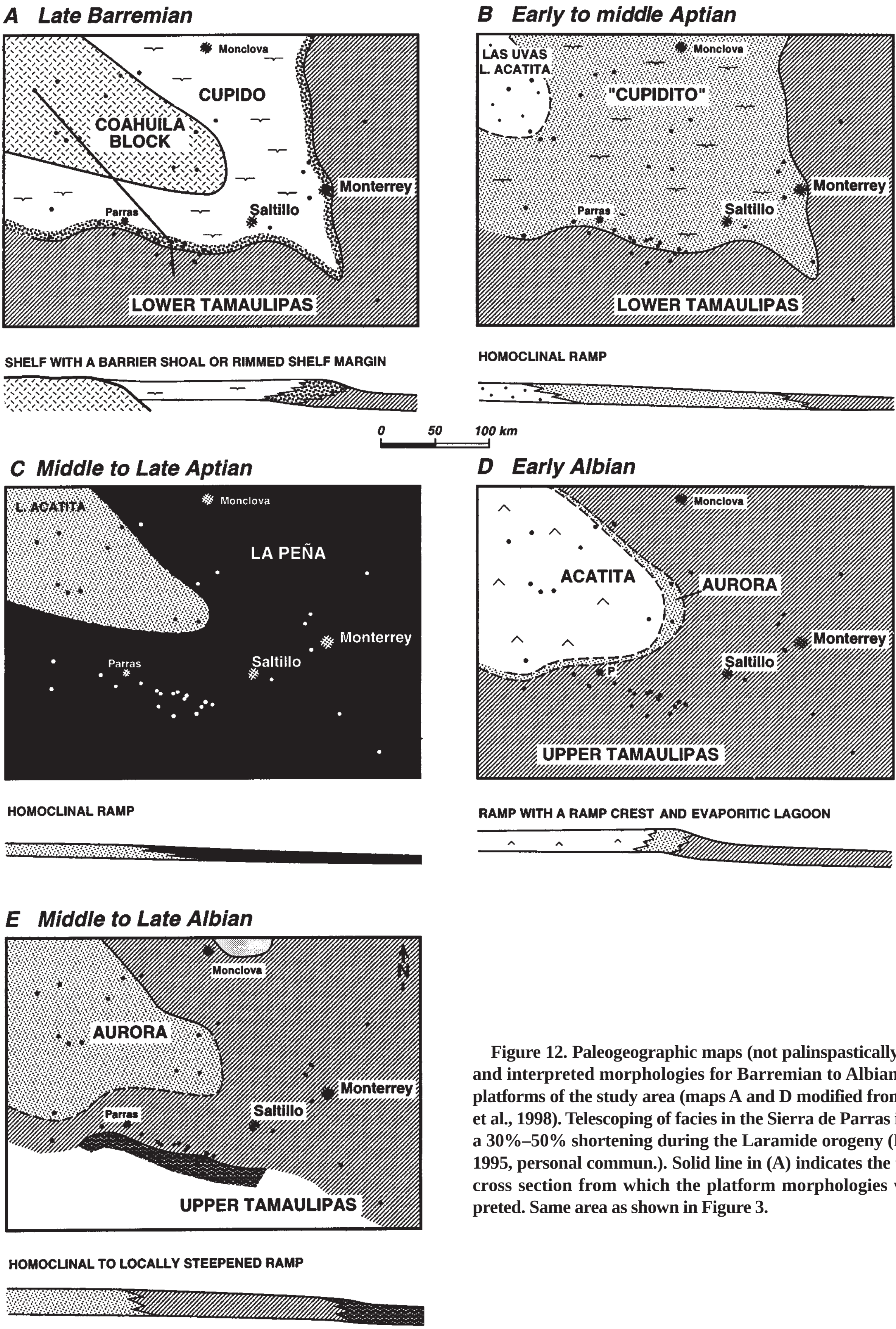


Figure 12. Paleogeographic maps (not palinspastically corrected) and interpreted morphologies for Barremian to Albian carbonate platforms of the study area (maps A and D modified from Lehmann et al., 1998). Telescoping of facies in the Sierra de Parras is related to a 30%–50% shortening during the Laramide orogeny (R. Marrett, 1995, personal commun.). Solid line in (A) indicates the trace of the cross section from which the platform morphologies were interpreted. Same area as shown in Figure 3.

both beneath and above evaporitic facies (Agua Chico, Cañon Corazon del Toro, Cañon Grande, El Roya, west side Sierra Acatita, Sierra de la Peña) suggests that similar carbonate facies may have composed the barrier margin of the Coahuila platform (Fig. 9).

By middle Albian time (Fig. 12E), the Acatita evaporitic lagoon was replaced by a fully developed carbonate system that produced abundant peloidal, miliolid-rich packstone and grainstone (Aurora Formation). Aurora shallow subtidal facies centered on the Coahuila block are interpreted to grade seaward into hemipelagic mudstones of the Upper Tamaulipas Formation across a homoclinal ramp profile. Subordinate amounts of peloids and fragmental echinoderms and rudists in the Upper Tamaulipas suggest downslope sediment transport from the shallow platform. In the southern part of the Sierra de Parras, calciturbidites, intraclast breccias, and Z-folded mudstones indicate gravitational transport along a paleoslope separating the proximal deep ramp of the Coahuila platform from a locally steepened distal ramp.

The two Lower Cretaceous platforms exhibit parallel changes in depositional profile in response to long-term changes in relative sea level or to environmental effects. The Cupido platform evolved during Barremian to middle Aptian time from a flat-topped, rimmed shelf with marginal reefs and barrier shoals to a homoclinal ramp. The Cupidito retrograde backstep preceded complete drowning by La Peña facies during late Aptian time. In similar fashion, the backstepped Coahuila platform initially developed a shallow subtidal barrier rim protecting an evaporitic interior, but eventually transformed into a homoclinal ramp by middle Albian time. The Aurora to Upper Tamaulipas ramp records the final stage of shallow-marine carbonate sedimentation in the region prior to onlap of Cuesta del Cura deep-water facies in late Albian through early Cenomanian time.

CONCLUSIONS

New biostratigraphic and isotope chemostratigraphic data dictate significant changes in the stratigraphic interpretation of Lower Cretaceous carbonates of northeastern Mexico and dramatically change paleogeographic relations in the region. Four critical refinements in the chronologic history and paleogeography of the Cupido and Coahuila platforms occur as a result of this study. (1) The western continuation of the Barremian-Aptian Cupido platform margin was unknown up to this point (see paleogeographic and isopach maps in Conklin and Moore, 1977; Smith, 1981; Selvius, 1982; Wilson et al., 1984), but our observations suggest that the Cupido rudist-reef margin in the vicinity of Monterrey turns sharply westward along the Sierra de Parras into a semicontinuous grainstone shoal. (2) The Cupido platform in the lee of the margin is now recognized to be a broad, flat-topped peritidal shelf-lagoon extending northwestward to the Coahuila basement block. (3) Initial flooding of the Coahuila block may have occurred earlier than previously suggested, perhaps beginning in late Barremian or early Aptian time with retrogradational backstep recorded in the Cupidito facies of the Cupido Formation. The peak Cupidito–La Peña flooding event is represented on the Coahuila block as a strongly condensed interval marked by very low accumulation rates. These new chronostratigraphic relationships genetically link the demise of the Cupido platform with the initiation of the Coahuila platform. (4) Shallow-water carbonates (Aurora Formation) of the Albian Coahuila platform are not developed in the Sierra de Parras as previously believed, but are restricted to the north, built upon the foundation of the Coahuila block.

On a broader scale, this study fills in a substantial gap in the Cretaceous paleogeography of the eastern Gulf of Mexico coast, improving regional correlations with adjacent hydrocarbon-rich platforms. Furthermore, the improved chronology of events recorded in the Cupido and Coahuila platforms provides a well-constrained template for comparison with coeval platforms worldwide, perhaps leading to an enhanced understanding of global versus regional controls on carbonate platform development during middle Cretaceous time.

ACKNOWLEDGMENTS

Financial support was provided by grants from the University of California Institute for Mexico and the United States, the American Association of Petroleum Geologists, Sigma Xi, and the Geological Society of America, and National Science Foundation grant EAR-9417872 to David A. Osleger. We thank James Lee Wilson and Bill Ward, who introduced us to the field area and discussed many of the findings of this paper. Wolfgang Stinnesbeck (Universidad Autónoma de Nuevo León) and Paul Enos (University of Kansas) also helped us to better understand the stratigraphy of northeastern Mexico, and Clyde Moore explained the Cretaceous of central Texas. We are grateful to José Longoria (Florida International University) for identifying planktonic foraminifers in samples from selected sections, Keith Young (University of Texas) for classifying ammonites, and Tim Bralower (University of North Carolina) for identifying nannoconids and providing input regarding Cretaceous isotopic excursions. Larry Mack and MaryLynn Musgrove of the University of Texas, Austin, provided analytical expertise. Scott Edwards, Raully Jones, and Brian Murtagh provided able field assistance. This paper benefited from careful reviews by James Lee Wilson, Bill Ward, Bob Scott, Robert Goldhammer, and Peter Sadler. We thank *Bulletin* reviewers Tim Bralower, Paul Enos, and John Humphrey for their constructive criticism and insight.

REFERENCES CITED

Anderson, T. H., and Schmidt, V. A., 1983, The evolution of Middle America and the Gulf of Mexico–Caribbean region during Mesozoic time: Geological Society of America Bulletin, v. 94, p. 941–966.

Banner, J. L., and Kaufman, J., 1994, The isotopic record of ocean chemistry and diagenesis preserved in nonluminescent brachiopods from Mississippian carbonate rocks, Illinois and Missouri: Geological Society of America Bulletin, v. 106, p. 1074–1082.

Bebout, D. G., and Loucks, R. G., 1974, Stuart City Trend Lower Cretaceous, South Texas: A carbonate shelf-margin for hydrocarbon exploration: University of Texas Bureau of Economic Geology Report of Investigations 78, 80 p.

Bemis, B. E., Spero, H. J., Bijma, J., and Lea, D. W., 1998, Reevaluation of the oxygen isotopic composition of planktonic foraminifera: Experimental results and revised paleotemperature equations: Paleoceanography, v. 13, p. 150–160.

Bishop, B. A., 1966, Stratigraphy and carbonate petrography of the Sierra de Picachos and vicinity, Nuevo Leon, Mexico [Ph.D. dissert.]: Austin, University of Texas, 449 p.

Bishop, B. A., 1970, Stratigraphy of Sierra de Picachos and vicinity, Nuevo Leon, Mexico: American Association of Petroleum Geologists Bulletin, v. 54, p. 1245–1270.

Bishop, B. A., 1972, Petrography and origin of Cretaceous limestones, Sierra de Picachos and vicinity, Nuevo Leon, Mexico: Journal of Sedimentary Petrology, v. 42, p. 270–286.

Bonet, F., 1956, Zonificacion microfaunistica de las calizas cretacias del Este de Mexico: Boletín de la Asociación Mexicana de Geólogos Petroleros, v. 8, nos. 7–8, p. 389–487.

Böse, E., 1921, On the Permian of Coahuila, northern Mexico: American Journal of Science, ser. 5, v. 1, p. 187–194.

Böse, E., 1923, Vestiges of an ancient continent in northern Mexico: American Journal of Science, ser. 5, v. 6, p. 127–136, p. 196–214, p. 310–337.

Böse, E., and Cavins, O. A., 1927, Cretaceous ammonites from Texas and northern Mexico: University of Texas Bulletin 2748, p. 143–357.

Bralower, T. J., Sliter, W. V., Arthur, M. A., Leckie, R. M., Allard, D. J., and Schlanger, S. O., 1993, Dysoxic/anoxic episodes in the Aptian-Albian, *in* Pringle, M. S., Sager, W. W., Sliter, W. V., and Stein S., eds., The Mesozoic Pacific: Geology, tectonics and volcanism: American Geophysical Union Geophysical Monograph 77, p. 5–37.

Bralower, T. J., Fullagar, P. D., Paull, C. K., Dwyer, G. S., and Leckie, R. M., 1997, Mid-Cretaceous strontium-isotope stratigraphy of deep-sea sections: Geological Society of America Bulletin, v. 109, p. 1421–1442.

Buffler, R. T., and Sawyer, D. S., 1985, Distribution of crust and early history, Gulf of Mexico Basin: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 333–344.

Burrows, R. H., 1909, Geology in northern Mexico: Mining and Scientific Press, v. 99, p. 290–294.

Cantú Chapa, C. M., Sandoval, R., and Arenas, R., 1985, Evolución sedimentaria del Cretácico inferior en el norte de México: Revista del Instituto Mexicano del Petróleo, v. 17, p. 14–37.

Charleston, S., 1974, Stratigraphy, tectonics, and hydrocarbon potential of the Lower Cretaceous, Coahuila Series, Coahuila, Mexico [Ph.D. thesis]: Ann Arbor, University of Michigan, 268 p.

Conklin, J., and Moore, C., 1977, Paleoenvironmental analysis of the Lower Cretaceous Cupido Formation, northeast Mexico, *in* Bebout, D. G., and Loucks, R. G., eds., Cretaceous carbonates of Texas and Mexico: University of Texas Bureau of Economic Geology Report of Investiga-

tions 89, p. 302–323.
Coogan, A. H., 1977, Early and middle Cretaceous Hippuritacea (rudists) of the Gulf Coast, *in* Bebout, D. G., and Loucks, R. G., eds., Cretaceous carbonates of Texas and Mexico: University of Texas Bureau of Economic Geology Report of Investigations 89, p. 32–70.
Coogan, A. H., Bebout, D. G., and Maggio, C., 1972, Depositional environments and geologic history of Golden Lane and Poza Rica trend—An alternative view: American Association of Petroleum Geologists Bulletin, v. 56, p. 1419–1447.
de Cserna, Z., 1956, Tectonica de la Sierra Madre Oriental de Mexico, entre Torreon y Monterrey: XX Congreso Geologico International, Mexico, 87 p.
Ekdale, A., Ekdale, S. R., and Wilson, J. L., 1976, Numerical analysis of carbonate microfacies in the Cupido Limestone (Neocomian-Aptian), Coahuila, Mexico: Journal Sedimentary Petrology, v. 46, p. 362–368.
Elliot, T. L., 1979, Deposition and diagenesis of carbonate slope deposits, Lower Cretaceous, northeastern Mexico [Ph.D. thesis]: Austin, University of Texas, 330 p.
Enos, P., 1974, Reefs, platforms, and basins of middle Cretaceous in northeast Mexico: American Association of Petroleum Geologists Bulletin, v. 58, p. 800–809.
Enos, P., and Stephens, B. P., 1993, Mid-Cretaceous basin margin carbonates, east-central Mexico: Sedimentology, v. 40, p. 539–556.
Föllmi, K. B., 1989, Evolution of the mid-Cretaceous triad, *in* Bhattacharji, S., Friedman, G. M., Neugebauer, H. J., and Seilacher, A., eds., Lecture notes in earth sciences: Berlin, Springer-Verlag, 153 p.
Föllmi, K. B., Weissert, H., Bisping, M., and Funk, H., 1994, Phosphogenesis, carbon-isotope stratigraphy, and carbonate-platform evolution along the Lower Cretaceous northern Tethyan margin: Geological Society of America Bulletin, v. 106, p. 729–746.
Fortunato, K. S., and Ward, W. C., 1982, Upper Jurassic–Lower Cretaceous fan delta complex, La Casita Formation of the Saltillo area, Coahuila, Mexico: Gulf Coast Association of Geological Societies Transactions, v. 32, p. 473–482.
Gao, G., Land, L. S., and Elmore, R. D., 1995, Multiple episodes of dolomitization in the Arbuckle Group, Arbuckle Mountains, south-central Oklahoma; field, petrographic and geochemical evidence: Journal of Sedimentary Research, v. 65, p. 321–331.
Garza, G. R., 1973, Model sedimentario del Albiano-Cenomaniano en la porcion sureste de la plataforma de Coahuila (Prospecto Parras, Edo. de Coahuila): Boletín de la Asociación Mexicana de Geólogos Petroleros, v. 25, p. 300–339.
Goldhammer, R. K., and Wilson, J. L., 1991, Tectonic development, *in* Goldhammer, R. K., Lehmann, P. J., Todd, R. G., Wilson, J. L., Ward, W. C., and Johnson, C. R., eds., Sequence stratigraphy and cyclostratigraphy of the Mesozoic of the Sierra Madre Oriental, northeast Mexico, a field guidebook: Gulf Coast Section, SEPM (Society for Sedimentary Geology), p. 7–14.
Goldhammer, R. K., Lehmann, P. J., Todd, R. G., Wilson, J. L., Ward, W. C., and Johnson, C. R., eds., 1991, Sequence stratigraphy and cyclostratigraphy of the Mesozoic of the Sierra Madre Oriental, northeast Mexico, a field guidebook: Gulf Coast Section, SEPM (Society for Sedimentary Geology), 85 p.
Gradstein, F. M., Agterberg, F. P., Ogg, J. G., Hardenbohl, J., Van Veen, P., Thierry, J., and Huang, Z., 1995, A Triassic, Jurassic and Cretaceous time scale, *in* Berggren, W. A., Kent, D. V., Aubry, M.-P., and Hardenbol, J., eds., Geochronology, time scales and global stratigraphic correlation: SEPM (Society for Sedimentary Geology) Special Publication 54, p. 95–126.
Grötsch, J., 1996, Cycle stacking and long-term sea level history in the Lower Cretaceous (Gavrovo Platform, NW Greece): Journal of Sedimentary Research, v. 66, p. 723–736.
Grötsch, J., Schroeder, R., Noe, S., and Flügel, E., 1993, Carbonate platforms as recorders of high-amplitude eustatic sea-level fluctuations: The late Albian appenninica-event: Basin Research, v. 5, p. 197–212.
Haarmann, E., 1913, Geologische Streifzüge in Coahuila: Zeitschrift der Deutschen Geologischen Gesellschaft, Monatsberichte, no. 1, Band 65.
Haq, B. U., Hardenbol, J., and Vail, P. R., 1988, Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change, *in* Wilgus, C., Posamentier, H., Ross, C., and Kendall, C. G. S. C., eds., Sea-level changes: An integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 71–108.
Humphrey, W. E., 1949, Geology of the Sierra de los Muertos area, Mexico (with descriptions of Aptian Cephalopods from the La Peña Formation): Geological Society of America Bulletin, v. 60, p. 89–176.
Humphrey, W. E., and Diaz, T., 1956, Jurassic and Lower Cretaceous stratigraphy and tectonics of northeastern Mexico: Unpublished manuscript (Mincat call number 36116 at the University of Texas Library, Austin, Texas).
Ice, R. G., 1981, The Cuesta del Cura Formation in north-central Mexico, *in* Smith, C. I., ed., Lower Cretaceous stratigraphy and structure, northern Mexico: West Texas Geological Society Publication 81–74, p. 58–74.
Ice, R. G., and McNulty, C. L., 1980, Foraminifers and calcispheres from the Cuesta del Cura and Lower Agua Nueva(?) Formations (Cretaceous) in east-central Mexico: Gulf Coast Association of Geological Societies Transactions, v. 30, p. 403–425.
Imlay, R. W., 1936, Evolution of the Coahuila Peninsula, Mexico, part 4, Geology of the western part of the Sierra de Parras: Geological Society of America Bulletin, v. 47, p. 1091–1152.
Imlay, R. W., 1937, Geology of the middle part of the Sierra de Parras, Coahuila, Mexico: Geological Society of America Bulletin, v. 48, p. 587–630.
Imlay, R. W., 1938, Studies of the Mexican geosyncline: Geological Society of America Bulletin, v. 49, p. 1651–1694.
Imlay, R. W., 1944a, Cretaceous formations of central America and Mexico: American Association of Petroleum Geologists Bulletin, v. 28, p. 1077–1195.
Imlay, R. W., 1944b, Correlations of the Cretaceous formations of the Greater Antilles, central America, and Mexico: Geological Society of America Bulletin, v. 55, p. 1005–1046.
Jenkyns, H. C., Paull, C. K., Cummins, D. I., and Fullagar, P. D., 1995, Strontium-isotope stratigraphy of Lower Cretaceous atoll carbonates in the Mid-Pacific Mountains, *in* Winterer, E. L., Sager, W. W., Firth, J. V., and Sinton, J. M., Proceedings of the Ocean Drilling Program, Scientific results, Volume 143: College Station, Texas, Ocean Drilling Program, p. 89–97.
Johnson, C. R., 1991, Depositional cycles of the Zuloaga (Oxfordian-Kimmeridgean?) Formation, Sierra de Buñuelos, Coahuila, Mexico [Master's thesis]: New Orleans, Louisiana, University of New Orleans, 242 p.
Jones, C. E., Jenkyns, H. C., Coe, A. L., and Hesselbo, S. P., 1994, Strontium isotopic variations in Jurassic and Cretaceous seawater: Geochimica et Cosmochimica Acta, v. 58, p. 3061–3074.
Kellum, L. B., Imlay, R. W., and Kane, W. G., 1936, Evolution of the Coahuila Peninsula, Mexico, Part 1, Relation of structure, stratigraphy and igneous activity to an early continental margin: Geological Society of America Bulletin, v. 47, p. 969–1008.
Kelly, W. A., 1936, Evolution of the Coahuila Peninsula, Mexico, part 2, Geology of the mountains bordering the valleys of Acatita and Las Delicias: Geological Society of America Bulletin, v. 47, p. 1009–1038.
King, R. E., and Adkins, W. S., 1946, Geology of a part of the Lower Conchos valley, Chihuahua, Mexico: Geological Society of America Bulletin, v. 57, p. 275–294.
Krutak, P. R., 1967, Structural geology of the Sierra de la Gavia, Coahuila, Mexico: Geological Society of America Bulletin, v. 78, p. 59–76.
Lehmann, C., 1997, Sequence stratigraphy and platform evolution of Lower Cretaceous (Barremian-Albian) carbonates of northeastern Mexico [Ph.D. dissert.]: Riverside, University of California, 261 p.
Lehmann, C., Osleger, D. A., and Montañez, I. P., 1998, Controls on cyclostratigraphy of Lower Cretaceous carbonates and evaporites, Cupido and Coahuila platforms, northeastern Mexico: Journal of Sedimentary Research, v. 68, p. 1109–1130.
Longoria, J. F., 1984, Cretaceous biochronology from the Gulf of Mexico region based on planktonic microfossils: Micropaleontology, v. 30, p. 225–242.
Longoria, J. F., and Gamper, M. A., 1977, Albian planktonic foraminifera from the Sabinas Basin of northern Mexico: Journal of Foraminiferal Research, v. 7, p. 196–215.
Longoria, J. F., and Monreal, R., 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, p. 7–31.
Loucks, R. G., 1977, Porosity development and distribution in shoal-water carbonate complexes—Subsurface Pearsall Formation (Lower Cretaceous) south Texas, *in* Bebout, D. G., and Loucks, R. G., eds., Cretaceous carbonates of Texas and Mexico: University of Texas Bureau of Economic Geology Report of Investigations 89, p. 97–126.
McFarlan, E., Jr., and Menes, L. S., 1991, Lower Cretaceous, *in* Salvador, A., ed., The Gulf of Mexico basin: Boulder, Colorado, Geological Society of America, Geology of North America, v. J, p. 181–204.
McKee, J. W., Jones, N. W., and Long, L. E., 1990, Stratigraphy and provenance of strata along the San Marcos fault, central Coahuila, Mexico: Geological Society of America Bulletin, v. 102, p. 593–614.
Meyer, M. G., and Ward, W. C., 1984, Outer-ramp limestones of the Zuloaga Formation, Asillero Canyon, Zacatecas, Mexico, *in* Ventress, W. P. S., Bebout, D. G., Perkins, B. F., and Moore, C. H., eds., The Jurassic of the Gulf Rim: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists, Proceedings of the Third Annual Research Conference, p. 275–282.
Michalzik, D., 1991, Facies sequence of Triassic-Jurassic red beds in the Sierra Madre Oriental (NE Mexico) and its relation to the early opening of the Gulf of Mexico: Sedimentary Geology, v. 71, p. 243–259.
Michalzik, D., and Schumann, D., 1994, Lithofacies relations and paleoecology of a Late Jurassic to Early Cretaceous fan delta to shelf depositional system in the Sierra Madre Oriental of north-east Mexico: Sedimentology, v. 41, p. 463–477.
Minero, C. J., 1988, Sedimentation and diagenesis along an island-sheltered platform margin, El Abra Formation, Cretaceous of Mexico, *in* James, N. P., and Choquette, P., eds., Paleokarst: New York, Springer-Verlag, p. 385–405.
Minero, C. J., 1991, Sedimentation and diagenesis along an island-protected windward carbonate platform margins of the Cretaceous El Abra Formation, Mexico: Sedimentary Geology, v. 71, p. 261–288.
Montañez, I. P., Banner, J. L., Osleger, D. A., Borg, L. E., and Bosserman, P. J., 1996, Integrated Sr isotope variations and sea-level history of Middle to Upper Cambrian platform carbonates: Implications for the evolution of Cambrian seawater $^{87}Sr/^{86}Sr$: Geology, v. 24, p. 917–920.
Ovianki, S. M., 1974, Paleodepositional environments in the Upper Jurassic Zuloaga Formation (Smackover), northeast Mexico: Gulf Coast Association of Geological Societies Transactions, v. 24, p. 258–278.
Padilla y Sanchez, R. J., 1982, Geologic evolution of the Sierra Madre Oriental between Linares, Concepcion del Oro, Saltillo, and Monterrey, Mexico [Ph.D. dissert.]: Austin, University of Texas, 233 p.
Perkins, B. F., 1960, Biostratigraphic studies in the Comanche (Cretaceous) Series of northern Mexico and Texas: Geological Society of America Memoir 83, 138 p.
Ross, M. A., 1979, Stratigraphy of the Tamaulipas Limestone, northeastern Mexico [Master's thesis]: Arlington, University of Texas, 96 p.
Ross, M. A., 1981, Stratigraphy of the Tamaulipas Limestone, Lower Cretaceous, Mexico, *in* Smith, C. I., ed., Lower Cretaceous stratigraphy and structure, northern Mexico: West Texas Geological Society Publication 81–74, p. 43–54.
Ross, M. A., and McNulty, C. L., 1981, Some microfossils of the Tamaulipas limestone (Hauterivian–lower Albian) in Santa Rosa Canyon, Sierra de Santa Rosa, Nuevo Leon, Mexico: Gulf Coast Association of Geological Societies Transactions, v. 31, p. 461–469.
Salvador, A., 1987, Late Triassic–Jurassic paleogeography and origin of the Gulf of Mexico basin: American Association of Petroleum Geologists Bulletin, v. 71, p. 491–451.
Scholle, P. A., and Arthur, M.A., 1980, Carbon isotope fluctuations in Cretaceous pelagic limestones: Potential stratigraphic and petroleum exploration tool: American Association of Petroleum Geologists Bulletin, v. 64, p. 67–87.
Scott, R. W., 1990, Models and stratigraphy of mid-Cretaceous reef communities, Gulf of Mexico: SEPM (Society for Sedimentary Geology) Concepts in Sedimentology and Paleontology, v. 2, 102 p.
Selvius, D. B., 1982, Lithostratigraphy and algal foraminiferal

biostratigraphy of the Cupido Formation, Lower Cretaceous, in Bustamente Canyon and Portrero Garcia, northeast Mexico [Master's thesis]: Ann Arbor, University of Michigan, 68 p.

Selvius, D. B., and Wilson, J. L., 1985, Lithostratigraphy and algal-foraminiferal biostratigraphy of the Cupido Formation, Lower Cretaceous, northeast Mexico, *in* Perkins, B. F., and Martin, G. B., eds., Habitat of oil and gas in the Gulf Coast: Proceedings of the Fourth Annual Gulf Coast SEPM Foundation, p. 285–312.

Sliter, W. V., 1989, Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section: Journal of Foraminiferal Research, v. 19, p. 1–19.

Sliter, W. V., 1995, Cretaceous planktonic foraminifers from Sites 865, 866, and 869: A synthesis of Cretaceous pelagic sedimentation in the central Pacific Ocean basin, *in* Winterer, E. L., Sager, W. W., Firth, J. V., and Sinton, J. M., Proceedings of the Ocean Drilling Program, Scientific results, Volume 143: College Station, Texas, Ocean Drilling Program, p. 15–30.

Smith, C. I., 1981, Review of the geologic setting, stratigraphy, and facies distribution of the Lower Cretaceous in northern Mexico, *in* Smith, C. I., ed., Lower Cretaceous stratigraphy and structure, northern Mexico: West Texas Geological Society Publication 81–74, p. 1–27.

Smith, C. I., and Bloxsom, W. E., 1974, The Trinity division and equivalents of northern Coahuila, Mexico: Geoscience and Man, v. 8, p. 67–76.

Stinnesbeck, W., 1991, Ammonites de la Formacion Cuesta del Cura (Albiano Superior-Cenomanio Inferior) en el area de Galeana, Nuevo Leon: Revista de la Sociedad Mexicana de Paleontologia, v. 4, p. 63–85.

Tinker, S. W., 1985, Lithostratigraphy and biostratigraphy of the Aptian La Peña formation, northeast Mexico and south Texas (Part 1), and The depositional setting of the Aptian Pearsall–La Peña Formations, Texas subsurface and northeast Mexico: Why is there not another Fairway Field? a(Part 2) [Master's thesis]: Ann Arbor, University of Michigan, 80 p.

Trejo, M., 1960, La Familia Nannoconidae y su alcance estratigrafico en America (protozoa, incertae saedis): Boletín de la Asociación Mexicana de Geólogos Petroleros, v. 12, p. 259–314.

Trejo, M., 1975, Zonificacion del limite Aptiano-Albiano de Mexico: Revista del Instituto Mexicano del Petroleo, v. 7, p. 6–29.

Vahrenkamp, V. C., Franseen, R. C. W. M., Grötsch, J., and Muñoz, P. J., 1993, Maracaibo platform (Aptian-Albian), northwestern Venezuela, *in* Simo, J. A., Scott, R. W., and Masse, J.-P., eds., Cretaceous carbonate platforms: American Association of Petroleum Geologists Memoir 56, p. 25–33.

Weissert, H., and Lini, A., 1991, Ice age interludes during the time of Cretaceous greenhouse climate? *in* Muller, D. W., McKenzie, J. A., and Weissert, H., eds., Controversies in modern geology: London, Academic Press, p. 173–191.

Wilbert, W. P., 1976, Geology of the Sierra de la Paila, Coahuila, Mexico [unpublished Ph.D. thesis]: Tulane University, 187 p.

Wilson, J. L., 1975, Carbonate facies in geologic history: Springer-Verlag, New York, 471 p.

Wilson, J. L., 1981, Lower Cretaceous stratigraphy in the Monterrey Saltillo area, *in* Smith, C. I., ed., Lower Cretaceous Stratigraphy and Structure, Northern Mexico: West Texas Geological Society Publication 81–74, p. 78–84.

Wilson, J. L., 1990, Basement structural controls on Mesozoic carbonate facies in northeastern Mexico: A review, *in* Tucker, M. E., Wilson, J. L., Crevello, P. D., Sarg, J. R., and Read, J. F., eds., Carbonate platforms, facies, sequences and evolution: International Association of Sedimentologists Special Publication 9, p. 235–255.

Wilson, J. L., and Pialli, G., 1977, A Lower Cretaceous shelf margin in northern Mexico, *in* Bebout, D. G., and Loucks, R. G., eds., Cretaceous carbonates of Texas and Mexico: University of Texas Bureau of Economic Geology Report of Investigations 89, p. 302–323.

Wilson, J. L., and Ward, W. C., 1993, Early Cretaceous carbonate platforms of northeastern and east-central Mexico, *in* Simo, J. A., Scott, R. W., and Masse, J.-P., eds., Cretaceous carbonate platforms: American Association of Petroleum Geologists Memoir 56, p. 35–50.

Wilson, J. L., Ward, W. C., and Finneran, J., 1984, A field guide to Upper Jurassic and Lower Cretaceous carbonate platform and basin systems, Monterrey-Saltillo area, northeast Mexico: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists, 76 p.

Winker, C. D., and Buffler, R. T., 1988, Paleogeographic evolution of early deep-water Gulf of Mexico and margins, Jurassic to Middle Cretaceous (Comanchean): American Association of Petroleum Geologists Bulletin, v. 72, p. 318–346.

Young, K., 1974, Lower Albian and Aptian (Cretaceous) ammonites in Texas, *in* Perkins, B. F., ed., Aspects of Trinity Division geology: Geoscience and Man, v. 8, p. 175–228.

Young, K., 1977, Middle Cretaceous rocks of Mexico and Texas, *in* Bebout, D. G., and Loucks, R. G., eds., Cretaceous carbonates of Texas and Mexico: University of Texas Bureau of Economic Geology Report of Investigations 89, p. 325–332.

Young, K., 1978, Lower Cenomanian and late Albian (Cretaceous) ammonites, especially Lyelliceridae, of Texas and Mexico: Texas Memorial Museum Bulletin 26, 99 p.

Young, K., 1984, Biogeography and stratigraphy of selected middle Cretaceous rudists of southwestern North America: Oxatepec, Mexico, Memoria III Congreso Latinoamericano de Paleontolgia, v. 3, p. 341–360.

Manuscript Received by the Society February 23, 1998
Revised Manuscript Received August 28, 1998
Manuscript Accepted September 23, 1998

Printed in U.S.A.