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THE MIDDLE CRETACEOUS EL ABRA LIMESTONE AT ITS TYPE LOCALITY (FACIES, DIAGENESIS AND OIL EMPLACEMENT), EAST-CENTRAL MEXICO

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ABSTRACT

The reef complex El Abra Limestone of the Cretaceous Valles-San Luis Potosí Platform at mid-eastern Mexico, is widely accepted to range from Albian to Cenomanian. However, at its type locality in Taninul quarries, the age of the outcropping formation is early Cenomanian at the lower part of the stratigraphic column, on the basis of rudists, other mollusk shells and ammonites. Moreover, the age of the upper portion of the El Abra is late Turonian, due to the presence of a layer rich in planktonic foraminifera located at the back-reef environment.

Two major sedimentary environments are identified in the El Abra reef complex: the rudist-reef (1) and the back-reef (2), with five zones: fore-slope reef (1a), shelf-edge reef (1b), near-back reef/lagoon (2a), tidal-flat/lagoon (2b), and lagoon (2c); all them are recognized on the basis of their lateral stratigraphic position, lithofacies, biofacies and their diagenetic patterns and distribution. The rudist-reef environment (1) consists of great faunal diversity, including scarce ammonites, all them deposited within a complex suite of layers and wedges of calcarenites and calcirudites. The back-reef environment (2) is characterized by micritic limestones with even stratification that contains biofacies with low diversity although abundant fauna, as miliolids, requieniids, stromatolitic layers and others.

The occurrence of the different diagenetic patterns within the Cretaceous reef complex is attributable to differences in size and distribution of the biogenic communities, and their calcareous matrix, to the repeated cycles of emersions and immersions of the Cretaceous Platform, and to the emplacement of hydrocarbons through time.

Key words: Stratigraphy, Cretaceous, El Abra Limestone, Mexico.

RESUMEN

Es ampliamente aceptado que el complejo arrecifal de la Caliza El Abra comprende del Albiano al Cenomaniano, en la plataforma cretácica Valles-San Luis Potosí, situada en la porción centro-oriental de México. No obstante, en su localidad tipo, en las canteras de Taninul, la edad de la formación expuesta en la base de la columna estratigráfica es del Cenomaniano temprano, por la presencia de rudistas, otros moluscos y amonites. Además, la parte superior de la columna es del Turoniano tardío, debido a la presencia de una capa con foraminíferos planctónicos localizada en el ambiente post-arrecifal.

En el complejo arrecifal El Abra, están identificados dos ambientes sedimentarios mayores: arrecife de rudistas (1) y post-arrecife (2), con cinco zonas: talud-frontal arrecifal (1a), borde de plataforma (1b), post-arrecife proximal/laguna (2a), planicie de mareas/laguna (2b), y laguna (2c); todos ellos son reconocidos con base en su posición estratigráfica lateral, litofacies, biofacies y rasgos diagenéticos. El arrecife de rudistas (1) consiste en gran diversidad de fauna, incluyendo amonites esporádicos; todos ellos depositados en estratos complejos y acuñamientos de calcarenitas y calcirruditas. El post-arrecife (2) se caracteriza por sus estratos uniformes de caliza micrítica con fauna abundante pero de baja diversidad, como miliólidos, requiénidos, carpetas de estromatolitos, entre otros.

La presencia de los rasgos diagenéticos en el complejo arrecifal del Cretácico, es atribuible a diferencias en el tamaño y distribución de las comunidades biológicas y de su matriz calcárea, a los ciclos repetidos de inmersión y de emersión que ocurrieron en la Plataforma del Cretácico, y al emplazamiento de los hidrocarburos a través del tiempo.

Palabras clave: Estratigrafía, Cretácico, Caliza El Abra, México.

INTRODUCTION

Since 1972, quarry exposures of the El Abra Limestone at its type locality were sampled in detail by Aguayo (1975). Later on, the expansion of the quarries by portland industry affords an excellent opportunity to continue the sampling and to study the complete suite of calcareous platform facies which range from shallow, protected back-reef to reef facies in an interval of 7 to 8 km along a trend normal to the margin of the Cretaceous Valles-San Luis Potosí Platform (Carrillo-Bravo, 1971).

The established suite of facies and their distribution have been consistent during the studies carried out in the last 25 years; however, new fauna was identified like ammonites from lower Cenomanian at the front of the reef facies, and other hori-

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zons with Turonian planktonic foraminifera at the back-reef environment. On the other hand, the previous diagenetic model has been enriched because the emplacement of oil during the evolution of the reef complex is more evident and, after so, at the new quarry exposures.

LOCALITY

The Sierra El Abra is an elongate carbonate complex on the easternmost side of the Sierra Madre Oriental and it extends about 150 km in the northwest-southeast direction, and about 7 to 15 km from east to west. It rises abruptly, roughly 250 to 300 m above the coastal plain in the east and some 100 to 150 m above the rolling hill country in the west. The type locality of the El Abra Limestone in the Sierra El Abra is situated at El Abra Station along the National Railroad and the Federal Highway-70, Valles-Tampico, about 9 km east of Ciudad Valles, San Luis Potosí State (Figure 1).

OBJECTIVES

The objectives of this project are: (1) to study and review the sedimentary environments of the El Abra Limestone previously established by Aguayo (1975, 1978) and other authors; (2) to establish the diagenetic patterns related with the sedimentary settings; (3) to establish the emplacement of hydrocarbons through time; (4) to propose a paleosedimentary model of the reef complex within more detailed facies may be considered in future research during the advancing work in the quarries.

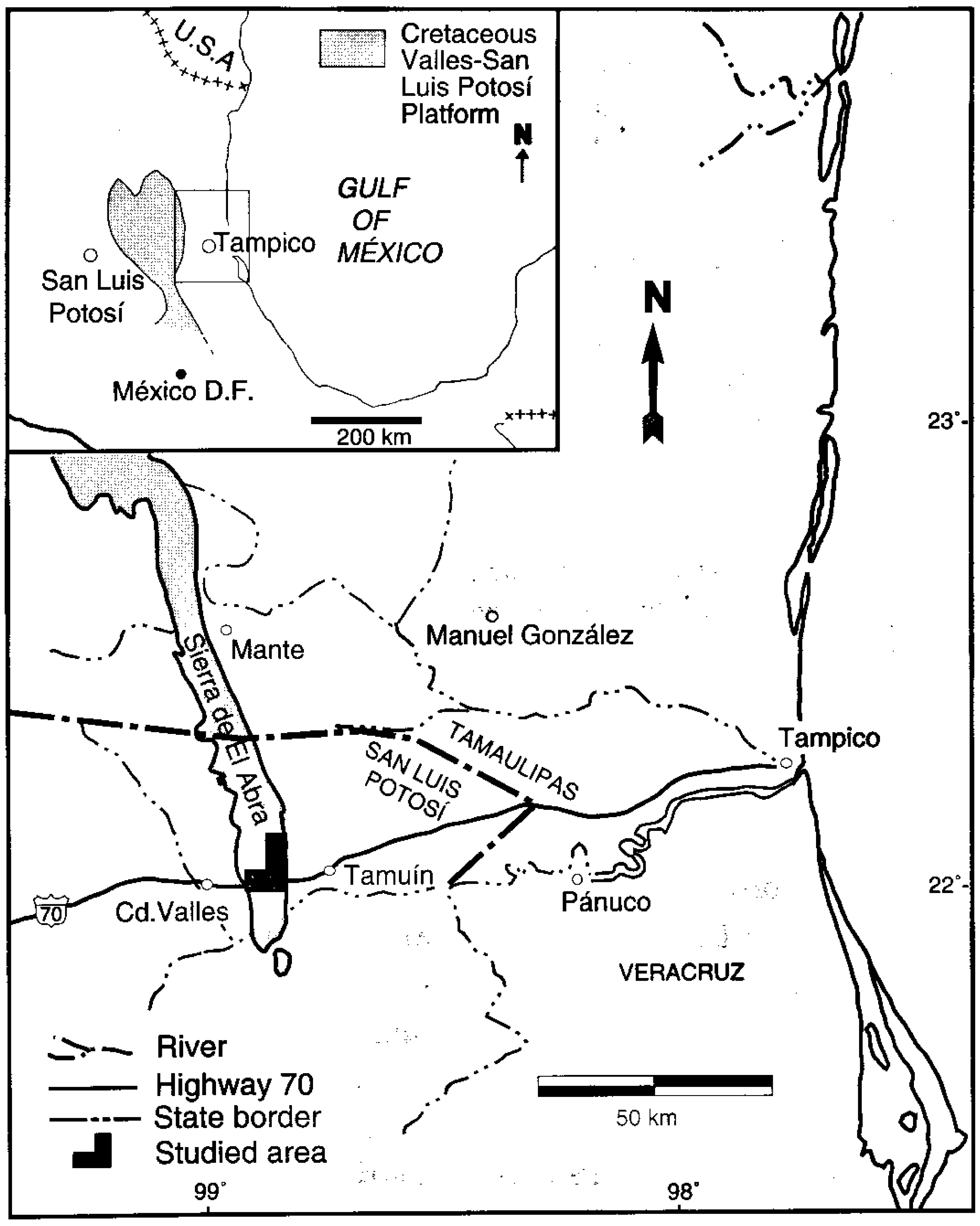

Figure 1. Reference map showing location of the studied area.

PREVIOUS WORK

Previous work in the type locality of the El Abra Limestone has been lithostratigraphic, structural and biostratigraphic in nature (Kellum, 1930; Muir, 1936; Imlay, 1944; Bonet, 1952, 1963; Rose, 1963; Griffith *et al.*, 1969; Carrillo-Bravo, 1971; Coogan, 1973, and others). Prior to the study carried out by Aguayo (1975, 1978), little attention has been given to detailed analysis of sedimentary facies and diagenesis. Rohel (1968) describes the diagenesis and porosity in relation to the migration of oil. Perkins (1970) recognized in the El Abra Limestone several subaerial features. After Aguayo (1975, 1978), other studies have been published (Minero *et al.*, 1983; Enos *et al.*, 1991; Aguayo, 1993).

METHODS

Field work included the measurement and description of eight stratigraphic sections in quarry exposures. Systematic sampling was carried out in selected localities. Polished slabs were prepared to observe large scale relationships among sedimentary structures, lithology and biota. The conventional petrographic microscope was used to identify textures and constituents. Several thin-sections were prepared for microprobe analysis in order to examine the trace element variations (Mg and Sr) in the calcite components as shells, matrix and cements. The instrument used was an ARL probe, type EMX, with an accelerating voltage of 15 kV and a beam current of 0.1 μA.

GEOLOGIC SETTING

The Cretaceous Platform divides the Mesozoic basin of central Mexico to the west from the Tampico embayment region to the east, which is the zone of major negative gravity anomalies in the coastal province of east-central Mexico. The embayment extends westward to the Sierra Madre Oriental and eastward to the Gulf of Mexico (Figure 1).

The pre-Mesozoic basement in eastern Mexico consists of igneous and metamorphic rocks, which were folded and faulted in Late Triassic and Early Jurassic, resulting in a chain of horst and graben structures, which extends across eastern Mexico, from Tamaulipas to Yucatán, as part of the Yucatán Archipelago (Murray, 1961).

El Abra Limestone was deposited on an upfaulted block, while on the downfaulted block the Tamabra Limestone, a transitional fore-reef to basinal pelagic deposit interfingered with the basinal, carbonate, pelagic sediments of the Tamaulipas Superior, and locally to the east, with the Agua Nueva Formation through Albian to Turonian (Figures 2 and 3).

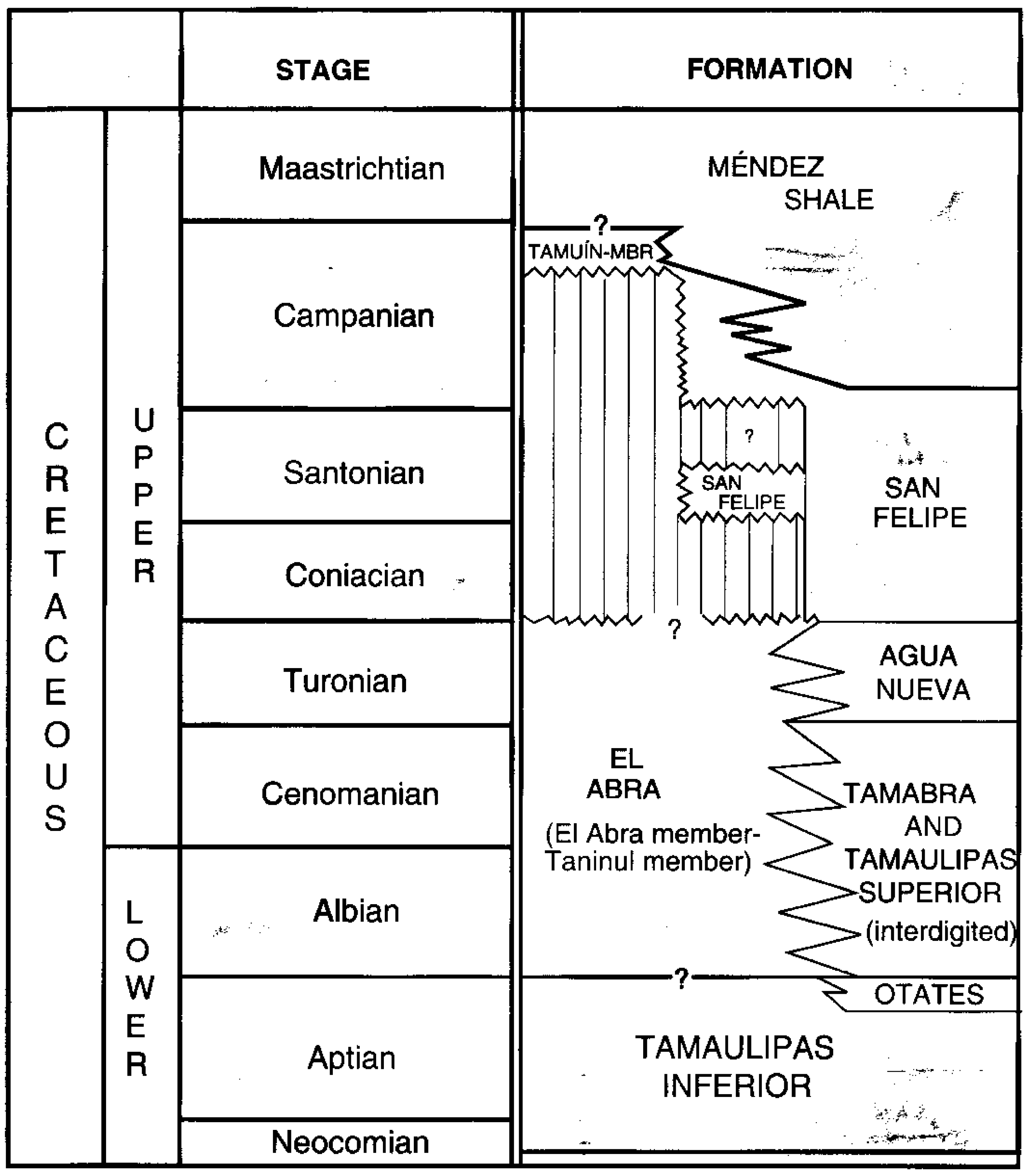

Figure 2. Generalized Cretaceous stratigraphic column of the easternmost Valles-San Luis Potosí Platform and adjacent western Tampico Embayment.

Deposition of shallow marine sediments was controlled largely by normal faulting, then continuous subsidence of the platform caused the El Abra Limestone to be deposited as repeated shallow marine carbonate facies, reaching about 1,800 m in thickness at the eastern edge of the platform (Figure 3); an average of approximately 100 m is visible in quarry exposures at its type locality and about 250 m in "Cementos Anáhuac" quarry (Figure 4).

STRATIGRAPHY

On the basis of lithofacies and biofacies, two members stratigraphically correlative are recognized in the El Abra Limestone at its type locality: Taninul member (A), the rudist-reef environment (S-I, II), and El Abra member (B, C, D), the back-reef environment (S-III, IV, V, VI, VII, VIII) (Figures 4 and 5). The Taninul member (A) consists of complex biofacies and lithofacies, from bottom to top: (1) monopleurid-requieniid-coral biolithite, and subordinated *Mexicaprina;* (2) monopleurid-caprinid biolithite, and discrete *Mexicaprina,* and ammonites; (3) caprinid-radiolitid biolithite; and on top, (4) shelf margin calcarenite facies. That suite of facies corresponds to a rudist-reef environment. Two sedimentary zones are recognized in the Taninul member according to their stratigraphic position through the platform, from open marine to semirestricted to restricted water circulation: The fore-slope reef zone (Aa), with complex overlapping of lenses, layers and wedges of calcarenites and scattered colonies of rudist bioherms, encrusting organisms; all them lithified by fibrous calcite and internal sediment. The shelf-edge reef zone (Ab) consists of complex overlapping of banks, lenses, layers, and wedges of unsorted grainstones and biostromes of colonial rudists in growth position, all cemented by neomorphic fibrous calcite and internal sediment. On the other hand, El Abra member (B, C, D) consists of light cream to gray interlayered mudstone and wackestone with well-stratified beds and weathered surfaces from 1 to 5 m thick, all rich in miliolids (*Nummoloculina*), *Toucasia* banks and algal stromatolite layers. Other benthonic organisms are: gastropods, pelecypods, ostracodes, as well as several planispiral and biserial small benthonic foraminifera. Collectively, the low faunal diversity, as well as the lithology and the sedimentary structures, suggest a back-reef environment. Three sedimentary zones are recognized in El Abra member: The near-back reef/lagoon zone (B), composed of a wide range of texturally angular and unsorted grainstones and rudstones derived from the peripheral reef-flat area and thrown back by wave action and during storms; these facies are interlayered and laterally interfingered with the lagoonal sediments composed of mudstone and stromatolitic layers. The tidal-flat/lagoon zone (C), is composed by even bedding of mudstone and packstone with miliolids, ostracodes and other scattered benthonic microfossils, interlayered with *Toucasia* banks and other mollusk shells, algal stromatolites and weathered surfaces occurring during the repeated cycles of emersions and immersions of the calcareous platform. The lagoon zone (D), consists of mudstone with abundant miliolids, mollusks, ostracodes and others; bioturbation is apparent in every layer; even so, primary laminations still are discernible.

Rudists are quantitatively the most important group in the El Abra Limestone besides other fauna reported in Bonet (1963): *Toucasia texana* (Roemer), *Eoradiolites* aff., *Eoradiolites quadratus* (Hill), *E.* cf. *davidsoni* (Hill), *Caprina (sphaerucaprina) occidentalis* (Conrad), *Caprinula* cf. *anguis* (Roemer). Lamellibranchs include: *Pecten* cf. *bonellensis* Kuiller, *Pecten* sp., *Lima wacoensis* (Roemer). *Chondronta* cf., and *C. munsoni* (Hill). Gastropods include: *Tronchus, Cerithium, Turritella, Actaeonella* and *Nerinea.* Brachiopods include: *Kingenia* cf. *wacoensis* (Roemer). Coogan (1973) reported *Radiolites abraensis* (Coogan), *Sauvagesia texana* (Roemer), *Caprinuloidea multitubifera* (Palmer), and the genus *Mexicaprina.* He also reported *Pecten roemeri* (Hill) and the stromatoporoid *Parkeria sphaerica* (Carpenter).

The age of the El Abra Limestone at its type locality has been controverted. Muir (1936) stated that it is Albian to early Cenomanian on the basis of the presence of *Pecten roemeri, Kingenia wacoensis* and *Chondronta* cf. *munsoni.* Bonet (1963) stated El Abra is Albian in the Golden Lane due to the presence of the benthonic foraminifera *Dictyoconus* and *Orbitolina;* then, it is stratigraphically lower than in the Sierra El Abra. Coogan (1973) suggested that the formation be Cenomanian and probably early Cenomanian at the Taninul quarry, because it contains

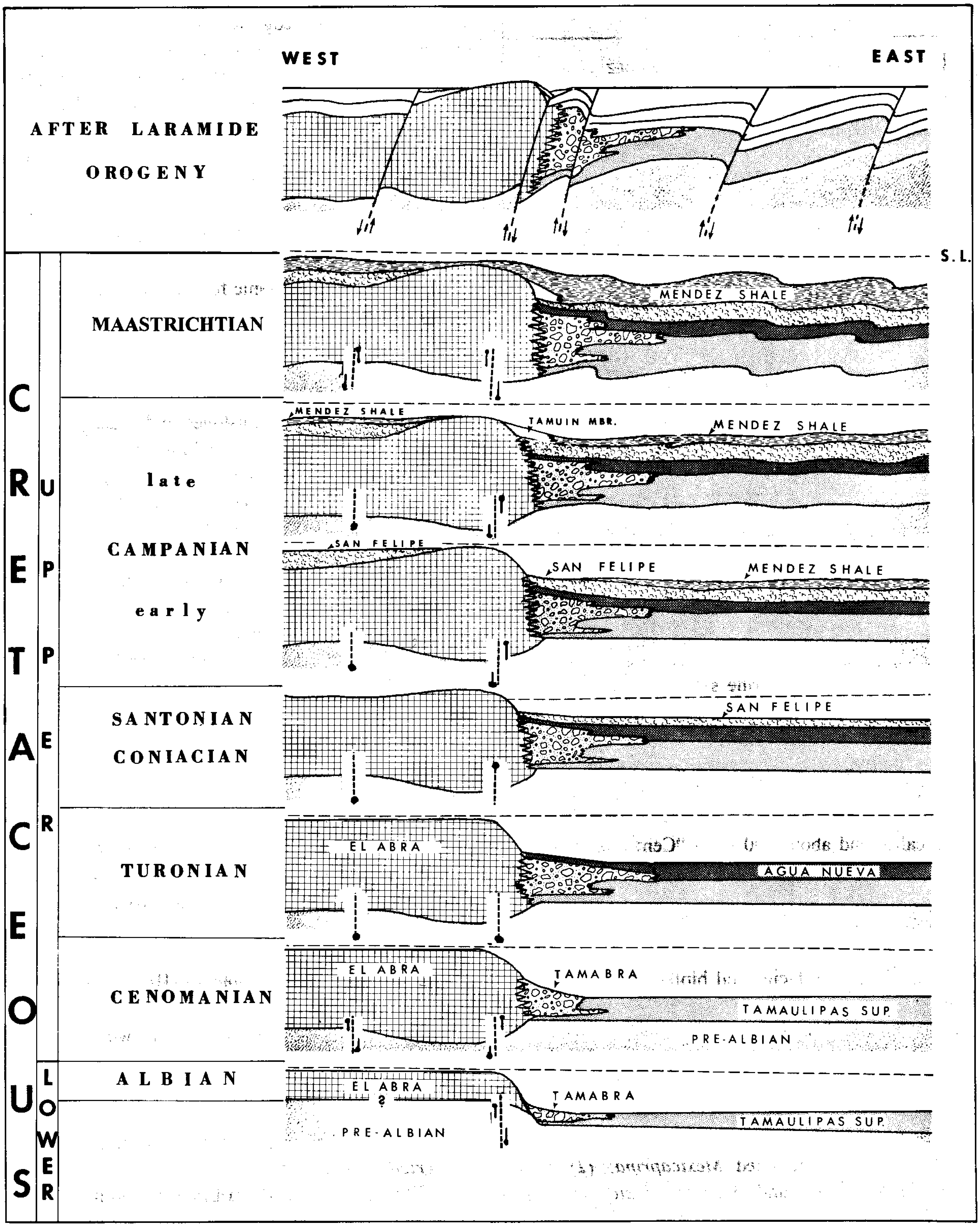

Figure 3. Generalized geologic evolution of the easternmost border of the Valles-San Luis Potosí Platform during Cretaceous in the Tampico region.

neither characteristic older middle Albian rudists nor foraminifera and the fauna *Pecten roemeri, Radiolites* and *Dicyclina* are not known to appear in strata older than Cenomanian. At the base of the Taninul quarry, Aguayo (1993, 1997) reported two specimens of the ammonite *Mariella* (*Plesioturrilites*) *bosquensis* (Adkins) from early Cenomanian according to determinations by Ma. Eugenia Gómez-Luna an Beatriz Contreras M. from Instituto Mexicano del Petróleo. Th ammonites were found associated to *Pecten roemeri* an *Mexicaprina* from early Cenomanian. Therefore, El Abr

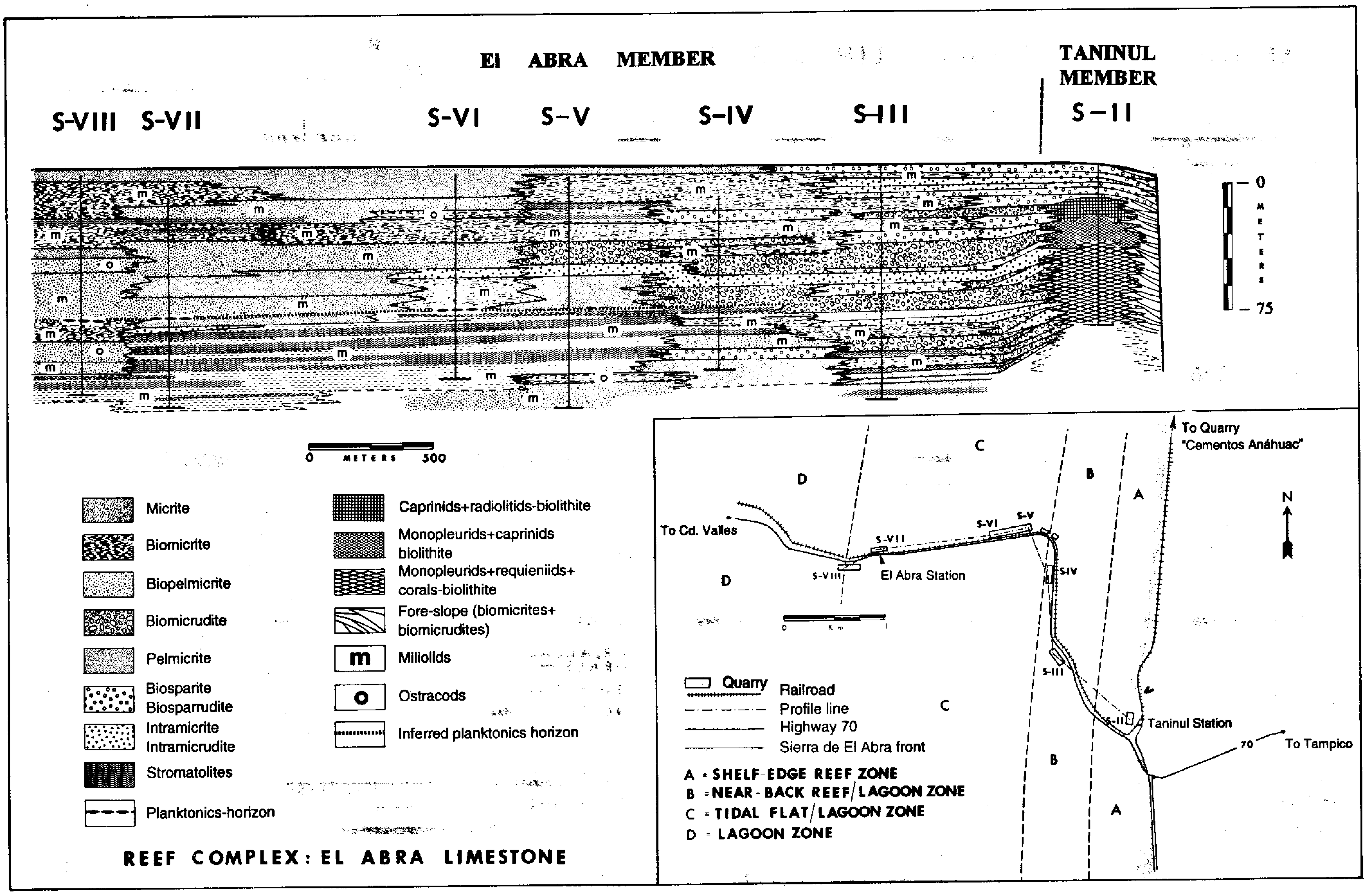

Figure 4. Stratigraphic cross-section of the reef complex El Abra Limestone in quarry exposures at its type locality.

Limestone may be Albian in subsurface, but in the base of the outcropping stratigraphic section at its type locality, the reef complex seems to be early Cenomanian. Moreover, at the uppermost portion of the stratigraphic section, El Abra Limestone is late Turonian on the basis of laterally continuous thin and wavy layers, 1 to 10 cm thick, containing planktonic foraminifera deposited at the back-reef environment, as was reported by Aguayo (1975, 1978, 1983, 1991, 1993, 1997). The horizons are interlayered with biomicrite containing miliolids and algal filaments into the back-reef environment. According to determinations by E. Emile A. Pessagno Jr. and Kunio Kanamori from The University of Texas at Dallas, the horizons are late Turonian by the planktonic foraminiferal assemblage: *Heteroelix reussi* (Cushman), *Marginotruncana canaliculata* (Reuss), *M. helvetica* (Bolli), *M. pseudolinneina* (Pessagno) and *M. sigali* (Reichel).

DIAGENESIS

Submarine and subaerial diagenesis occurred during the reef-growth period. These were controlled largely by repeating emergence and submergence of the Cretaceous platform. To distinguish between early submarine and late subaerial diagenesis, a summary of the petrographic criteria considered most important diagenesis in the several sedimentary environments of the El Abra Limestone, is as follows:

A. EARLY DIAGENESIS

Several generations of fibrous rim cement lining voids and binding grains, micritic rind binding grains, fine-grained internal sediment interlayered with micritic and fibrous calcite cement, syntaxial fibrous calcite overgrowth, disconformities within internal sediment, borings in shells and nontectonic fractures lined with fibrous and micritic rind cements, and early compaction in muddy sediments.

B. LATE DIAGENESIS

Syntaxial sparry calcite cement, gravity and drusy sparry calcite cements, vadose internal sediment, vadose calcite silt, solution voids and fossil molds, weathered truncation surfaces, caliche layers, karst surfaces and collapse breccias.

GEOCHEMISTRY

Carbonate constituents from both reef and back-reef environments were analyzed for magnesium and strontium. The

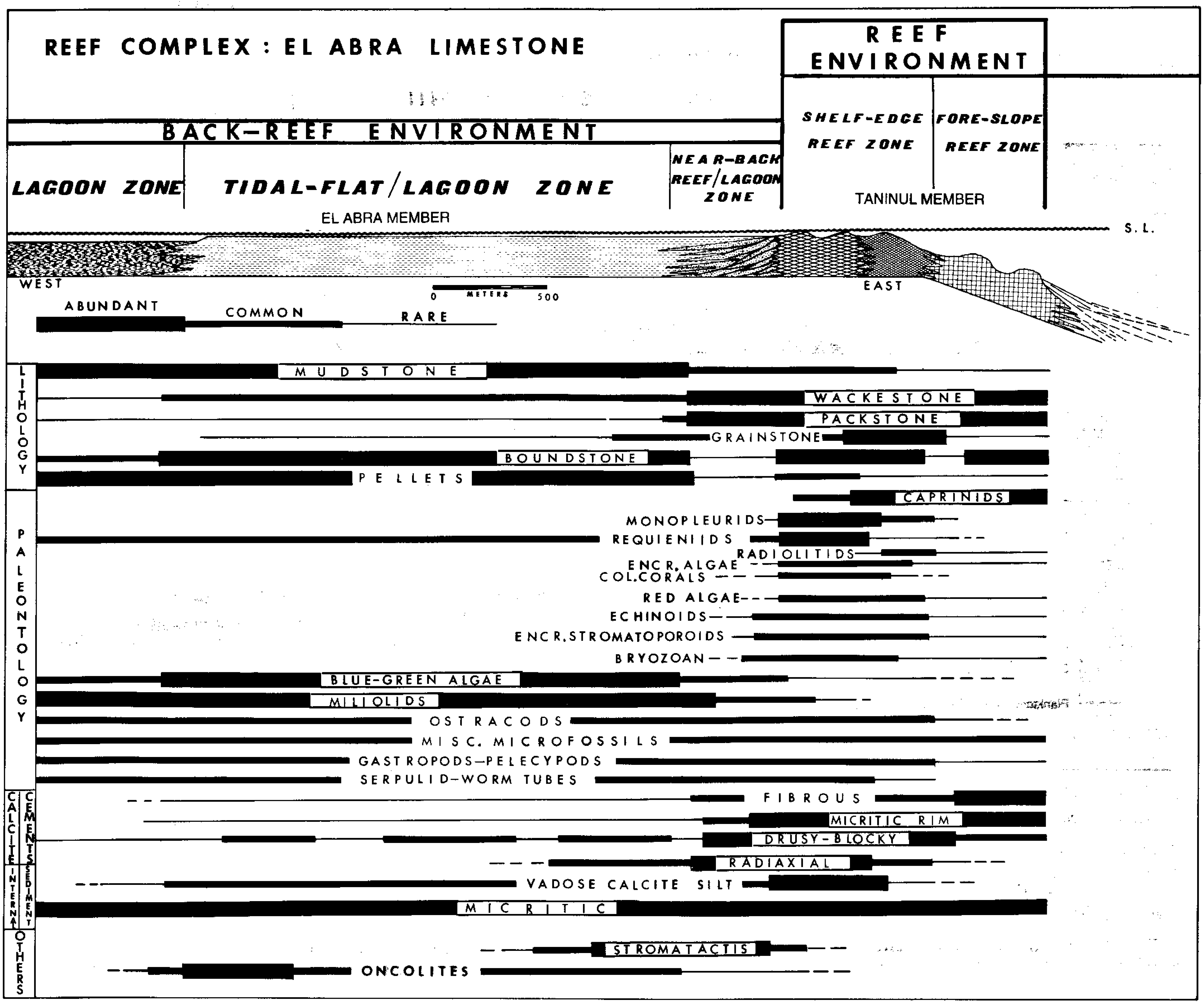

Figure 5. Conceptual model of the reef complex El Abra Limestone showing the distribution of its principal sedimentary, biological and diagenetic components.

magnesium content in most reef samples is generally less than 2,000 ppm. In back-reef samples, magnesium in general exceeds 2,000 ppm. On the other hand, strontium ranges from 76 ppm to 458 ppm in both major depositional environments; therefore, it does not discriminate the two major sedimentary environments.

EMPLACEMENT OF HYDROCARBONS

On the basis of field observations and laboratory determinations, at least four geologic situations during the hydrocarbon emplacements in the exposed Cretaceous stratigraphic column are interpreted herein. Geochemical research to characterize hydrocarbons and source rocks is in advance, and it is not reported in this study.

1. Oil migrated as seepage penecontemporaneously with the shallow marine limy sedimentation; the bioclastic grainstone and packstone were impregnated with oil, and also by early dissolution oil is present in the skelmoldic and in the primary porosity of the rudists. The mudstone facies bearing miliolids and other foraminifera, is cemented with asphalt which is mixed with the matrix and it is present in the inter- and intraparticle porosities of the benthonic organisms. Moreover, the vuggy porosity due to early and brief exposures to meteoric water and the borings by biological erosion including plant-roots, all them are impregnated with asphalt.
2. Diffuse seepage impregnation overlying reservoir; the uppermost surface of the Taninul member is an erosional Coniacian-Santonian karstic surface; the voids are filled with rudist limestone fragments surrounded by early Campanian planktonic foraminifera rich argillaceous matrix impregnated with asphalt.
3. Stylolite systems parallel to bedding formed during the burying stage of the stratigraphic column, they were in part the conduits of oil during its migration from the reservoir.

4. Seepage at geologic conduits that breach the reservoir, as transversal stylolites and fracturing occurring during and after Laramide stresses through Maastrichtian and after so; both systems still are conduits of oil migration toward the exposed surface.

CONCLUSIONS

1. The El Abra Limestone at its type locality is a reef complex deposited on the eastern margin of the Valles-San Luis Potosí Cretaceous Platform.
2. The calcareous reef complex was deposited on an up-faulted block, while the Tamaulipas Superior pelagic formation was deposited on the downfaulted basinal block to the east. A slope facies is represented by the "Tamabra" Formation.
3. The lower portion of the outcropping El Abra Limestone at its type locality, is early Cenomanian, based on the presence of rudists and other mollusk shells, and scattered ammonites in the reef environment (Taninul member). The uppermost stratigraphic section of the Cretaceous formation is late Turonian, on the basis of thin and wavy layers 1 to 10 cm thick containing planktonic foraminifera, which are interlayered with biomicrite with miliolids and algal filaments in the back-reef environment (El Abra member).
4. The stratigraphic sequence is defined by two major sedimentary environments: (1) the reef and (2) the back-reef, and by their five sedimentary zones, which are recognized by means of their lateral stratigraphic position, lithofacies, biofacies, primary sedimentary structures and diagenetic patterns.
5. The two major sedimentary settings are discriminated by magnesium content in their different calcareous components, which is less than 2,000 ppm at the reef environment and greater than 2,000 ppm at the back-reef, as was expected due to the hydrodynamic conditions of the environments during their evolution. Strontium does not discriminate the suite of sedimentary facies.
6. Four stratigraphic times were interpreted herein during oil emplacement: (a) penecontemporaneous seepage with the shallow marine limy sedimentation during Cenomanian-Turonian; (b) diffuse seepage in the Coniacian-Santonian erosional karstic surface impregnated with oil during early Campanian; (c) stylolite systems parallel to bedding as conduits of oil formed during the burying stage of the Cretaceous stratigraphic column; and (d) transversal stylolites and fracturing are conduits of oil migration during and after Laramide stresses.
7. No further geochemical research was carried out to characterize the hydrocarbons neither to identify the source rocks.

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BIBLIOGRAPHICAL REFERENCES

Aguayo-Camargo, J.E., 1975, Sedimentary environments and diagenetic implications of the El Abra Limestone at its type locality, east Mexico: University of Texas at Dallas, Ph. D. dissertation, 159 p. (unpublished).

——— 1978, Sedimentary environments and diagenesis of a Cretaceous reef complex, eastern Mexico: Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnología, Anales, v. 5, no. 1, p. 83–140.

———1983, Sedimentation and diagenesis of mid-Cretaceous platform margin, east-central Mexico, *in* Minero, C.J.; Enos, Paul; and Aguayo-Camargo, J.E., eds., Sedimentation and diagenesis of mid-Cretaceous platform margin, east-central Mexico: Dallas Geological Society, Publication with accompanying Field guide, April 1983, 168 p.

———1991, Geologic evolution of the Sierra El Abra and its sedimentary and diagenetic implications, east-central Mexico, *in* Enos, Paul; Minero, C.J.; Aguayo-Camargo, J.E.; and Stephens, B.P., eds., Sedimentation and diagenesis of middle Cretaceous platform margins, east-central Mexico: Dallas Geological Society, Annual Convention, Field trip-1, April 3-7, p. 1–21.

———1993, The middle Cretaceous El Abra Limestone at its type locality and Laguna Colorada, east-central Mexico, *in* Alencáster, Gloria, and Buitrón, B.E., eds.: Universidad Nacional Autónoma de México, Instituto de Geología, Third International Conference on Rudists, Mexico, D.F., Nov. 20–28, Guidebook for field trip "A", 43 p.

——— 1997, The middle Cretaceous El Abra Limestone at its type locality (facies and diagenesis), east-central Mexico: Instituto de Investigaciones en Ciencias de la Tierra de la Universidad Autónoma del Estado de Hidalgo e Instituto de Geología de la Universidad Nacional Autónoma de México, Convención sobre la Evolución Geológica de México y Recursos Asociados, 2nd, Pachuca, Hgo., Simposio sobre Estratigrafía y Paleogeografía del Mesozoico en México, Memoria, [4 p.] (abstract).

Bonet, Federico, 1952, La facies urgoniana del Cretácico medio de la región de Tampico: Boletín de la Asociación Mexicana de Geólogos Petroleros, v. 4, nos. 5–6, p.153–262.

——— 1963, Biostratigraphic notes on the Cretaceous of eastern Mexico, *in* Boyd, D.R., ed., Geology of Peregrina Canyon and Sierra El Abra: Corpus Christi Geological Society, Annual Field trip, v. 15, p. 36–38.

Carrillo-Bravo, José, 1971, La plataforma Valles-San Luis Potosí: Boletín de la Asociación Mexicana de Geólogos Petroleros, no. 13, nos. 1–6, 113 p.

Coogan, A.H., 1973, New rudists from the Albian and Cenomanian of Mexico and south Texas: Revista del Instituto Mexicano del Petróleo, v. 5, no. 2, p. 51–83.

Enos, Paul; Minero, C.J.; Aguayo, J.E.; and Stephens, B.P., 1991, Sedimentation and diagenesis of middle Cretaceous platform margins, east-central Mexico: Dallas Geological Society, Annual Convention, Field Trip 1, April 3–7, 200 p.

Griffith, L.S.; Pitcher, M.G.; and Rice, G.W., 1969, Quantitative environmental analysis of a Lower Cretaceous reef complex: Society of Economic Paleontologists and Mineralogists, Special Publication 14, p. 120–138.

Imlay, R.W., 1944, Cretaceous formations of Central America and Mexico: American Association of Petroleum Geologists, v. 28, no. 8, p. 1077–1195.

Kellum, L.B., 1930, Similarity of surface geology in front ranges of Sierra Madre Oriental to subsurface in Mexican south fields: American Association of Petroleum Geologists, v. 140, p. 73–91.

Minero, C.J.; Enos, Paul; and Aguayo, J.E., 1983, eds., Sedimentation and diagenesis of mid-Cretaceous platform margin, east-central Mexico: Dallas Geological Society, Publication with accompanying Field Guide, 168 p.

Muir, J.M., 1936, Geology of the Tampico region, Mexico: American Association of Petroleum Geologists, Tulsa, Oklahoma, Special volume, 180 p.

Murray, G.E., 1961, Geology of the Atlantic and Gulf Coastal Provinces of North America: New York, Harper, 692 p.

Perkins, B.F., 1970, Genetic implications of rudist reef architecture: American Association of Petroleum Geologists, v. 54, p. 863-864 (abstract).

Rohel, P.O., 1968, Preliminary guidebook to selective features of the El Abra Limestone outcrops in the Sierra Madre Oriental, Mexico: Union Research Center of Union Oil Co. of California (technical report), 156 p.

Rose, P.R., 1963, Comparison of the El Abra of Mexico with "Edwards Reef Trend" of south-central Texas, *in* Boyd, D.R., ed., Geology of Peregrina Canyon and Sierra de El Abra: Corpus Christi Geological Society, 15, Annual Field Trip, 146 p.