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Peter T. Flawn, Director

Report of Investigations—No. 65

Lower Cretaceous Stratigraphy, Northern Coahuila, Mexico

By

Charles Isaac Smith

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PREFACE

In 1960, I completed a three-year stratigraphic study of the Middle and Upper Albian limestones of the Comanche Series exposed in the Edwards Plateau of West Texas. A comprehensive report of those investigations is now in the files of Shell Development Company, Houston, Texas, and excerpts from that report, relating to stratigraphic nomenclature and formation name proposals, have recently been published (Lozo and Smith, 1964). The results of those studies, and of subsurface investigations by geologists of Shell and other oil companies, indicate that the Comanche Series in the southern Edwards Plateau represents the up-dip extremities of a shelf-carbonate and evaporite facies sequence. This sequence apparently developed in response to variations in rates of subsidence and in reef-growth along the shelf-edge now located over 100 miles to the south in the subsurface of Southwest Texas. Facies patterns defined in these studies trend into Mexico, toward the mountains of northern Coahuila. It was considered likely that exposures in Coahuila might be properly located to show full genetic relationships between basin, shelf-edge, and shelf facies developments.

On a clear day from high points along the southwestern edge of the Edwards Plateau, the mountains of northern Coahuila are visible some 50 miles to the south as an indistinct profile on the horizon. They seem to beckon with the promise of answers to many intriguing questions. This report represents the fulfillment of a long-held dream to explore those mountains both geologically and geographically. Numerous people and institutions aided in making this dream come true, and I wish to express to them my sincere appreciation and thanks.

The full support of Petroleos Mexicanos was essential to the successful completion of a study of this scope. Ingeniero Raul Pérez Fernandez, Superintendent of Exploration, Northeast Mexico, provided men and equipment throughout this investigation. He recognized that studies of this nature and the knowledge and use of modern carbonate rock classification and interpretation of facies would contribute to the successful future exploration for petroleum accumulations in the carbonate reservoirs of Mexico. Ing. Teodoro Díaz G., District Geologist, Northeast Mexico, led initial reconnaissance trips into the area and imparted to the writer much of his extensive knowledge of the regional geology and geography of northern Mexico. The writer is especially grateful to Ingenieros Santiago Reynolds M., Santiago Charleston A., and Jesús Alfonso Zwanziger. These Pemex geologists assisted with all phases of field work and handled arrangements for working and living in the field. The regional geologic map (Pl. 1) was derived from their original detailed photogeologic mapping. Ing. Jorge Tovar R. gave valuable field assistance during the latter part of the study.

Professor Lewis B. Kellum, Director of the Museum of Paleontology, The University of Michigan, directed the project, made initial arrangements for field work in Mexico, and identified most of the fossil specimens collected. Dr. F. E. Lozo, Senior Geologist, Shell Development Company, lent his full support to these studies and particularly contributed in organization and completion of the included maps and diagrams. Dr. Louis I. Briggs, The University of Michigan, visited the party in the field and offered many helpful suggestions. Dr. Bob F. Perkins, paleontologist with Shell Development Company, also visited the writer in the field and helped make a plane-table traverse across the Sierra de San Gerónimo.

The ranch owners and operators in the area were most friendly and helped in many ways. The writer would particularly like to express his appreciation to Charles Sellars, foreman, Rancho Las Norias, and to Guillermo Osuna, Rancho El Cedral.

Shell Development Company, Houston, Texas, through a grant to the Museum of Paleontology, The University of Michigan, financed all field and laboratory expenses for the writer and later generously allowed time and use of their facilities at Houston for work on the manuscript and plates.

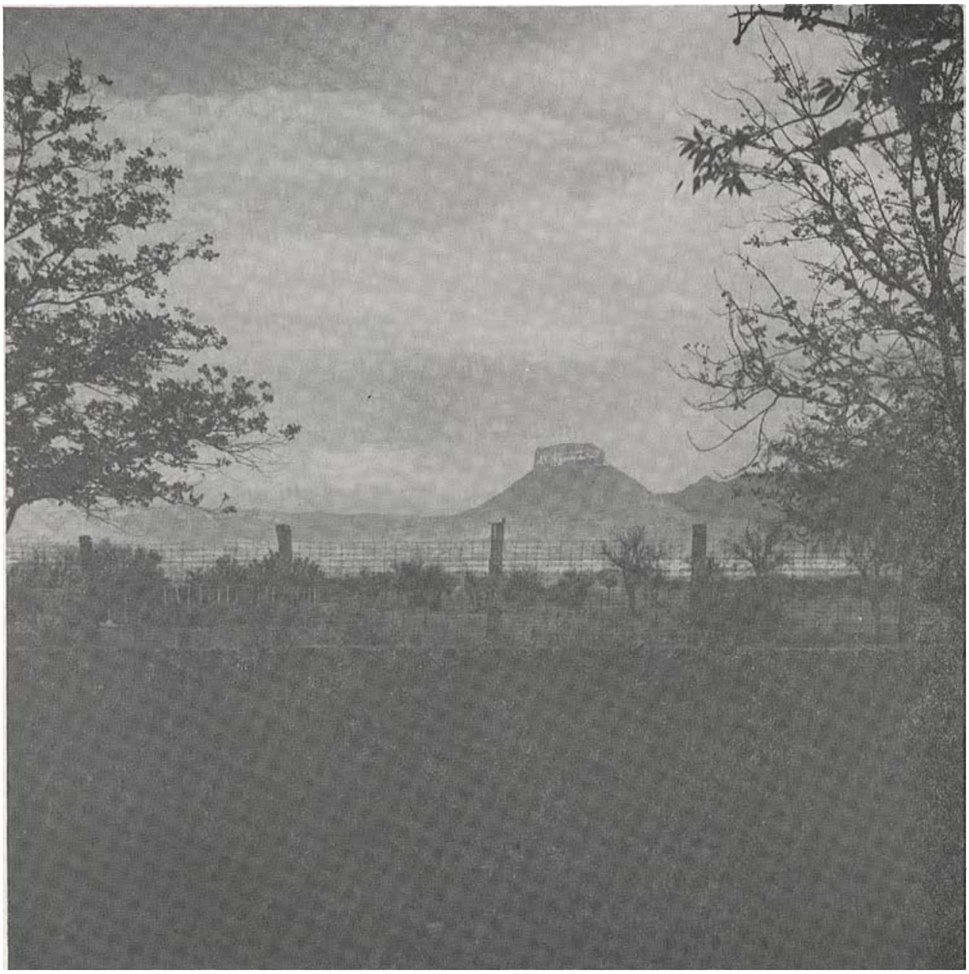

FIG. 1. View of Cerro El Palomo in the heart of the Serranía del Burro, northern Coahuila. West Nueces Limestone forms the cliffs at the top of the mountain; Telephone Canyon and Glen Rose Formations form the slopes.

Lower Cretaceous Stratigraphy, Northern Coahuila, Mexico

Charles Isaac Smith[1]

ABSTRACT

Northern Coahuila is at the head of the Late Jurassic Sabinas Gulf at the juncture between the Tamaulipas and Coahuila Peninsulas. Early Cretaceous seas transgressed the peninsulas and marine deposition persisted from then until late Cretaceous time. The lower part of the Cretaceous System in northern Coahuila is subdivided into the Coahuilan (lower) and Comanche (upper) Series.

The Coahuila Series is divided into two formations—basal La Mula Shale and overlying Cupido Limestone. The La Mula shales probably represent the last period of time during which a significant amount of material was eroded from the peninsulas and deposited in basinal areas. Cupido sedimentation was transgressive but characterized by numerous minor fluctuations; the preserved sedimentary record consists of littoral and shallow-water sublittoral deposits. By the end of Cupido deposition the sea had covered all but the northern tip of the State.

The Comanche Series is subdivided into the Trinity, Fredericksburg, and Washita Groups and the informally named Aurora lime mudstone. The Aurora is equivalent in age to the upper Trinity, Fredericksburg, and lower Washita but of different facies. These lithologic units are closely related parts of a continental shelf-ocean basin sedimentary complex developed and terminated during Comanche time. The bulk of this report is concerned with the description and interpretation of this stratigraphic sequence.

Trinity Group.—The Trinity Group is comprised of the lower La Peña Shale and upper Glen Rose Formation. The La Peña Shale is distributed across the Gulf Coast Province and was probably eroded from continental areas to the north following epeirogenic uplift and slight southward tilting in a broad region of southern United States. This was one of two major tectonic movements that profoundly affected Lower Cretaceous deposition in northern Coahuila. Rapid subsidence succeeded this uplift and deeper water lime muds (Aurora facies) onlapped shallow-water deposits northward during lower Glen Rose time. Through middle and upper Glen Rose deposition, the rate of subsidence was slower and shallow-water environments and deposition offlapped seaward over Aurora globigerinid lime muds deposited in deeper waters. The seaward edge of shallow-water deposition was increasingly populated by reef-building organisms during upper Glen Rose deposition. By the end of Glen Rose deposition, as a result of this seaward expansion of shallow-water environments and reef-building, there was a wide continental shelf extending across northern Coahuila and into Texas. The seaward edge of this shelf supported a belt of shallow sublittoral to supralittoral environments with bioclastic bars and banks, reefs, tidal flats, and low islands which later formed a barrier to water circulation. Southward from the shelf-edge, within a distance of about 20 miles, the sea bottom sloped to bathyal depths.

Fredericksburg and Washita Groups.—The formations of these groups were laid down on the continental shelf constructed during Trinity deposition. Sedimentation on the shelf was controlled by the rate of

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influx of terrigenous clastics, rate of subsidence, and variation in degree of restriction of waters by the shallow shelf margin. Southward from the shelf-edge, at bathyal depths, deposition of globigerinid-bearing lime mudstone continued.

This Lower Cretaceous, continental shelf-ocean basin depositional framework was terminated by a second major tectonic uplift followed by deposition of the Del Rio clays. Rapid subsidence again followed uplift, and deeper, open marine lime muds of the Buda Formation were deposited across all of northern Coahuila.

INTRODUCTION

Theories of the origin of continental shelves have been intensively debated in recent years. Academic interest in this subject is supported by an equally strong economic interest because much of the world petroleum reserves are found within this geologic setting. Unfortunately, few documented examples of shelf development within the geologic record are available to provide a solid basis for comprehensive theories. This report presents stratigraphic data and interpretations pertaining to the origin of a continental shelf-ocean basin sedimentary complex developed during Lower Cretaceous time in northern Coahuila, Mexico. This shelf was developed within a carbonate depositional régime and provides a specific descriptive example which should be useful in the development of a comprehensive process-response model of shelf origin.

LOCATION

Northern Coahuila, Mexico, lies below the great northern arc of the Rio Grande near the middle of the border between Texas and Mexico (fig. 2). It is the larger Mexican counterpart of the Big Bend area of Texas which joins it on the west. The area mapped by geologists of Petroleos Mexicanos during the course of this investigation (fig. 2 and Pl. 1) covers about 16,000 square miles and measures at a maximum about 160 miles east-west and 120 miles north-south. Lower Cretaceous outcrops in the Serranía del Burro and southern part of the Sierra del Carmen were studied by the author.

PREVIOUS INVESTIGATIONS

Previous studies of the Lower Cretaceous formations in northern Coahuila, Mexico (north of the 28th parallel) were reconnaissance in nature. Distribution of the series had been mapped at a scale of 1:2,000,000 (Carta Geologica de la República Mexicana, 1960) and the basic formations had been recognized but not adequately described or mapped. R. T. Hill (1893, p. 320) was the first to point out that the mountains of northern Mexico were composed of Cretaceous (not older) limestones. E. T. Dumble (1895, pp. 377–378) described a line-of-section in the Serranía del Burro from the headwaters of the Rio San Diego (Cañón de los Árboles) on the eastern side of the Serranía del Burro to the mouth of Arroyo de la Zorra on the Rio Grande. Except for minor differences in thicknesses and names used, his division of the sedimentary sequence was quite accurate and essentially the same as that of the present report.

In 1913, Emil Böse, then Chief Geologist of the Mexican Geological Survey, made a reconnaissance trip into northern Coahuila and entered the valley of Arroyo de la Babia, where he discovered outcrops of red beds at the base of the southern Sierra del Carmen scarp (Böse and Cavins, 1927, p. 19). Between 1920 and 1925, Böse and Charles Laurence Baker made several trips into the Serranía del Burro—Sierra del Carmen area. They recognized, as had Dumble, the primary subdivision of the sequence in this region and collected diagnostic Cretaceous zonal fossils but made no detailed lithologic observations. Baker, using data from trips with Böse and from later trips made between 1925 and 1934, wrote several manuscripts, each of which contains excellent geographic and general geologic descriptions of the region. Unfortunately, none of these was pubilshed.

Between 1922 and 1927, Böse and O. A. Cavins were employed by Richland Oil Company (a subsidiary of Standard of California) to study the Cretaceous and Tertiary rocks of southern Texas and northern Mexico. The publication resulting from these studies (Böse and Cavins, 1927) summarized the existing data on the region and presented an excellent preliminary account of Cretaceous facies (environment of deposition in their usage) distribution in this region.

In addition to Richland Oil Company,

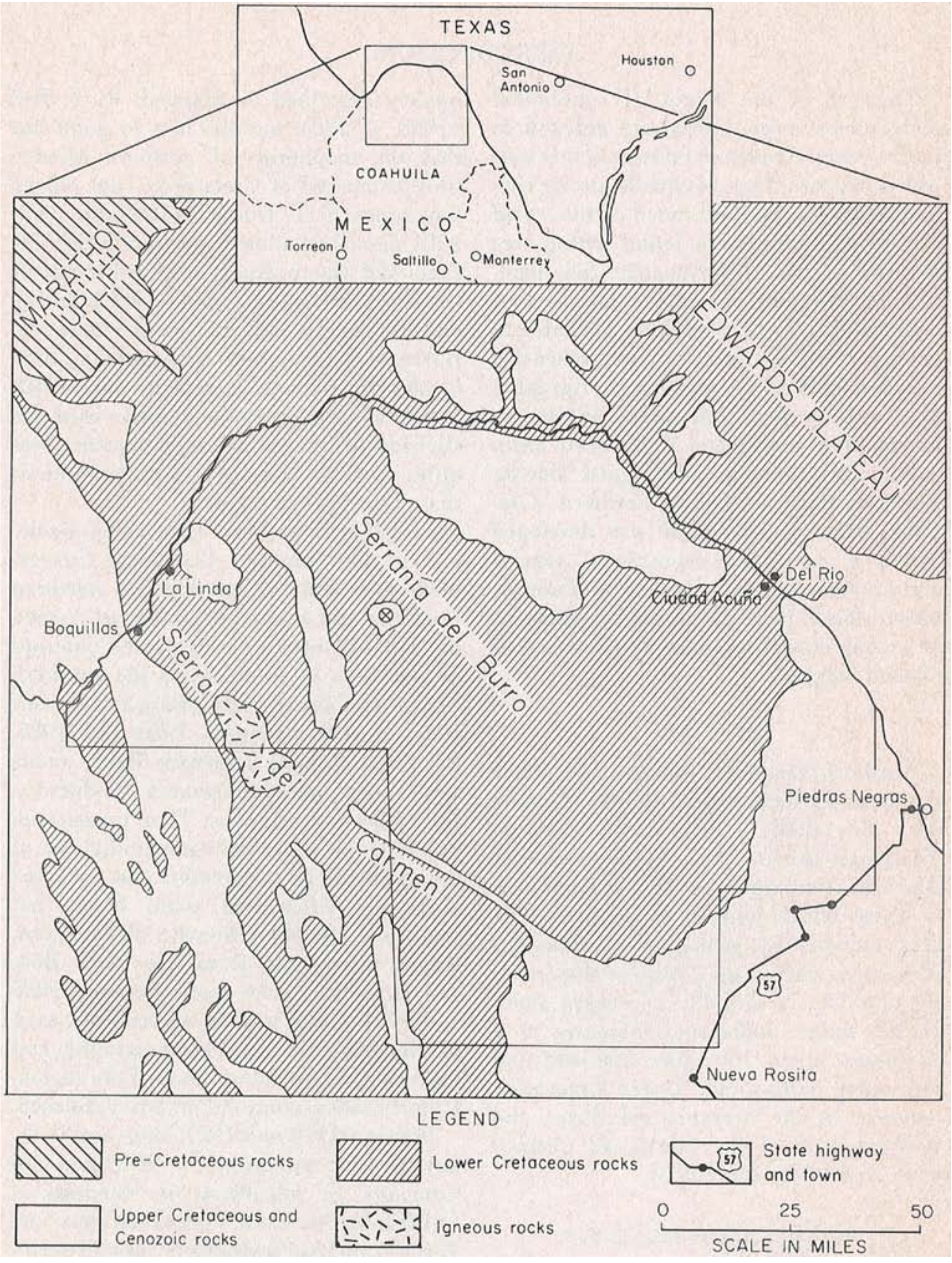


FIG. 2. Location of area and generalized distribution of the Lower Cretaceous rocks in northern Coahuila, Mexico, and southwestern Texas. Modified from Sellards, Adkins, and Plummer (1933) and the Carta Geologica de la República Mexicana, 1960. Area outlined shown on geologic map (Pl. 1).

other oil companies had parties of geologists working in the plains area surrounding the Serranía del Burro between 1920 and 1930. Reports of their investigations are in the files of Petroleos Mexicanos. W. R. Fehr (1930) and W. S. Adkins collected fossils and mapped in the El Remolino—Las Albercas area off the southeastern tip of the Serranía del Burro for the El Águila (Royal Dutch/Shell group). J. W. Hunter (1928a, b), A. H. Petsch (1927, 1928), W. F. Eastman (1927), and R. W. Calvert (1926) mapped the Treviño-Chupadero anticline (fig. 5) in the plains between the Serranía del Burro and the Rio Grande for Huasteca Petroleum (Standard of Jersey) between 1926 and 1929. L. B. Kellum and Q. D. Singewald mapped most of the region between the Serranía del Burro and the Rio Grande west of Piedras Negras and Nuevo Laredo between 1927 and 1928 for the Cia.-Transcontinental de Petróleo (Standard of New Jersey). F. M. Getzendaner made observations near Rancho El Cedrito in 1941 which were reported by Imlay (1945, p. 1465).

Interest of Petroleos Mexicanos in the area began in 1953 with reconnaissance trips into the area by W. E. Humphrey (DeGolyer and MacNaughton consultant) and Teodoro Díaz (District Geologist, Northeast Mexico) revisiting localities described 30 years previously by Böse and Baker. The same year, Benjamin Marquez (1953) described the lower Albian section at Cerro Palomo in the heart of the Serranía de Burro, Baker's old San Vicente section (Böse and Cavins, 1927, p. 19).

The most recent work in the area was by F. W. Daugherty (1962, 1963; Daugherty and Powell, 1963), who mapped and described the geology of the Pico Etéreo area, and by McAnulty and others (1963), who described the Aguachile fluorspar district.

FIELD AND LABORATORY PROCEDURE

Field work for the present study was conducted during June and July 1962 and between February and July 1963, a total of eight months. Inasmuch as the area had not been previously mapped, much of the field time was spent in reconnaissance. After general relations and outcrop distribution had been determined, stratigraphic sections were measured in critical localities. Two of the most significant sections are described and shown in graphic form on Plates 2 and 6. The other sections are described in the Appendix or shown graphically on stratigraphic diagrams. The approximate location of all measured sections is shown on figure 7, as is the location of all other northern Coahuila section localities and oil tests mentioned in the text.

Stratigraphic sections were measured with hand or Abney level and tape. Graphic profiles were drawn in the field to show relative resistance to weathering of lithologic units. The degree of detail in which a particular section was measured varied greatly as dictated by need and availability of exposure. Outcrop characteristics and hand lens descriptions of specific lithologies made in the field were subsequently supplemented by microscopic examination of polished slabs and thin sections in the laboratory. All descriptive information, including general faunal content, was compiled in summary descriptions and is given by unit designations on the appropriate section.

Paleontologic collections were made of specific stratigraphic units where possible. These collections have been identified by Dr. L. B. Kellum, and his faunal lists are included under the appropriate stratigraphic section in the text.

The area was mapped by various geologists of Petroleos Mexicanos during 1962 and 1963 (index map, Pl. 1). Stereo-paired aerial photographs (scale 1:50,000; taken in 1957 by Jack Ammann Photogrammetric Engineers, Inc.) were used. Ground control for construction of base maps was provided (in all but western areas) by survey teams who were locating points for a gravimetric survey. Copies of the individual geologic maps, at a scale of 1:50,000 and each covering an area of about 2,500 square kilometers, were made available by Pemex. These maps were reduced to a scale of 1:250,000, compiled and edited by the writer, and redrafted at that scale by Shell Development Company.

GEOLOGIC SETTING

BACKGROUND OF REGIONAL MESOZOIC HISTORY

Permo-Triassic orogeny and uplift on the North American continent resulted in withdrawal of epicontinental seas so that most of the present land mass was exposed in Early and Middle Jurassic time. In the Late Jurassic, seas readvanced, spreading northwestward from the vicinity of the Gulf of Mexico and southeastward from the Arctic Ocean. By late Early Cretaceous time, these seas had united to form a broad seaway through the Western Interior of the United States (fig. 3). The interior regions of the continent inundated by these seas were of low topographic relief and tectonically stable, whereas the southwestern marginal regions of the continent, northern Mexico and southwestern United States, possessed considerable relief prior to the transgression and were tectonically mobile.

As Late Jurassic seas encroached in northern Mexico and southwestern Texas, red beds, evaporites, and limestones were deposited in basinal areas between highlands. Thicker sequences of similar sediments accumulated in the Mexican geosyncline. By Neocomian Early Cretaceous time, the basins were mostly filled and limestone deposition predominated except around the remnant highlands where carbonate sediments were interbedded with arkosic sediments. During the succeeding Aptian and Albian (late Early Cretaceous) time, the highlands were mostly submerged and limestone deposition, periodically interrupted by influxes of terrigenous clastics from the west and north, prevailed over the

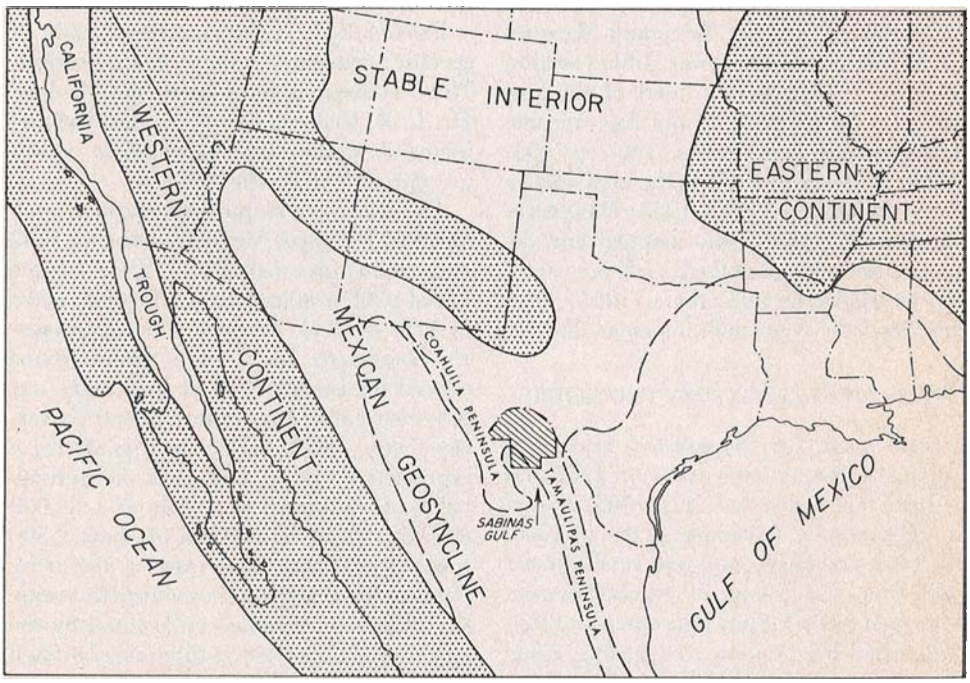


FIG. 3. Paleogeographic map of the Late Jurassic and Early Cretaceous. The dashed line shows the land-sea boundary in northern Mexico and southwestern United States during the Late Jurassic; shaded areas indicate land in the Early Cretaceous. Lower Cretaceous stratigraphy of the ruled area is the subject of this report. (Modified after Eardley, 1962; Kellum et al., 1936; Imlay, 1943; and Humphrey, 1956.)

entire region. These widely distributed, lithologic couplets of alternating, thin, terrigenous clastics and thick marine limestones approximate time units and constitute the basic units of lithostratigraphic subdivision in the late Early Cretaceous deposits of this region.

The limestone members of these Aptian and Albian couplets are characterized by complex facies changes which, it is believed, relate to the Jurassic topography of the region as well as to contemporaneous environmental and tectonic controls of deposition. Early workers in this region recognized and pointed out the existence of some of these major facies changes (Böse and Cavins, 1927, p. 80; Kellum, Imlay, and Kane, 1936, p. 983) but many of the detailed relations have yet to be described.

Northern Coahuila is at the head of the Late Jurassic Sabinas Gulf at the juncture between the Tamaulipas and Coahuila Peninsulas (figs. 3 and 6; Imlay, 1943, p. 524; Humphrey, 1956, p. 27). Evidence for this high position on the Jurassic land mass is derived from exposures in the northern Sierra del Carmen where Lower Cretaceous beds (lower Aptian or upper Neocomian) rest unconformably on Paleozoic metamorphic rocks (Pl. 1; Böse, 1923, p. 133; Baker, 1935, p. 146; Flawn and Maxwell, 1958). Additional evidence is available from wells drilled along the Treviño-Chupadero anticline (fig. 5) where the Lower Cretaceous rests on basal Mesozoic arkoses (Adkins, 1933, p. 292; Flawn, 1959, p. 77) and on the Peyotes anticline where the Lower Cretaceous rests on metamorphic rocks (Humphrey, 1956, p. 34). The peninsulas were submerged by Early Cretaceous seas and marine deposition persisted from then until Late Cretaceous time.

PHYSIOGRAPHY

The physiography and drainage of the region are shown on figure 4. The principal mountain ranges and alluvium-filled valleys of the area trend northwest parallel to the regional structure. The ranges, from northeast to southwest, are the Serranía del Burro, Sierra El Cedral, and Sierra del Carmen. The valleys separating these ranges are Valle Las Norias, Valle El Infante, and the large valley of Arroyo de la Babia. Drainage of the entire region is north and east into the Rio Grande.

Northwest of the Valle Las Norias is a broad, flat bolson, the Llano de los Buras. Between the Llano and the Rio Bravo, to the north, is a series of low hills named Sierra del Bravo on T. S. Abbott's 1905 map of the State of Coahuila. Between the Llano de los Buras and the Sierra del Carmen to the southwest is a region of moderate relief characterized by numerous igneous intrusions, the Pico Etéreo area (Daugherty, 1962), named for its most striking landmark, Pico Etéreo, a resistant mass of intrusive igneous rock.

South and southeast of the Sierra del Carmen a series of valleys and ranges have a more northerly trend. Of these, only the northern end of the Sierra de San Gerónimo was studied. East of the Sierra de San Gerónimo is a broad area of low foothills, the Lomerío del Chicapú.

A detailed description of the principal ranges, climate, culture, and accessibility is given in the Appendix under Geography.

STRUCTURE AND TECTONICS

The last episode of folding, faulting and uplift of northern Coahuila occurred during the Laramide orogeny in Late Cretaceous—Middle Tertiary time (Böse and Cavins, 1927, p. 141; Kellum, Imlay, and Kane, 1936, p. 1007; Humphrey, 1956, p. 28). The primary structural features are shown on figure 5 in their relation to topography; details are shown on the geologic map (Pl. 1).

The Serranía del Burro is a long, low upwarp, narrow on the north and broadening somewhat toward the south. This structure is folded into many smaller anticlines and synclines generally trending parallel to the main uplift. Normal faults, probably developed after the folding, are common in the northern and central Serranía del Burro but rare in the southern part.

The southwest flank of the Serranía del Burro is cut by the large El Cedral fault.

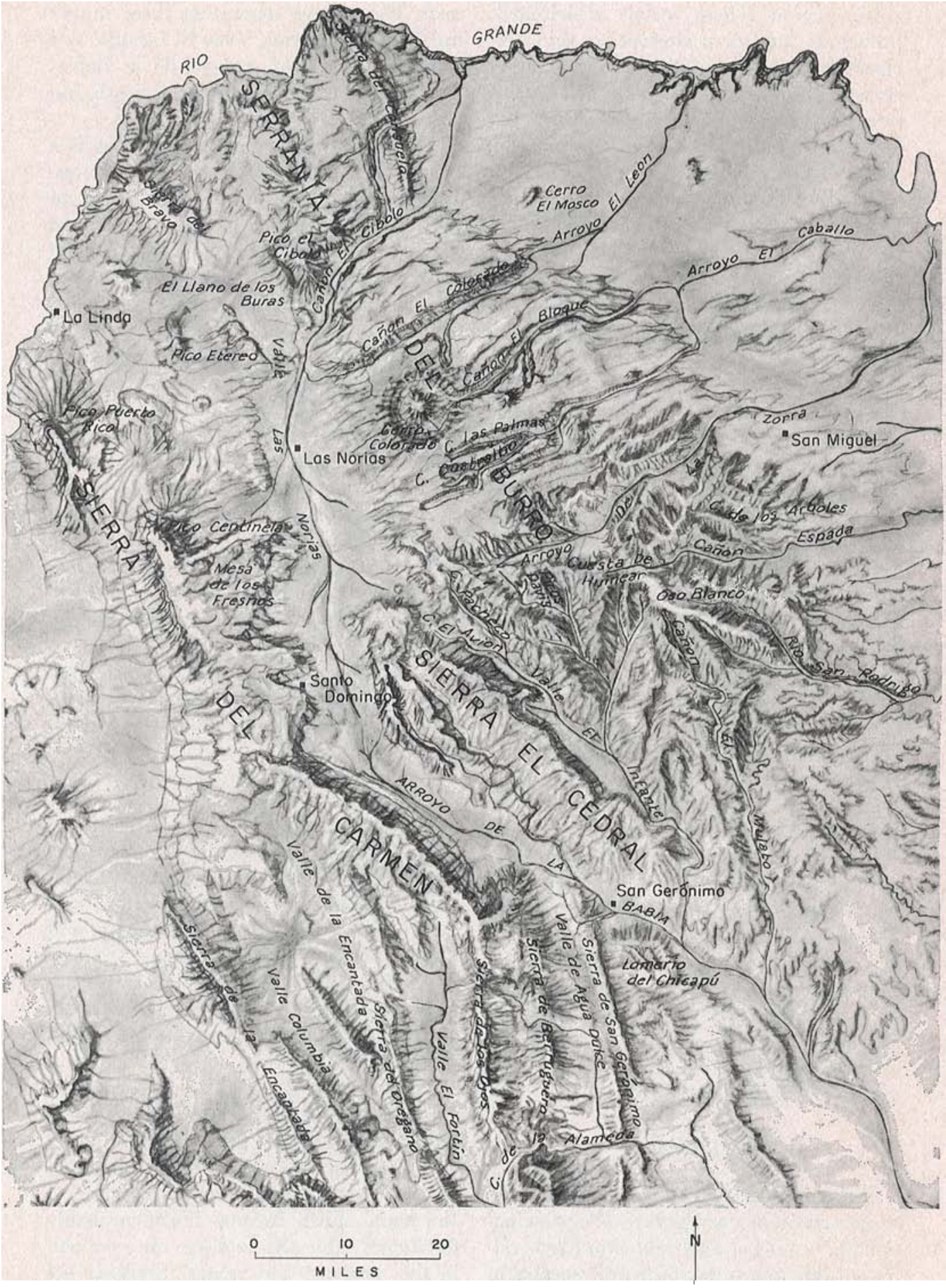


Fig. 4. Physiographic map of northern Coahuila, Mexico.

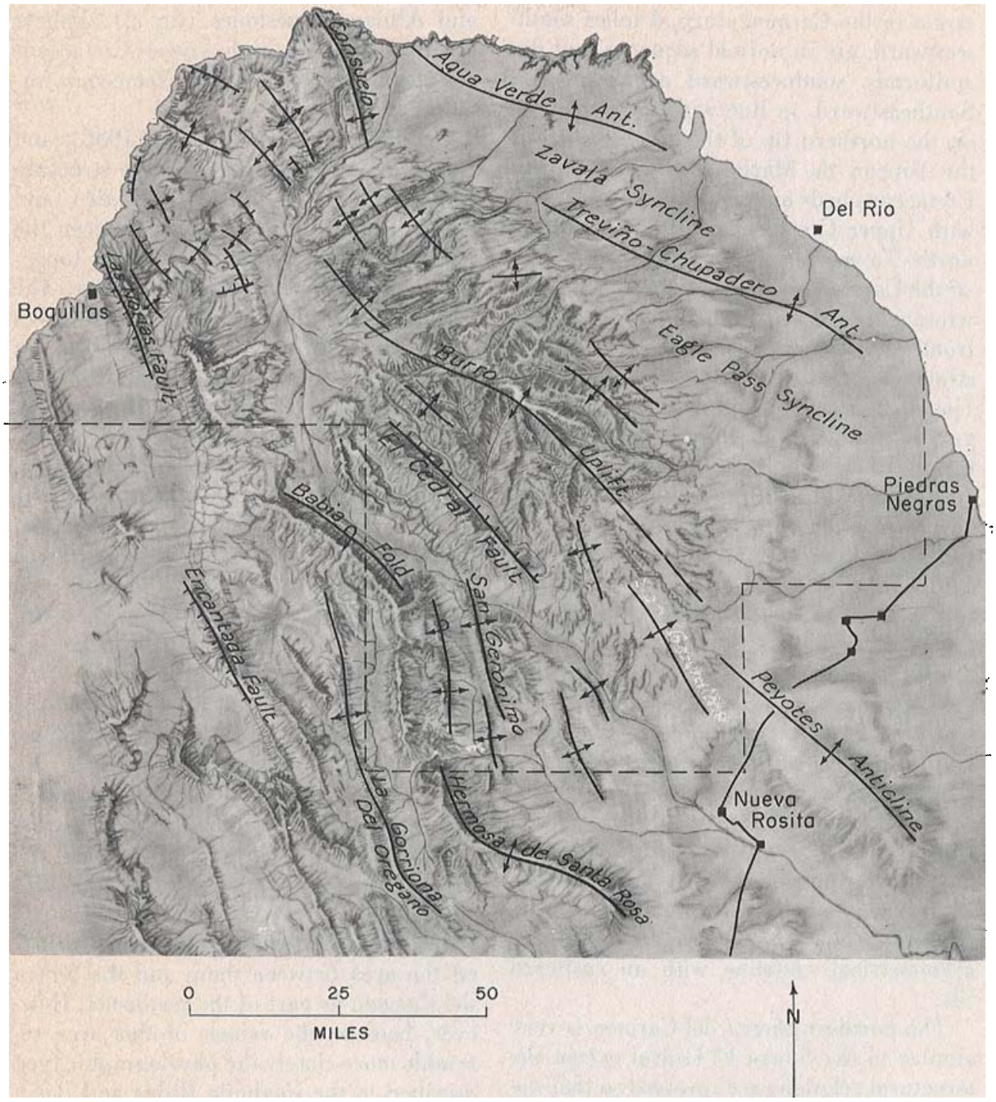


FIG. 5. Principal structural features of northern Coahuila, Mexico. Mapped area is outlined.

This northwest-trending, normal or vertical fault has about 5,000 feet of throw near its mid-point. The downthrown block, on the northeast, forms the Valle El Infante and the upthrown block, on the southwest, the Sierra El Cedral. Toward each end the fault branches into a number of smaller faults with decreasing displacement and apparently dies out. The northwest end is covered by the alluvium of the Valle Las Norias and relations are uncertain. The formations of both the upthrown and downthrown blocks dip gently southwestward into the Arroyo de la Babia and Valle El Infante, respectively. Some reversal of dip (resulting from drag) occurs on both blocks adjacent to the fault.

The structure forming the valley of Arroyo de la Babia and the great, southern escarpment of the Sierra del Carmen is different from either the Serranía del Burro or Sierra El Cedral structures. Near the center of the Babia valley, and trending parallel to the Carmen scarp, is a series of low hogbacks of overturned strata, dipping steeply southwestward (Pl. 1). Equivalent strata in the Carmen scarp, 4 miles southwestward, are in normal sequence and dip uniformly southwestward at about 21°. Southeastward, in line with the hogbacks, on the northern tip of the eastern wing of the Rincón de María, overturned Lower Cretaceous beds on the south are in contact with Upper Cretaceous formations on the north. To explain the structure and origin of the Carmen scarp, C. L. Baker (1927?) wrote: "The scarp is made either by the front of an overthrust sheet or else the strata bent vertically downward beyond (just northeast) of the scarp, and being greatly fractured in the abrupt bending, this northeast limit of the fold has been entirely eroded away, and its eroded stumps covered by alluvium." Baker's analysis appears to be correct and the structure is an anticline (Babia fold; fig. 5) overturned to the northeast with possible thrusting on the northeast flank.

The southeast end of the Sierra del Carmen merges with a series of north-northwest-trending anticlines and synclines. The two easternment of these ranges, Sierra de San Gerónimo and Sierra de Berruguero, are both asymmetrical with axial planes tilted eastward. South of these ranges, the Sierra Hermosa de Santa Rosa swings sharply east-southeastward and then southeastward. This sinuous range is also an asymmetrical anticline with an eastward tilt.

The northern Sierra del Carmen is very similar to the Sierra El Cedral except the structural relations are reversed so that the southwestern block has been dropped down and the northeastern block uplifted to form a high south-facing scarp. Baker (1927?, p. 16) stated that the southwest escarpment of the Sierra de la Encantada, south-southeast of the Carmen fault, is also a fault of 2,000 to 3,000 feet of throw down to the west. East of the northern Sierra del Carmen is the complexly folded, faulted, and intruded Pico Etéreo region and southeastward the high intrusive mass and lava flows of the central Sierra del Carmen.

Except for the central Sierra del Carmen, all the mountain masses of the area are composed of Lower Cretaceous (Aptian and Albian) limestones (fig. 2). Valleys are underlain by high Lower Cretaceous (Cenomanian) or Upper Cretaceous formations.

Kellum, Imlay, and Kane (1936) and Humphrey (1956) discussed the structure and tectonics of northern Mexico and pointed out the close relation between the type of folding and pre-Cretaceous topography as related to stratal thickness. The folds developed in relatively thin sequences overlying high pre-Cretaceous areas are relatively low and open as contrasted to long, narrow anticlines with steep flanks developed in thick sequences of strata accumulated in previous topographic lows. Furthermore, they noted that near the southern and eastern borders of the Coahuila Peninsula, anticlines of the low areas are asymmetrical with axial planes tilted toward the land mass (Kellum et al., 1936, pp. 995 and 1001; Humphrey, 1956, pp. 28 and 29). Humphrey (1956, p. 31) following Imlay (1943, p. 526) outlined the boundaries of the Coahuila and Tamaulipas Peninsulas and named the intervening region the Sabinas Gulf (paleogeographically) or Coahuila Ridge and Basin province (structurally; fig. 6). He placed the western boundary of the Tamaulipas Peninsula southwest of the Sierra Hermosa de Santa Rosa (dotted line, fig. 6) and included the area between there and the Sierra del Carmen as part of the peninsula. However, because the ranges of this area resemble more closely the physiographic type ascribed to the Coahuila Ridge and Basin province, and the anticlines have an eastward or northeastward directed asymmetry (axial planes dip westerly), it seems reasonable to consider this region as part of the Coahuila Ridge and Basin province as defined by Humphrey and to modify the boundaries drawn by Imlay and Humphrey, as shown on figure 6. Changes in trend of fold axes would then conform to irregularities in the edge of the Tamaulipas Peninsula with any fold asymmetry always pointing toward the land mass. The large El Cedral and Carmen-Encantada normal faults do not appear to be directly related to Jurassic paleogeography and possibly reflect reactivation of Paleozoic faults during relaxation of Laramide compressive forces.

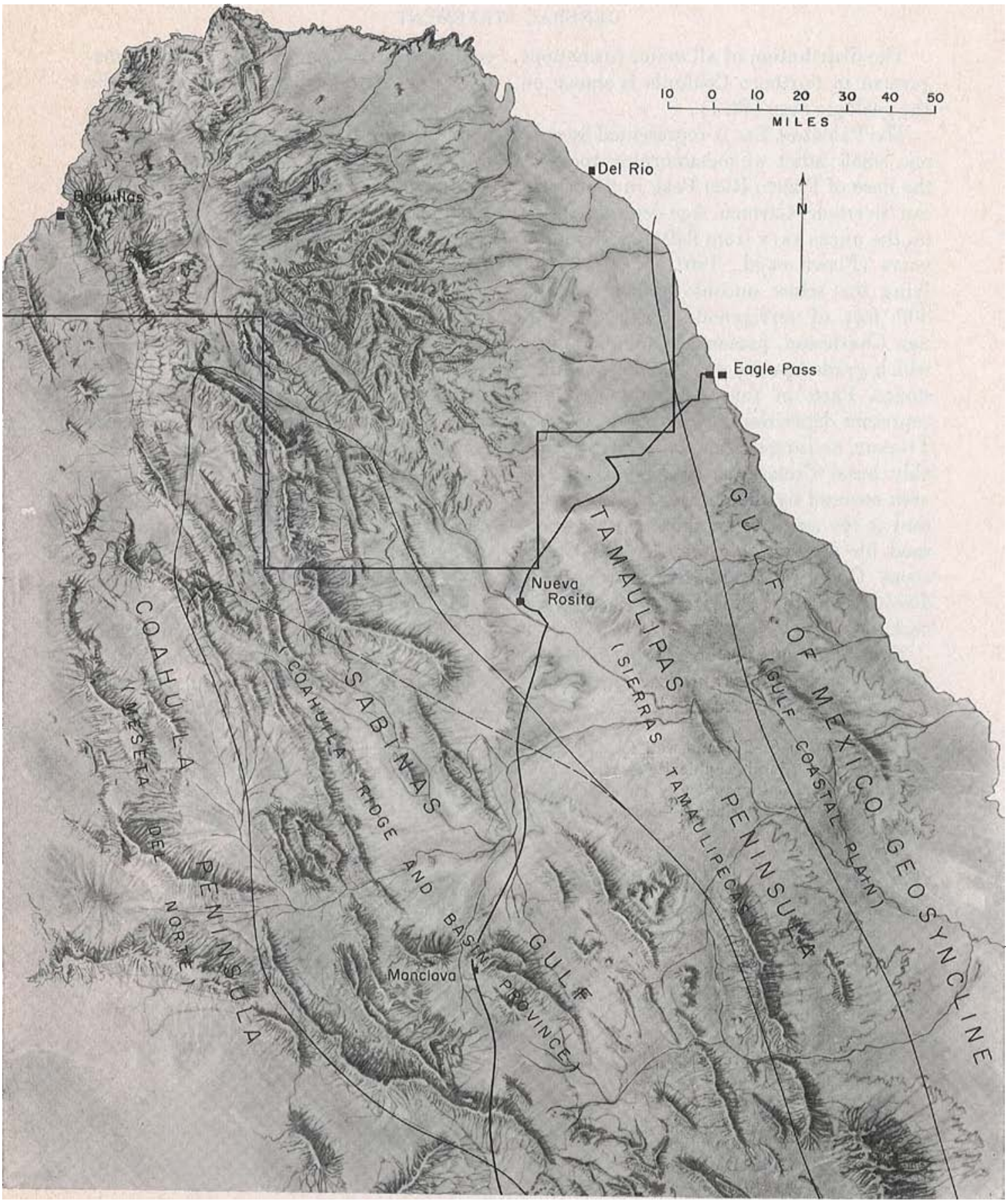


FIG. 6. Early Upper Jurassic paleogeography and tectono-geomorphologic provinces in northeastern Mexico (modified after Humphrey, 1956, p. 31). Dashed line indicates Humphrey's northern limit of the Sabinas Gulf.

STRATIGRAPHY

GENERAL STATEMENT

The distribution of all major formations present in northern Coahuila is shown on the geologic map (Pl. 1).

The Paleozoic Era is represented by only one small inlier of metamorphic rocks at the base of Puerto Rico Peak in the northern Sierra del Carmen. Age determinations on the micas vary from 240 to 370 million years (Flawn et al., 1961, p. 99). Overlying the schist unconformably is about 300 feet of terrigenous clastics (Santiago Charleston, personal communication) which grade upward into Cretaceous limestones. Parts of this clastic section may represent deposition during late Paleozoic, Triassic, or Jurassic time but is more probably basal Cretaceous conglomerate. The area covered by the outcrop of this clastic unit is too small to be shown at the scale used for the geologic map, so the Cretaceous Cupido Formation appears to lie directly on the Paleozoic metamorphic rock.

The Cretaceous System is represented by a thick series of shales and limestones which comprise all the marine sedimentary formations present in northern Coahuila. All the main mountain masses of the region are composed of these formations except the middle Sierra del Carmen, which is igneous rock. Valleys between the ranges are filled with alluvium which probably ranges from late Tertiary to Quaternary in age. There are several terrace levels in the alluvial sequence but no attempt was made to separate them on the map (Pl. 1).

The age of the igneous rocks shown on the map has not been determined. They are designated as Tertiary because the intrusives penetrate Upper Cretaceous rocks. Terrestrial fossils of late Eocene age have been found associated with igneous sequences to the west in Texas in the Big Bend National Park that are probably products of the same igneous event (St. John, p. 1965, p. 57).

The Cretaceous System in northern Coahuila is divided into three series. In ascending order these are the Coahuilan, Comanchean, and Gulfian. The Gulfian is referred

FIG. 7. Section (1–27) and well (A, B, C) location map, northern Coahuila, Mexico. Section code: hexagon—generalized graphically on stratigraphic diagrams and described in detail on Plates 2 and 6; square—generalized graphically on stratigraphic diagrams and described in Appendix C (except 19, 21, 22, and 24); triangle—described in Appendix C only; circle—localities mentioned but not described herein.

Sections—

1. Agua Verde
2. Cañón San Rosendo
3. Cañón de Ceferino
4. Pico Puerto Rico
5. Cerro de Aguachili
6. Puerto Prieto
7. Cañón El Cíbolo, Sec. III
8. Cañón El Cíbolo
9. Cañón El Colorado
10. Cañón La Palma
11. Rancho San Miguel
12. Cerro El Palomo
13. Rancho El Bonito
14. Rancho Santo Domingo
15. Sierra El Cedral
16. Cañón El Mulato
17. Cañón Las Calabazas
18. La Ventana de La Encantada
19. Rancho El Melón
20. Rancho La Peña
21. Rincón de María
22. Sierra de San Gerónimo
23. Valle de Huilotes
24. Cañón de La Alameda
25. Cañón Potrero
26. Potrero de La Mula
27. Potrero de Oballos

Wells—

A. Ohio-Mexican Oil Company No. 1 Zambrano
B. Ohio-Mexican Oil Company No. 1 Treviño
C. Petroleos Mexicanos No. 1 Chupadero

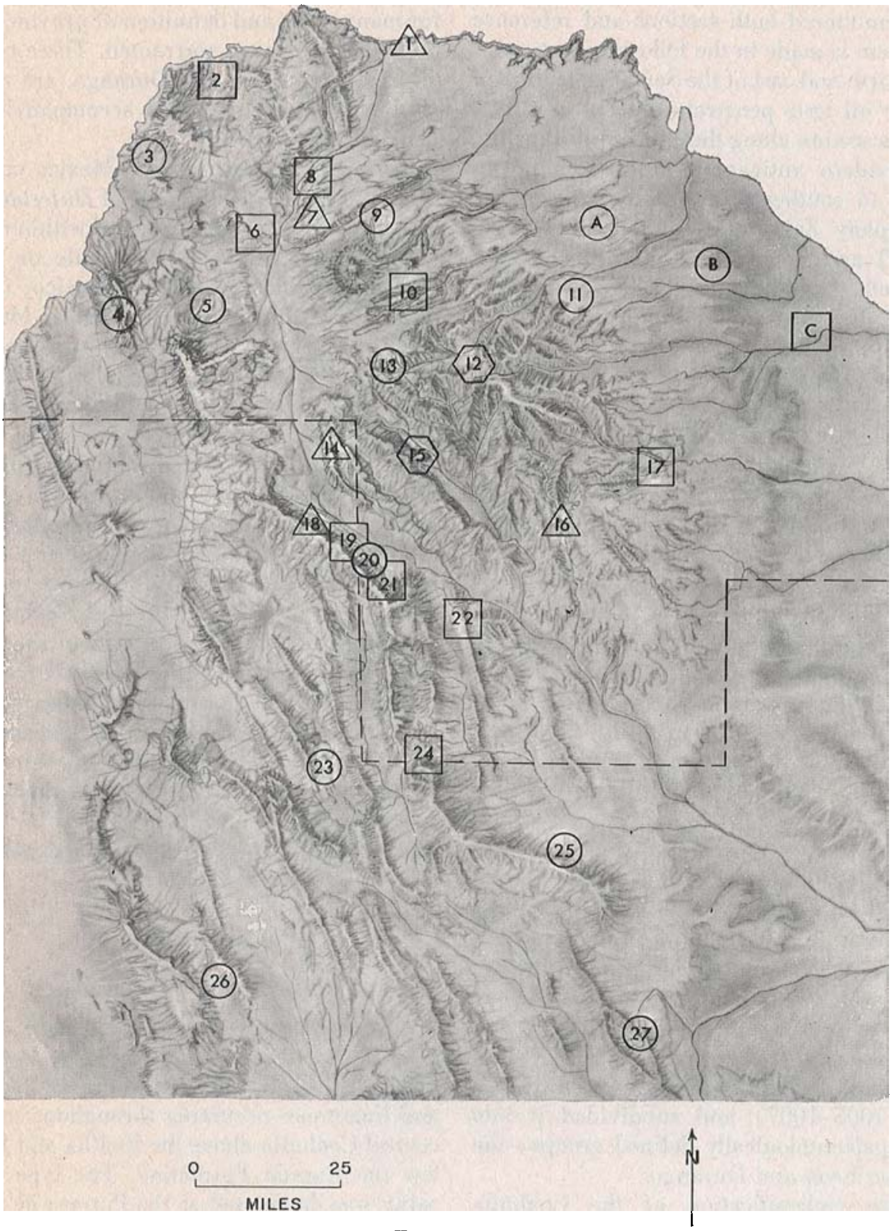


FIGURE 7.

to as the Upper Cretaceous and the Coahuilan and Comanchean together as the Lower Cretaceous. The Lower Cretaceous formations are the subject of this report.

Facies changes between formations typical of the Texas Comanchean and formations typical of the Mexican Comanche Series take place in northern Coahuila. Two stratigraphic sections south of the area of this study are important for definition of this facies change. These sections are in Cañón de la Alameda and in Cañón Pot-ero (fig. 7, sections 24 and 25), 20 miles southeast of Cañón de la Alameda, on the east flank of the Sierra Hermosa de Santa Rosa. The former section was measured and described by Santiago Reynolds and the latter by Teodoro Díaz. The author has reconnoitered both sections and reference to them is made in the following text.

North and east of the Serranía del Burro, three oil tests penetrate the Lower Cretaceous section along the axis of the Treviño-Chupadero anticline. These, from northwest to southeast, are Ohio-Mexican Oil Company Zambrano No. 1 and Treviño No. 1 and Pemex Chupadero No. 1 (fig. 7, wells A, B, and C). The first two wells were described by Robert H. Cuyler for the Ohio Oil Company; they are cited by Imlay (1945, pp. 1431–1432). T. C. Peters, Shell Oil Company, also described these samples and his lithologic log is referred to in this report. The Chupadero No. 1 samples were described by F. E. Lozo and J. L. Wilson, Shell Development Company, and an electric log is available of this well. These well data are used to correlate surface sections of northern Coahuila with subsurface sections in South Texas and with surface sections measured by the author in the Edwards Plateau region.

COAHUILA SERIES

General Statement

The Coahuila Series was originally defined as a group by Imlay (1940, pp. 124, 125) "... to include all Lower Cretaceous strata older than the *Dufrenoya texana* zone which were deposited in the ancestral Gulf of Mexico, in the Mexican sea, and in closely connected waters." He later reclassified the unit as a series (Imlay, 1944, pp. 1005–1007) and subdivided it into two paleontologically defined groups—the Nuevo Leon and Durango.

The reclassification of the Coahuila Group as a series meets the specifications of the Code of Stratigraphic Nomenclature for definition of a time-stratigraphic unit. However, definition of the Nuevo Leon and Durango Groups paleontologically is not acceptable under the Code (or previously accepted practice) nor are these units of great practical value in the field. By definition, these terms are actually provincial stages. Paleontologically defined European stages have been recognized in this region for many years and definition of provincial units does not seem warranted. These two terms, Nuevo Leon and Durango, are not used in this report or on the accompanying geologic map (Pl. 1).

Throughout northeastern Mexico and southwestern Texas, the zone of *Dufrenoya texana* (= *D. justinae*) is found within the lower part of the La Peña shale or its equivalents: Otates in eastern Mexico; upper Cuchillo of eastern Chihuahua, Mexico; and Pearsall in southwestern Texas (Imlay, 1945, p. 1446; Humphrey, 1956, pp. 32–34; Humphrey and Díaz, MS.). The base of the La Peña shale appears to be a very nearly perfect physical time-stratigraphic horizon and in practice is mapped as the top of the Coahuila Series.

A complete Coahuila section is not exposed in northern Coahuila. The lower part is cut out by onlap onto the Coahuila Peninsula; only the upper parts of the La Mula Formation and the Cupido Formation crop out. At Potrero de Oballas (fig. 7, section 27), well within the paleogeographic Sabinas Gulf, a complete Coahuilan section has been described by Humphrey and Díaz (MS.) and Humphrey (1956). The formations of the Coahuilan exposed there are shown in table 1.

Description

La Mula Formation

Name and type section.—The term La Mula Formation was introduced by Imlay (1940, Pl. 1; p. 122) for a unit of shales and limestones occurring throughout east-central Coahuila above the Padilla and below the Cupido Formation. The type locality was designated as the Potrero de La Mula (fig. 7, section 26) about 50 miles northwest of Cuatro Ciénegas, Coahuila. The name had previously been used in this sense by William G. Kane in unpublished oil company reports.

The name "La Mula" was first used in northern Coahuila by Humphrey and Díaz (MS.) and Humphrey (1956) for about 145 feet of red shales and limestones cropping out at the base of the southern Sierra del Carmen escarpment west of Rancho de

TABLE 1. *Coahuilan Series at Potrero de Oballos, Coahuila, Mexico.* Modified after Humphrey and Díaz (Humphrey, 1956, p. 33).

TIME UNITS		TIME-ROCK UNITS		ROCK UNITS
System	Series	Stage (European)		Formation
CRETACEOUS	COAHUILAN	Aptian	Bedoulian	Cupido 1,287 feet
		Neocomian	Barremian	?
				La Mula 2,508 feet
				?
			Hauterivian	Padilla 561 feet
				?
				Barril Viejo 1,425 feet
				?
			Valanginian	Menchaca 386 feet
			Berriasian	

la Babia on Rancho La Peña (fig. 7, section 20.)

Occurrence, lithology, and thickness.—The only extensive outcrop of the La Mula Formation in northern Coahuila is at the foot of the southern Sierra del Carmen, extending from the Rincón de María (fig. 7, section 21) 15 miles northwest to the vicinity of Rancho El Melón (fig. 7, section 19). The only other exposures are at the foot of the Sierra El Cedral, adjacent to the El Cedral fault, one-half mile west of El Infante ranch house (fig. 7, section 15) and a questionable few feet in Cañón de la Alameda. At Pico Puerto Rico (fig. 7, section 4) in the northern Sierra del Carmen, the formation is absent, apparently by onlap onto the Paleozoic rocks or by facies change to fluvial clastics.

In the Sierra del Carmen the lithology is predominantly red-weathering, silty shales interbedded with thick, buff-weathering lime mudstones[2] with rare oyster fragments, whereas in the Sierra El Cedral the lithology is red-weathering clays and silty clays with only one interval of thin-bedded, gray lime mudstone with ripplemarks and scattered fossils.

North of the Serranía del Burro, Pemex Chupadero No. 1 penetrated a 250-foot section of red, sandy siltstones and gray limestones below the Cupido and above basal Mesozoic(?) conglomerates (fig. 9, p. 22). This section is probably equivalent to upper La Mula. In Ohio-Mexican Zambrano No. 1, 45 miles northwest of Chupadero No. 1, no marine sediments equivalent to the La Mula Formation are present.

The contact of the La Mula with the overlying Cupido Formation is gradational in northern Coahuila and is arbitrarily designated where gray limestones of the Cupido predominate over the red shales and the buff limestones of the La Mula.

Cupido Formation

Name and type section.—R. W. Imlay (1937, p. 606) named the Cupido limestone from exposures in the middle part of the Sierra de Parras about 37 miles southeast of Parras, Coahuila. The unit was defined to include ". . . the thick-,medium-, and thin-bedded gray limestones above the Taraises Formation and below La Peña Formation." W. E. Humphrey (1949, p. 103) redefined the unit to include Imlay's lower limestone member of the La Peña Formation.

In the type area, the Monterrey area, and farther south and east the Cupido constitutes the upper two-thirds of the entire Coahuilan with only the marly Taraises Formation between it and the Jurassic. However, north and west of the type area, around the edge of the Coahuila Peninsula, clastic sediments were being deposited along with the limestones at this time and the time-equivalent of the type Cupido is divided into several different formations (Humphrey and Díaz, MS., and Humphrey, 1956, p. 33). Throughout central and northern Coahuila, only the uppermost limestone unit of the Coahuilan takes the name Cupido. It is equivalent to the uppermost part of the Cupido of the type area (Humphrey and Díaz, MS.).

Occurrence, lithology, and thickness.—The Cupido Formation crops out at the same localities in northern Coahuila as mentioned for the La Mula (at the base of the southern Sierra del Carmen and Sierra El Cedral escarpments and in Cañón de la Alameda) and in addition is exposed above the basal Mesozoic(?) clastic section at the Pico Puerto Rico section in the northern Sierra del Carmen. The formation also crops out in the Valle de Huilotes (fig. 7, section 23) about 20 miles west of the section in Cañon de la Alameda. The latter exposures were not described and are not discussed herein.

The formation ranges in thickness from about 800 to 900 feet in the Sierra El Cedral and southern Sierra del Carmen areas to 520 feet at Pico Puerto Rico (Santiago Charleston, personal communication).

The Sierra El Cedral section (Pl. 2) was measured in detail. The Cupido here is about 803 feet thick and is divisible into three gross units. The upper and lower units are thinner, massive, cliff-forming sections whereas the thicker middle unit weathers to form a slope.

The lower Cupido (units 5–8, Pl. 2) is about 163 feet thick and is divided by a disconformity or diastem into two parts. The lower part (units 5 and 6) consists of thin- to medium-bedded lime mudstones or wackestones with common lithoclasts at the base and an upper series of medium-bedded, oolite, coated pellet, shell fragment grainstones to wackestones (Pl. 3, A). The grainstones are commonly cross-bedded. The top of these beds is an iron-stained, clam-bored surface indicative either of subaerial exposure and consequent cementation (Perkins, 1966) or of submarine nondeposition and cementation (E. A. Shinn, personal communication, 1969). The upper part of the lower Cupido (units 7 and 8) consists of about 19 feet of dark-

[2] The limestone classification of Dunham (1962) is followed in this report. A synopsis of this classification is included in Appendix B.

gray, thin-bedded, dolomitic mudstone and wackestone at the base overlain by a 63-foot thick, cliff-forming section of medium-bedded, shell fragment wackestones with two thin oolite grainstone beds. Capping this series is a thin, laminated, algal stromatolite layer (Pl. 3, B).

The middle Cupido (units 9–31, Pl. 2) is about 408 feet thick at the Sierra El Cedral section and consists of a variety of lithologies. The lower 239 feet (units 9–19) consists of two thick sequences of thin-bedded clayey lime mudstones* separated and capped by thinner units of ledge-forming, shell fragment, oolite lime wackestones and grainstones (Pl. 3, C). Thin *Gryphaea* wackestones are common near the base. The overlying 26 feet (unit 20) provides a good local mapping datum; it consists of brown, locally cross-bedded, calcite or lime mud cemented, fine quartz sand basally (Pl. 3, D) and oolite, lithoclast grainstones and wackestones above (Pl. 3, E).

The upper 143 feet of the middle Cupido (units 22–31) consists of variations of thin-bedded mudstone and medium-bedded, shell fragment wackestones with miliolids, *Gryphaea*, and other oysters. This sequence includes one bed of oolite grainstone (unit 23), one coarse-grained dolomite bed (unit 29), and a thin algal(?) stromatolite layer near the top.

The upper massive Cupido (units 32–38, Pl. 2) is about 234 feet thick and is predominantly gray to dark gray, medium-bedded, miliolid, shell fragment, pellet lime wackestone to mudstones. This lithology is broken by three beds (units 33, 35, and 37) of yellowish-weathering, gray, nodular, soft, shell fragment wackestone with *Gryphaea*, *Tylostoma*, and various clams. The lower 30–40 feet contains numerous beds of pellet grainstone (Pl. 3, F) and the upper bed contains very abundant large *Lunatia*, various clams, and other gastropods.

The contact of the Cupido with the overlying La Peña shale is sharp but apparently conformable (Pl. 4, A).

* On re-examination of this section in May 1969, many of these "clayey lime mudstones" were found to be fine-grained dolomites with common salt crystal molds.

About 20 miles south-southwest of the Sierra El Cedral section in the Rincón de María (fig. 7, section 21) the Cupido is about 900 feet thick and has essentially the same characteristics as in the Sierra El Cedral.

In the Chupadero No. 1 (fig. 9, well C), east of the Serranía del Burro, the Cupido is about 835 feet thick and is divisible into three units as in the Sierra El Cedral. The lower unit consists of about 130 feet of oolitic limestones; the middle unit is 410 feet of red, silty shale and sandstones intercalated with thin, pink to gray limestone; and the upper unit comprises 295 feet of gray, shell fragment, oolite limestone. Imlay (1945, p. 1440) reported 400 feet of Cupido (Sligo Formation) in the Zambrano No. 1 (fig. 7, well A). However, according to correlations by the writer, the limestones reported to be Cupido are actually lower Glen Rose limestones of the Comanche Series.

To the south, in Cañón de la Alameda, Santiago Reynolds (personal communication) measured 1,472 feet of Cupido (fig. 8) and described it as gray to black, thin- to medium-bedded, oolite, shell fragment lime wackestones below and thick-bedded, *Gryphaea*, miliolid wackestone with scattered oolites above.

Interpretation

During the period of time represented by La Mula-Cupido deposition in northern Coahuila, the Sabinas Gulf basin was filled and the northern part of the Coahuila and Tamaulipas Peninsulas extensively transgressed by the sea. The La Mula shales probably represent the last period of time during which a significant amount of material was eroded from the peninsulas and deposited in basinal areas. The beginning of Cupido deposition was marked by a pronounced drop in the percentage of clays being deposited around the edges of the peninsulas as local terrigenous source areas were submerged.

La Mula Formation

At the beginning of La Mula deposition,

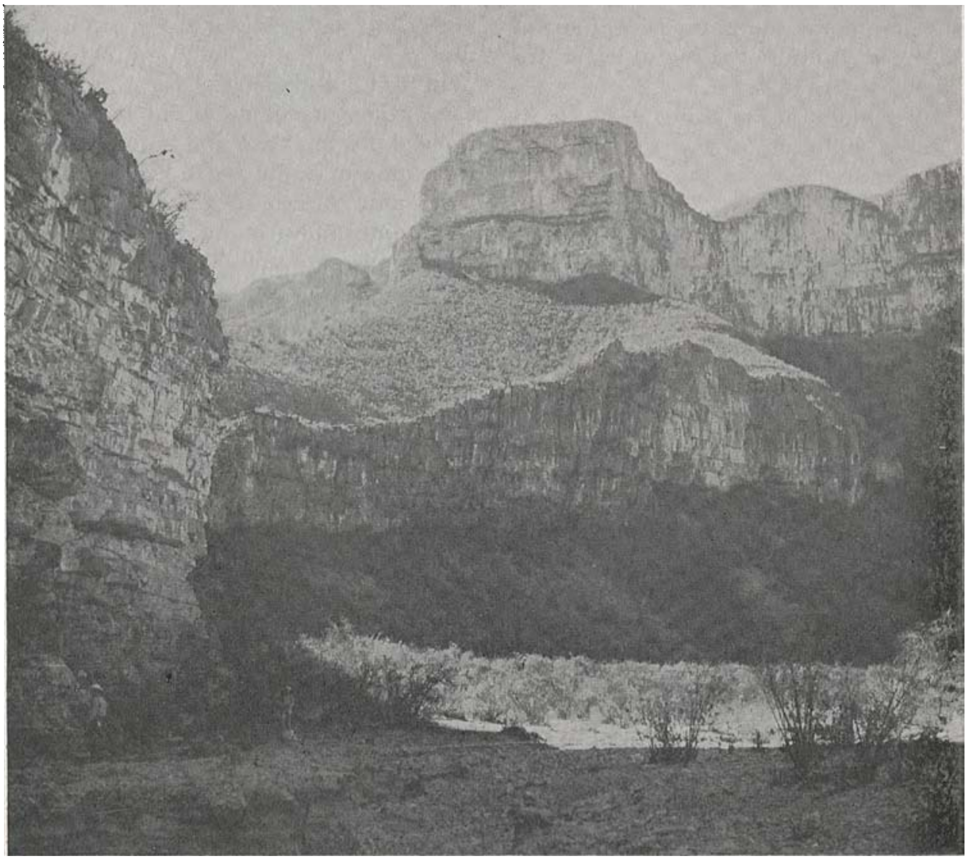


FIG. 8. View of the south wall of Cañón de la Alameda, northern Coahuila, Mexico. Thick-bedded Cupido limestone forming cliffs above a questionable few feet of La Mula Formation shown in the left foreground.

the shoreline was some distance south of Sierra El Cedral. Most of the Tamaulipas Peninsula had been submerged since early Coahuilan time. The northern part of the Coahuila Peninsula was still emergent but its topographic character and sediment contribution are unknown.

Northward from the La Mula shoreline the land surface rose fairly rapidly. Rough calculations considering the amount of stratigraphic onlap (± 3,100 feet) between the Sierra El Cedral and outcrops of Paleozoic rock 90 miles to the north (in Texas) indicate an average surface slope of 30 to 35 feet per mile. Considerable terrigenous sediment was being deposited in northern Coahuila during this time as evidenced by the basal Mesozoic(?) sand sequences in wells on the Treviño-Chupadero anticline. It is probable that most of the southern Serranía del Burro is underlain by similar sand sequences.

By the end of La Mula deposition, transgression of the sea had moved the shoreline to a position approximated by the dashed line on figure 10.

The bulk of La Mula deposition represents a time of relatively heavy influx of fine terrigenous clastics into the Sabinas Gulf marine depositional area from the north and probably also from the Coahuila Peninsula to the west and southwest. Fluvial deposition inland (e.g., the Pico Puerto Rico section and Ohio-Mexican Zambrano No. 1) graded seaward to littoral zone sedimentation (e.g., Sierra El Cedral and southern Sierra del Carmen area).

Cupido Formation

The Cupido Formation of northern Coahuila, as described in the Sierra El Cedral, and the Rincón de María, is basically transgressive marine limestone and shale deposited as the sea moved northward over the continent. Recorded within this overall transgressive sequence are variations in terrigenous influx and temporary regressions and standstills of the shoreline which modified but did not change the dominant character of the formation.

The La Mula-Cupido contact is gradational and probably time-transgressive perpendicular to the strand line. At Sierra El Cedral the last of La Mula deposition was in open but muddy water probably 15 to 20 miles off-shore (fig. 10). As the shoreline moved northward, influx of terrigenous clastics decreased, the water became clearer, calcium carbonate deposition predominated, and Cupido deposition was initiated.

The lower Cupido records a period of low influx of terrigenous clastics. The basal shell fragment mudstones and wackestones, probably deposited a considerable distance off-shore and in a zone where the sea bottom was not frequently agitated, change facies upward to consist of interbedded oolite, shell fragment grainstones, and wackestones. These vertically alternating grainstones and wackestones seem to intergrade laterally and may represent deposition on bar and swale topography. This environmental and consequent facies change, from mudstones and wackestones to wackestones and grainstones, may have been caused by a standstill of sea level and bottom aggradation or from a relative drop in sea level. In either case a more highly agitated bottom environment resulted. After a period of stability between this environment and the rate of subsidence, the depositional surface was cemented and bored by *Lithophagus*-type clams. The cementation may have been either subaerial or submarine but in either case represents a depositional hiatus.

The upper part of the lower Cupido at Sierra El Cedral consists of a sequence that records one complete cycle of sea transgression and regression. The lower, dark, thin-bedded, dolomitic mudstones were deposited possibly in a tidal-flat and lagoonal environment as sea level rose and the disconformity surface was covered. With continued transgression, the sea became slightly deeper, with better circulation, and thicker-bedded, shell fragment wackestones were deposited in this area. Subsequently, the sea shallowed again and an algal stromatolite bed, considered to be of intertidal origin by analogy with recent examples (Logan, Rezek, and Ginsburg, 1964), was deposited on the wackestones.

The middle Cupido contains a much larger percentage of terrigenous material and was deposited entirely under the variable conditions of littoral and shallow sublittoral environments.[3] Algal stromatolites at the top and bottom indicate intertidal sedimentation. The dominant thin-bedded, marly lime mudstones and clays with oyster biostromes were probably deposited in a shallow but open sublittoral environment, and the oolite, quartz sand, lithoclast grainstones represent a temporary increase in competence of the currents bringing terrigenous clastics into this area.

The upper Cupido is interpreted to represent the period of maximum shoreline transgression and deepening of the sea during Cupido deposition. Oolite grainstones immediately overlying the stromatolite at the top of the middle Cupido indicate movement of a high energy zone across tidal flats. Seaward, the bottom was probably grass covered in part, and tests of miliolids living on the grasses were deposited along with lime mud to form a miliolid wackestone.

[3] The environmental classification scheme used here follows Krumbein and Sloss (1963, pp. 259–262).

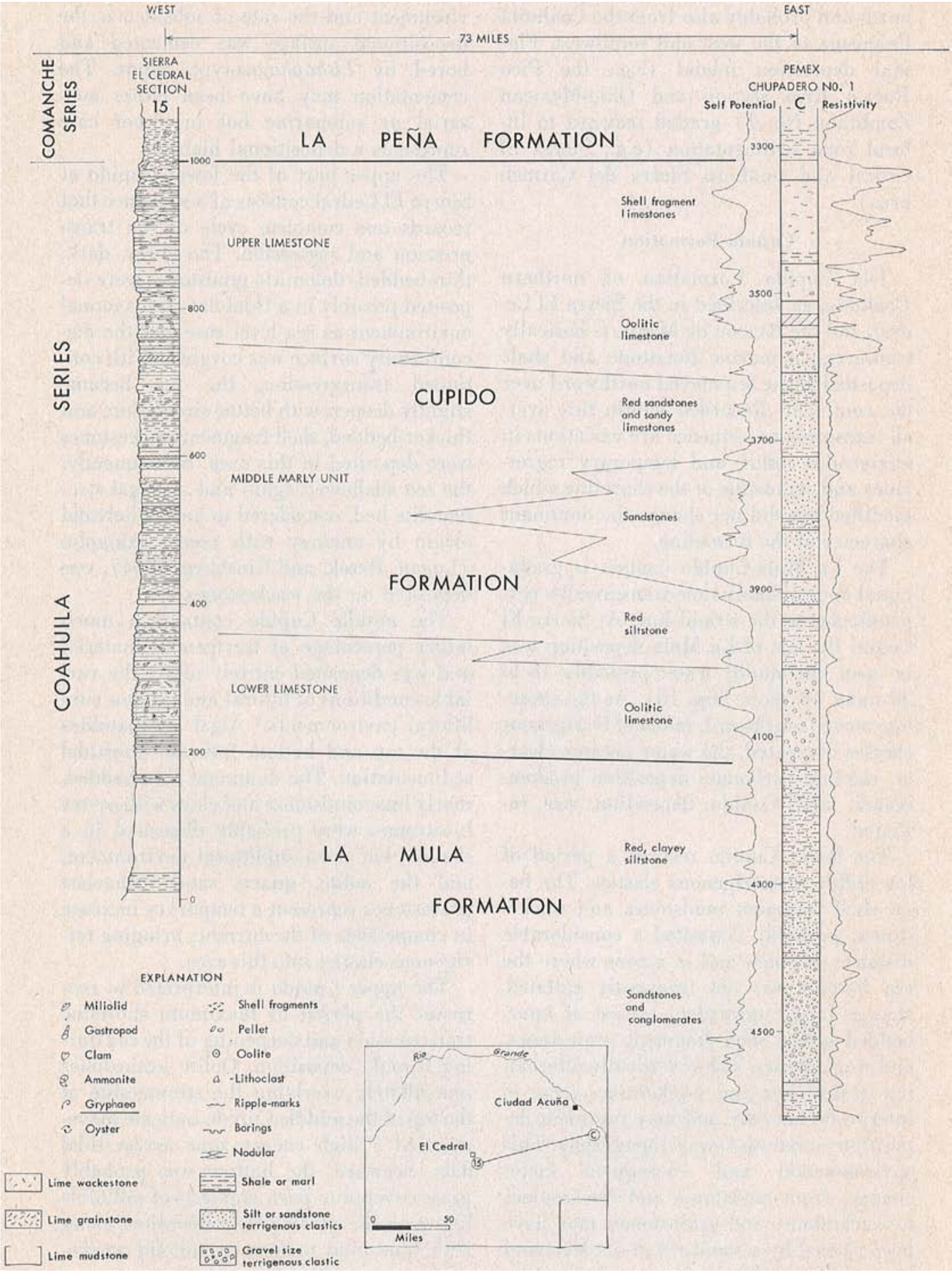


FIG. 9. Correlation of the Upper Coahuilan formations between the Sierra El Cedral and the Pemex Chupadero No. 1 oil test.

The nodular wackestones which interrupt the sequence contain a small percentage of terrigenous clay in contrast to almost none in the remainder of the upper Cupido. Analysis by Shell Development Company of samples from similar beds in Texas indicates that about 2 percent clay is an essential characteristic of this facies. The clay is apparently detrimental to miliolids and grasses but promotes the abundance of burrowing and plowing mollusks. The periodic increase in clay deposition is probably related to the rate of influx.

Correlation of the Sierra El Cedral section with the Pemex Chupadero No. 1 oil well 73 miles eastward is shown in figure 9. The similarity in thickness of the Cupido in these two sections (considering the distance between them) attests to their similarity in tectonic setting. The major difference between the two is the greater abundance of sands, red silts, and shales in the middle Cupido of Chupadero No. 1. This relation is interpreted to indicate that either the Chupadero location was nearer shore or the source of middle Cupido clastics was nearer to the Chupadero and probably arrived in the Sierra El Cedral area by along-shore transport. The latter interpretation is supported by data from the overlying formations presented below.

To summarize, it appears that early Cupido deposition in northern Coahuila was marked by regression of the shoreline from its initial position as shown on figure 10, to a position somewhat southeast of Rancho El Cedral. Subsequently, transgression brought the shoreline back northwest of El Cedral but probably not as far as it was originally. At the same time, terrigenous clastics began to enter the area from the northwest in the vicinity of Chupadero

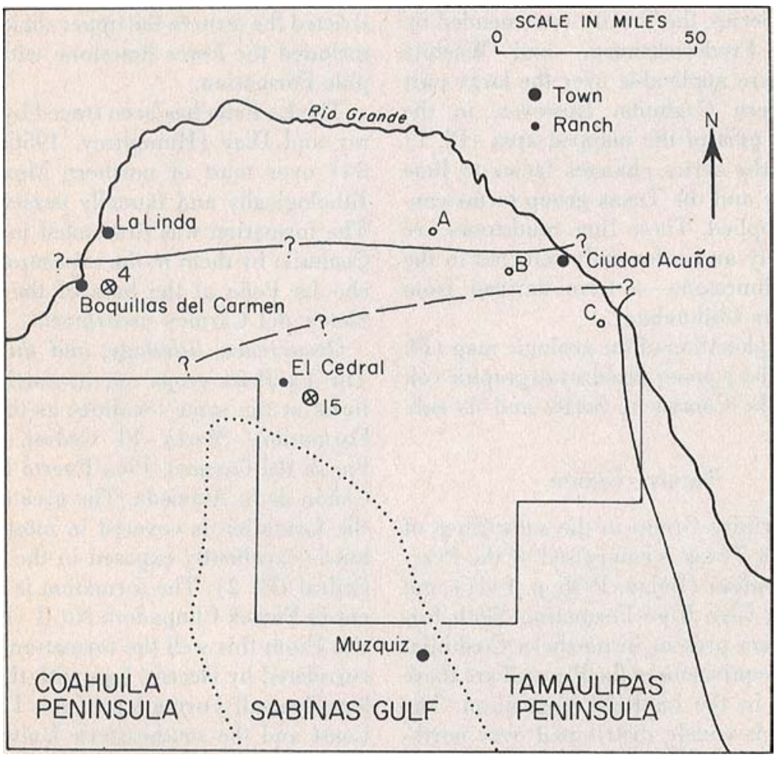


Fig. 10. Shoreline positions at the beginning (dashed line) and end (solid line) of deposition of the Cupido Formation (uppermost Coahuilan). Numbers and letters give locations of critical wells and outcrop sections used for this reconstruction. The dotted line outlines the paleogeographic Sabinas Gulf.

No. 1 and were transported westward by along-shore currents. Throughout middle Cupido time, shoreline position was relatively stable. Thereafter, the sea rapidly transgressed northward to the terminal position as shown on figure 10.

COMANCHE SERIES

General Statement

The term Comanche Series was initially applied to the provincial Lower Cretaceous in North and Central Texas (Hill, 1887a, b) and subsequently to adjoining and outlying regions. Imlay's (1944) re-classification of the pre-*Dufrenoya texana* zone strata as a series, by definition, emended the extent of the Comanche Series to the Lower Cretaceous sequence overlying the Coahuila Series. This emended usage is now accepted by most workers in northern Mexico and is so used by the writer.

The standard subdivisions of the Comanche Series, the Trinity (as emended by Imlay), Fredericksburg, and Washita Groups, are applicable over the large part of northern Coahuila. However, in the southern part of the mapped area (Pl. 1) most of the series changes facies to lime mudstone and the Texas group terms cannot be applied. These lime mudstones are collectively and informally referred to the Aurora limestone—a term derived from the west in Chihuahua.

The explanation of the geologic map (Pl. 1) provides a generalized stratigraphic column of the Comanche Series and its subdivisions.

Trinity Group

The Trinity Group in the subsurface of Southwest Texas is comprised of the Pearsall Formation (Imlay, 1945, p. 1441) and overlying Glen Rose Formation. Both formations are present in northern Coahuila, but beds equivalent to the Pearsall are there included in the La Peña Formation. The La Peña is widely distributed over northern Mexico but the Glen Rose is confined to northern Coahuila.

Only two complete surface sections of the Trinity Group are available in northern Coahuila. These are in the Sierra El Cedral where the Trinity is 2,220 feet thick, and at Pico Puerto Rico where it is 2,070 feet thick (Santiago Charleston, personal communication, 1963).

The Pemex Chupadero No. 1 penetrated 2,320 feet of Trinity. The Trinity section in this well has been correlated with subsurface sections in Texas and is very similar in thickness and lithology to the surface sections measured in the Sierra El Cedral.

Description

La Peña Formation

Name and type section.—R. W. Imlay (1936, p. 1119) named the La Peña Formation from exposures in the Sierra de Parras in southern Coahuila. The formation as defined by Imlay included a thick lower unit of limestone and a thinner upper shale unit. Humphrey (1949, p. 103) restricted the term to the upper shale unit and included the lower limestone with the Cupido Formation.

The La Peña has been traced by Humphrey and Díaz (Humphrey, 1956, pp. 32–34) over most of northern Mexico, as a lithologically and faunally persistent unit. The formation was first noted in northern Coahuila by them in the exposures on Rancho La Peña at the base of the southern Sierra del Carmen escarpment.

Occurrence, lithology, and thickness.—The La Peña crops out in northern Coahuila at the same localities as the Cupido Formation—Sierra El Cedral, southern Sierra del Carmen, Pico Puerto Rico, and Cañón de la Alameda. The greater part of the formation is covered in most outcrops but is excellently exposed in the Sierra El Cedral (Pl. 2). The formation is also present in Pemex Chupadero No. 1 (Pl. 5, well C). From this well the formation has been correlated by electric logs with the equivalent Pearsall Formation of the Texas Gulf Coast and the southeastern United States. Correlation of Chupadero No. 1 with the Sierra El Cedral section is shown on Plate 5.

In the Sierra El Cedral the contact of

the La Peña with the Glen Rose is gradational and could be placed as low as the base of unit 43 (Pl. 2) or as high as the top of unit 49. The lower position is used arbitrarily, yielding a La Peña thickness of about 192 feet.

The La Peña in this section (Pl. 4, B) consists of lower and upper shale members and a middle limestone member. The shale members (units 39 and 42, Pl. 2) consist of dark gray to black calcareous shale with interbeds of marly lime mudstones. Ammonites and various pelecypods are common and most are partly replaced by pyrite. The middle limestone (units 40, 41) has an 8-foot thick basal bed of shell fragment lime wackestone overlain by alternating, medium-bedded lime mudstones and shales. This entire member contains abundant ammonites and common pelecypods.

Surface sections of the La Peña in the southern Sierra del Carmen are not well enough exposed for accurate measurement or description. The Pico Puerto Rico section has not been described in detail but the La Peña here appears to be about the same, both lithologically and faunally, as in the Sierra El Cedral.

Eastward from Sierra El Cedral, the La Peña is completely in the subsurface. In Pemex Chupadero No. 1 the formation is about 200 feet thick and tripartite, but the shales here are very sandy. Northwestward in the Ohio-Mexican Zambrano No. 1 the formation equivalents probably occur between 2,900 and 3,100 feet but here contain abundant quartz sand throughout.

Paleontology and age.—Fossils collected from the La Peña Formation in the Sierra El Cedral and Rincón de María and identified by L. B. Kellum and Santiago Charleston are listed below. The University of Michigan Museum of Paleontology catalog numbers are included on this and succeeding fossil lists.

Lower La Peña—
- Pelecypoda—
  - *Exogyra quitmanensis* Cragin (UM 42598)
  - *Trigonia* sp. (UM 53231)
  - *Cardium* sp. (UM 53240)
  - *Tellina* sp. (UM 53241)
  - *Arctica* sp. (UM 53242)
- Gastropoda—
  - *Lunatia* sp. (UM 52496)
  - *Buccinopsis* sp. (UM 53244)

Middle La Peña—
- Cephalopoda—
  - *Kazanskyella arizonica* Stoyanow (UM 52179)
  - *Acanthohoplites* n. sp. (UM 52187)
  - *Sonneratia* n. sp. (UM 42188)
  - *Sonneratia* n. sp. (UM 52191, 52195)
  - *Sonneratia* n. sp. (UM 52190)

Upper La Peña—
- Pelecypoda—
  - *Exogyra quitmanensis* Cragin (UM 52501, 52497, 52495)
  - *Gryphaea* sp. (UM 52500, 52502, 52664)
  - *Nucula* ? sp. (UM 53237)
  - *Lucina* sp. (UM 52496)
- Cephalopoda—
  - *Dufrenoya* sp. aff. *D. boesei* Humphrey (UM 52172)
  - *Parahoplites* sp. cf. *P. umbilicostatus* Scott (UM 52497)
  - *Deshayesites* ? sp. (UM 53236)
  - *Sonneratia* ? sp. (UM 52665)

Dufrenoya with *Parahoplites* indicates Upper Aptian age. The La Peña shale is considered to be upper Aptian throughout the area of its occurrence in northern Mexico and southwest Texas (Humphrey, 1956, pp. 31–33).

Glen Rose Formation

Name and type section.—R. T. Hill (1891, p. 504) named the upper Trinity Glen Rose Formation from exposures along the Paluxy River near the town of Glen Rose, Somervell County, in north-central Texas. Here, as elsewhere in Texas, the formation consists of alternating resistant limestone ledges and soft marls which weather to form a characteristic stairstep topography. The formation has been mapped on the surface south and west as far as the West Nueces River in Kinney County, Texas (about 50 miles east of Del Rio). From this point westward the formation occurs as a subsurface unit across the Rio Grande embayment where it is identifiable in the oil wells along the Treviño-Chupadero anticline. The formation reappears on the surface in the Serranía del Burro uplift and is characterized by the stairstep topography as in the type area 350 miles to the northeast.

The presence of the Glen Rose in northern Coahuila was first noted by E. T. Dumble in 1895. Since that time numerous authors have commented on the occurrence, but only the section at Cerro El Palomo had been measured prior to the present study.

Occurrence, lithology, and thickness.—The Glen Rose occurs in typical facies throughout the Serranía del Burro and in the northern Sierra del Carmen. No typical Glen Rose occurs in the southern Sierra del Carmen or anywhere south of the valley of Arroyo de la Babia (fig. 4). Across this valley the entire Glen Rose changes facies (Pl. 5) and is equivalent to the lower part of what Humphrey and Díaz have referred to as the Aurora limestone (Humphrey, 1956, p. 33).

The lithology of the Glen Rose as exposed in the Sierra El Cedral (Pl. 4, C) is described in detail on Plate 2 and shown in summary form on Plate 5. The contact with the underlying La Peña is arbitrary. The 266 feet above the La Peña (units 43–49, Pl. 2) are gradational upward from black La Peña shales to gray shales and lime mudstones or wackestones with the limestones becoming predominant near the top. This entire interval is very fossiliferous, containing abundant large *Gryphaea* sp., *Exogyra* sp., clams, and common ammonites and echinoids.

The overlying 200 feet of strata (units 50–53) is not characteristic Glen Rose lithology but is included in the Glen Rose for mapping purposes (Pl. 1). These beds are barren of large fossils and grade from lime mudstones interbedded with shales to a medium-bedded lime mudstone without shale. This interval is succeeded by about 433 feet (units 54–48) of partly covered, alternating shales and lime mudstones. The first occurrence of the large foraminiferan *Orbitolina texana* is 55 feet below the top of this interval.

In contrast to the lower Glen Rose mudstones and shales with large fossils in the bottom part, the upper part of the formation is characterized by two extremely abundant foraminifera—miliolids and *Orbitolina texana*. These are associated with various small mollusks (gastropods, clams, and oysters) and with rudists in biostromes or bioherms. Large mollusks (ammonites, large *Gryphaea*, etc.) are not common.

Units 56–61 consist of a rudist bioherm and related deposits (Pl. 4, D). Unit 59 is 25 feet of level-bedded *Toucasia, Dictyoconus, Orbitolina* wackestone. Unit 60 is the bioherm proper. It is about 63 feet thick and varies from massive, caprinid, stromatoporoid, *Chondrodonta, Toucasia* wackestone to inclined, shell fragment talus beds. Unit 61, capping the bioherm, is a 63-foot thick series of level-bedded, *Toucasia,* miliolid wackestones with scattered *Orbitolina.*

Overlying the bioherm interval is 704 feet (units 62–76) of alternating thick, nodular marls or marly shell fragment wackestones and resistant, thin, miliolid, gastropod wackestones. *Orbitolina* is common in the lower 145 feet and occurs up to the top of unit 72. The middle portion of this thick interval contains fewer resistant ledges and weathers to a broad slope. *Toucasia* occurs sporadically as does *Gryphaea.*

The uppermost 277 feet of the Glen Rose (units 77–79) in the Sierra El Cedral contain very little marl and are mostly miliolid, gastropod wackestones or grainstones. A layer of chert occurs 125 feet below the top. *Toucasia* biostromes have been noted in this interval a few miles to the southeast.

At Cerro El Palomo (frontispiece), 23 miles to the northeast, 1,681 feet of Glen Rose are excellently exposed beneath overlying Fredericksburg marls (Pls. 5 and 6). Some significant differences and similarities between this section and the Sierra El Cedral section are as follows. (These comparisons are most easily followed by reference to Pl. 5.) The oldest exposed bed (unit 1, Pl. 6) is a 3-foot thick coated pellet, oolite grainstone (Pl. 7, A) with a bored, iron-stained upper surface (Pl. 4, E). This surface (interpreted to be a diastem or disconformity) is overlain by 32 feet of alternating nodular, shell fragment, quartz sand lime wackestones and shell fragment, pellet grainstones (units 2, 3). These beds are in turn overlain by about 60 feet (units 4–6) of *Monopleura, Toucasia,* miliolid wackestones with common oysters and with *Orbitolina texana* (Pl. 7, B) near the top. From shales and mudstones immediately above this interval (unit 1) ammonites have been collected. The series of beds described above was not found at Sierra El Cedral. They are apparently represented there by the lower part of the thick lime mudstone and shale sequence described at that locality (Pl. 2, units 50–53).

Units 8–11 at Cerro El Palomo consist of lime mudstones and shales with echinoids and pelagic foraminifera (Pl. 7, C). This section is very similar to the mudstones at Sierra El Cedral but much thinner. More typical Glen Rose lithology with *Orbitolina texana* gradationally overlies these mudstones.

Unit 16 at Cerro El Palomo consists of a thick *Dictyoconus* bed (Pl. 7, D) at the base, overlain by a series of beds containing *Toucasia* and other mollusks, and capped by a series of three bored surfaces. This sequence is probably correlative with the rudist bioherm and related beds described at Sierra El Cedral.

Above the bioherm (Sierra El Cedral) or bored surface (Cerro El Palomo) level there are only two major differences between the two sections. First, the upper 275 feet at Sierra El Cedral contain much less marl than the equivalent interval at Cerro El Palomo. Second, several bored surfaces were found at Cerro El Palomo and not at Sierra El Cedral.

Two paleontologic zones of major importance to regional Glen Rose stratigraphy are found at Cerro El Palomo. About 800 feet above the base of the section is a resistant bed with an iron-stained top which contains abundant *Corbula* (a small clam). Immediately above this bed occurs *Porocystis* (the fruiting organ of a dasycladacian alga as determined by R. Rezak). This paleontologic association occurs as a middle-Glen Rose horizon over most of the entire Central Texas Glen Rose outcrop (Stricklin and Smith, 1956, p. 16), a geographic area of several thousand square miles. About 375 feet higher, or 1,175 feet above the base, is a zone of *Loriola* (a regular echinoid) which is usually found above *Corbula* throughout Central Texas.

In Pemex Chupadero No. 1, 60 miles east of Cerro El Palomo, the Glen Rose thickness is about the same as in the Sierra El Cedral (Pl. 5), but the lower part of the formation (below the *Dictyoconus* level) is quite different. The lower 390 feet (3,130 to 2,740 feet, Pl. 5) consist of alternating glauconitic sands and oolitic limestones. The overlying 460 feet (2,740 to 2,280 feet, Pl. 5) are mostly oolitic, shell fragment limestones. Above 2,280 feet in the well, lithologies appear to be about the same as at Cerro El Palomo above *Dictyoconus*. One difference of importance is the occurrence of a gypsum layer at 1,700 feet. This layer can be correlated in the subsurface with an upper Glen Rose gypsum horizon which occurs above *Corbula* and below *Loriola* in Central Texas. No descriptions are available above 1,640 feet in Chupadero No. 1.

In Cañón El Cíbolo (fig. 7, section 8), 42 miles northwest of Cerro El Palomo, the upper 1,220 feet of the Glen Rose are exposed (Pl. 11, A). The lithology here is almost identical with that at Cerro El Palomo and bored surfaces are also common. The only notable difference is that the upper 275 plus feet are even more marly here than at Cerro El Palomo.

In the northern Sierra del Carmen, at Pico Puerto Rico (65 miles west of Cerro El Palomo), Santiago Charleston reported (personal communication) the Glen Rose lithology and paleontology to be similar to the section described above in the Serranía del Burro.

Southeastward from Cerro El Palomo, in the southeastern Serranía del Burro, the upper 250 feet of Glen Rose was described in Cañón Las Calabazas (Appendix C, section 17) and the upper 405 feet in Cañón El Mulato (Appendix C, section 16). Both these sections of upper Glen Rose are very similar to the equivalent section at Sierra El Cedral. Very little marl is present and miliolid, *Toucasia*, gastropod lime wackestones and grainstones with some chert are predominant. Between the Sierra El Cedral and the Rincón de María, 20 miles to the south, the Glen Rose changes facies to

Aurora globigerinid lime mudstone and wackestone. This zone of change apparently has a linear trend slightly south of east. The Sierra del Carmen trends northwest from the Rincón de María and crosses the zone of facies change at an angle. Thus, a section measured on Rancho El Melón, 18 miles northwest from the Rincón de María, appears to be intermediate in facies and is shown in this position on the stratigraphic section (Pl. 5).

A tongue of the Aurora lime mudstone facies extends into the Sierra El Cedral and even to Cerro El Palomo, 23 miles farther north, as shown on Plate 5. However, this tongue is arbitrarily cut off and mapped as Glen Rose Formation (Pl. 1). Thus, the facies change is actually spread out over a zone about 43 miles wide north to south (Pl. 5).

At Rancho El Melón (Pl. 5, section 19) the lower 1,320 feet, classed as Aurora, consist predominantly of white to gray, thick-bedded globigerinid lime mudstone to wackestone with some chert in the upper 250 feet. The overlying 830 feet, classed as Glen Rose, consist mostly of thick-bedded, miliolid, *Toucasia* wackestone without marls. As pointed out previously, the complete absence of marl in this section represents the culmination of a trend toward southward marl reduction in the upper Glen Rose. The total Trinity section at Rancho El Melón is about 140 feet thicker than in Sierra El Cedral.

Between Rancho El Melón and the Rincón de María (Pl. 5, section 21) the upper Glen Rose also changes to lime mudstone and is referred to as Aurora limestone. It seems probable that part of the uppermost Glen Rose may become the lower part of the Devils River Formation, as shown on Plate 5. This possibility is suggested by paleontologic evidence based on rudist types (B. F. Perkins, personal communication, 1963) and by simple projection of horizons. The top of the Glen Rose has not been traced into the Rincón de María section. The projection of the base of the Telephone Canyon Formation into the section at the Rincón de María as shown on Plate 5 is the highest position probable and it could be placed as much as 160 feet lower. Therefore, between 125 and 285 feet of the lower Devils River may be Glen Rose equivalent. These same figures apply to the increase in Trinity thickness between the Sierra El Cedral and Rincón de María sections, a distance of 40 miles.

The Aurora in the Rincón de María (Pl. 12, C) is mostly white to gray, thick-bedded, globigerinid lime mudstone or wackestone (Pl. 8, A). Globigerinids were not seen in hand-lens examination of the upper part of this section. It is possible that much of the Aurora will be classed as wackestone rather than mudstone when examined in thin section. Hand-lens examination is inadequate because of the small particle sizes.

Southward from the Rincón de María, the Aurora maintains the same facies but is drastically reduced in thickness and becomes black or very dark gray. In addition, the overlying Fredericksburg and Washita Groups also change to Aurora facies and are inseparable from underlying Glen Rose equivalents. Further discussion of this relation will follow the description of these higher groups.

Two other lithologies in addition to lime mudstone occur within the Aurora. These lithologies occur as beds 2 to 6 feet thick and appear (not necessarily together) perhaps once in every 100 to 200 feet of mudstone section. The first is a finely crystalline, brown dolostone (Pl. 8, B); the second is a mixed lithology, with globigerinid lime mudstone irregularly mixed with lithoclast(?) lime grainstone (Pl. 8, C). The lithoclasts(?) are irregular in shape and size, are made up of globigerinid limestone, and are without sorting or orientation.

Paleontology and age.—Fossils collected from the Glen Rose Formation in the Sierra El Cedral and Cerro El Palomo sections and identified by L. B. Kellum and Santiago Charleston are:[4]

[4] An oral presentation of the "Paleontology of the Glen Rose Formation in Northeastern Coahuila, Mexico" was made by Kellum and Charleston to the Michigan Academy of Science, Arts, and Letters at the 68th Annual Meeting (1964) in East Lansing, Michigan.

Lower Glen Rose at Sierra El Cedral—
Exogyra quitmanensis Cragin (UM 52488, 52493, 51937)
Cymatoceras sp. (UM 52194)
Parahoplites n. sp. (UM 52173)
Hypacanthoplites mayfieldensis Scott (UM 52182, 53183, 52184)
Hypacanthoplites n. sp. (UM 52186, 52185)
Cerro El Palomo—
Lowest beds on Arroyo de la Zorra, correlative with 1,577-foot level on Plate 6—
Gryphaea mucronata Gabb (UM 51967)
Douvilleiceras sp. cf. *D. spathi* Scott (UM 51968)
Hemiaster sp. (UM 51971)
Collections shown on Plate 6—
CP-I-P-A—
Kingena ? sp. (UM 48310)
Tylostoma sp. (UM 48316)
Hemiaster sp. (UM 48317, 48324, 48330)
CP-I-8P—
Rudistid fragment
CP-I-9P—
Limestone containing fragmentary rudistids
CP-II-P-B—
Hypacanthoplites ? sp. cf. *H. mayfieldensis* Scott (UM 48303, 48304, 48313, 48314)
Hypacanthoplites ? sp. cf. *H. bakeri* Scott (UM 48302, 48309)
Knemiceras ? spp. (UM 48332, 48318)
Hemiaster comanchei Clark (UM 48322, 48333, 48334, 48328)
Exogyra quitmanensis Cragin (UM 48634)
CP-II-12P—
Hemiaster sp. (UM 51971)
CP-IV-25P—
Nerinea sp. (UM 48640, 48635)
CP-IV-26—
Enallaster obliquatus Clark (UM 48012)
Porocystis globularis (Giebel) (UM 48643)
Homomya sp. (UM 48642)
Pecten sp. (UM 48641)
CP-IV-P-C—
Gryphaea wardi Hill & Vaughan (UM 48305, 48326, 48329, 48336)
Arctica n. sp. (UM 48307, 48311)
Arctica n. sp. (UM 48312)
Arctica n. sp. (UM 48308)
Cardium n. sp. (UM 48315)
Tapes n. sp. (UM 48323)
Tapes n. sp. (UM 48320)
Protocardia n. sp. (UM 48325)
Liopistha spp. (UM 48301, 48300)
Lucina sp. (UM 48306)
Cucullaea n. sp. (UM 48327)
Porocystis globularis (Giebel) (UM 48331)
Enallaster obliquatus Clark (UM 48335)
Lunatia ? *praegrandis* (Roemer) (UM 48299)
Orbitolina texana (Roemer)

The ammonites collected from the lower part of the Glen Rose *(Parahoplites, Hypacanthoplites,* and *Douvilleiceras)* in the absence of *Dufrenoya* indicate a lowermost Albian age. Critical ammonite zonal fossils have not been found in the upper Glen Rose of this region. However, it is certain that the entire Glen Rose is lower or middle Albian in age since oxytropidoceratid ammonites, middle Albian zonal markers, are found as high as the Sue Peaks Formation of the Washita Group.

The large foraminiferan *Orbitolina texana* is found in great abundance through most of the Glen Rose in northern Coahuila. This fossil is commonly used by stratigraphers in this region as an indication of lower Albian time, as a Glen Rose index fossil, and for regional to local correlation. This *Orbitolina* species, in the broad sense,[5] should not be used in any of these three ways. It occurs abundantly in the Aptian Cupido Formation, has recently been found by the writer in the upper middle Albian Santa Elena Formation of the Del Norte Mountains in Texas, and, as shown on Plate 5, its occurrence is variable even in local areas.

The discovery of the zone of *Corbula* in association with *Porocystis* at Cerro El Palomo and its significance to Glen Rose stratigraphy was noted previously. This find is important because it provides a reliable stratigraphic correlation horizon and demonstrates the similarity of middle Glen Rose depositional environments between northern Coahuila and the Texas outcrops.

INTERPRETATION

The position of the shoreline at the end of the Coahuilan deposition is shown on figure 10 (p. 23). Transgression continued during deposition of the succeeding Trinity Group and by early Glen Rose time the sea covered all of northern Coahuila.

The two formations of the Trinity Group, La Peña and Glen Rose, are very different types. The La Peña is a regionally extensive, thin, black shale. In areal continuity it rivals the well-known Upper Devonian Chattanooga black shale of east-

[5] Douglass (1960) recognized 8 species (7 new) among forms previously assigned to *Orbitolina texana* from Texas, New Mexico, and Arizona.

central United States. The Glen Rose, on the other hand, is almost exclusively a Texas and northern Coahuila formation and contains numerous facies variations.

La Peña Formation

From its characteristic facies of black shale and gray lime mudstones with an abundant ammonite and pelecypod fauna, the La Peña depositional environment is interpreted as open, normal marine waters, well below zones of constant bottom agitation. The prevalent black color and pyritized fossils indicate the presence of abundant organic matter and reducing conditions below the sediment-water interface. The abruptness of the lower contact and the origin of the immense quantities of fine terrigenous clastics (mostly clays) present problems in interpretation.

No evidence of a disconformity at the Cupido-La Peña contact was observed in northern Coahuila. Nor is there any evidence that the underlying Cupido was deposited in appreciably shallower, more agitated waters. To explain the abruptness of this contact it is necessary to consider evidence from adjacent areas.

Farther south, on the southern tip of the Coahuila Peninsula, and nearer to an up-dip limit of the La Peña, Humphrey and Díaz (MS.) state that upper Cupido limestones ". . . are almost always composed of rudistid accumulations and debris, calcarenytes with intraformational breccias, oolites with corals, or by coarse-textured dolomites. The uppermost surfaces of the upper Cupido limestones often present a pitted and scalloped appearance indicative at least of strong submarine, if not subaerial, erosion." To the east, in Southwest Texas, D. L. Amsbury (personal communication, 1964) reported that the upper part of the Sligo (= Cupido) Formation, in up-dip areas, is usually either a cross-bedded, oolite lime grainstone or other very shallow-water to inter-tidal limestone and that the contact with the overlying Pearsall (= La Peña) Formation is disconformable. In the Cañón de la Boca, of the Sierra de la Silla, south of Monterrey, Nuevo Leon, the entire Cupido, along with all the Lower Cretaceous, is a basinal, globigerinid lime mudstone facies. Here, the contact with the La Peña shales is not disconformable or sharp but graditional.

Considering the above evidence, it seems probable that near the end of Cupido deposition, a regression was initiated and the principal zone of wave and current action moved seaward, thus accounting for the lithologic character of the upper Cupido in up-dip areas. Continued regression exposed up-dip regions, producing the disconformity characteristics noted there. At the same time the zone of bottom agitation by currents and waves moved proportionately farther seaward producing a depositional hiatus without disconformity, as is observed in northern Coahuila. In basinal areas, the bottom was not affected by this relatively minor regression and a gradational contact, as is found in the Sierra de la Silla, would be expected.

In view of the succeeding regional influx of fine terrigenous clastics, it seems probable that the reason for this regression was either epeirogenic uplift of continental areas across the entire southern United States and western Mexico or a eustatic drop in sea level. Broad, gentle uplift and slight basinward tilting of this vast region would have rejuvenated stream gradients across this extensive source area to produce the required amounts of fine terrigenous clastic without greatly increasing quantities of coarser materials derived from local sources. A simple eustatic change in relative land-sea elevations could have produced the upper Cupido facies and sharp to disconformable contact relations but not necessarily have increased the supply of fine clastics unless climatic change was involved. The tripartite nature of the La Peña (shale to limestone to shale) may indicate at least minor repetition of the events described above.

The absence of coarse, basal La Peña transgressive deposits is to be expected for two reasons: (1) because of the low surface slopes only small amounts of coarse terrigenous clastics were introduced, and (2) since the sea was flooded with fine clays, production of clastics by lime-secreting marine organisms was virtually halted. Deposition of the clays began first in basinal areas where the contact is gradational. As transgression moved the shoreline and zones of bottom disturbance by waves and currents inland, clays were deposited farther shoreward; first, directly on upper Cupido surfaces which had not been exposed but kept clean by currents, and, second, on the disconformity surface which was free of sediment. In places, such as in Central Texas, the Hammett shales (= La Peña) have overstepped the Sligo (= Cupido) Limestone in the subsurface and at the outcrop rest on older basal Mesozoic conglomerates of the Sycamore (Lozo and Stricklin, 1956, p. 69).

From the Sierra El Cedral southward (Pl. 5, section 15 to section 25) and northwestward (to Pico Puerto Rico; fig. 7, section 4) the La Peña does not appear to vary appreciably. However, from the same place northeast to Chupadero No. 1 (Pl. 5, section 15 to well C) the lower shale becomes very sandy and the middle limestone thicker. This modification is probably the result of proximity to the same source of terrigenous clastics that provided the middle Cupido sand and silts (p. 23).

Glen Rose Formation and Aurora Lime Mudstone

The typical Glen Rose of northern Coahuila, particularly as exposed at Cerro El Palomo, was deposited under almost identical environmental conditions as the Glen Rose of Central Texas. Some of the same horizons can be recognized in both areas. The characteristic stairstep topographic expression of the Glen Rose results from alternations of marly layers and more resistant limestone ledges which are in turn due to periodic variation in the amount of fine terrigenous clastics deposited. The shoreline during most of Glen Rose time was as much as 75 to 100 miles to the north, in Texas. However, the abundant clam-bored surfaces in the Cerro El Palomo and Cañón El Cíbolo sections are probably evidence that the shoreline varied widely exposing the sea bottom and allowing cementation of sediment. On the other hand, these cemented, bored surfaces may be analogus to those observed to be forming at the present time in the shallow waters of the Persian Gulf (E. A. Shinn, personal communication, 1969). In either case, it is inferred that the sea bottom had but very little seaward slope and that waters were comparatively shallow.

The variations noted in the lower Glen Rose between Sierra El Cedral and Chupadero No. 1 (Pl. 5, section 15 to well C) probably resulted from proximity of the latter to the same source of terrigenous clastics noted in discussion of the stratigraphy of the Cupido and La Peña Formations (pp. 23, 31). The sandy marl at the base of the Cerro El Palomo section probably came from there also. This source area was probably located north of Pemex Chupadero No. 1 and was apparently covered by the lower Glen Rose sea since terrigenous clastics do not reappear in later sediments in this area.

The depositional environment of the typical Glen Rose seems to have been a broad, very shallow-water, flat sea bottom. In most areas, there was good circulation but waters were too shallow to permit large waves and the development of strong, well-defined currents. The bottom was probably covered extensively with vegetation which supported the large population of miliolids and *Orbitolina*. At times the waters were clear enough for filter-feeding rudists to thrive and at other times they were too muddy for these organisms.

This general depositional environment which produced the typical Glen Rose facies existed throughout the time of Glen Rose deposition in a band some 75 to 100 miles wide, extending east across northern Coahuila and Southwest Texas, thence northeast through Central Texas. Glen Rose isopach lines are parallel to this band and show a gradual south to southeast thickening. They are considered to parallel depositional strike. Thus, the north-south part of the stratigraphic section shown on Plate 5, section 15 to section 25, is considered to be a depositional dip section, whereas the east-west part, from section 15 to well C, is a strike section. In contrast to the persistence of the Glen Rose in a broad band parallel to depositional strike, the dip section shows strong lithologic, faunal, and thickness variations, although these changes are spread out over a distance of some 50 miles.

The following descriptive summary is pertinent to an interpretation of the changes shown on Plate 5. Insufficient data are available to tell much about the lower Glen Rose fossiliferous, gray shales at Sierra El Cedral except that somewhere between there and Rancho El Melón (section 19) they are replaced by globigerinid lime mudstone. A tongue of these lime mudstones extends northward, by onlap of Glen Rose lithologies, to and beyond Cerro El Palomo (section 12). Subsequently, the area of typical Glen Rose deposition expanded southward by progressive offlap over the Aurora lime mudstone tongue. Considering the north-south changes within any particular upper Glen Rose horizon, there is first a gradual southward decrease in fine terrigenous clastics and a corresponding increase in limestone which culminates in a rudist or rudist-stromatoporoid biostrome and, second, a rather abrupt facies change southward to globigerinid lime mudstones of the Aurora facies. Farther south the mudstone interval thins greatly.

These changes are interpreted as the result of deposition across a transition of sub-sea topography from shallow water in Glen Rose depositional areas to much deeper water in areas of Aurora lime mudstone deposition. At the beginning of Glen Rose deposition the rate of subsidence was more rapid and resulted in a progressive deepening of water from south to north, and deeper-water globigerinid muds of the Aurora facies onlapped northward across shallower-water lower Glen Rose sediments. When the rate of subsidence slowed, the area of shallow-water sedimentation expanded seaward (offlap) over deeper-water deposits. The average slope of the offlap boundary is about 30 feet per mile through the upper Glen Rose but probably varies areally. As the edge of shallow-water deposition moved seaward, sources of terrigenous clastics were farther away and the sea water became clearer. Rudist banks, bioclastic bars, and associated littoral deposits developed more rapidly, forming a sharper topographic break. Near the end of Glen Rose deposition, the topographic break, that had developed at the margin of facies change to Aurora lime muds, was some 40 to 50 miles south of its original position. By the end of Glen Rose time it supported a flourishing growth of coral, rudist, and stromatoporoid reefs or banks now exposed in the Rincón de María and Sierra de San Gerónimo. Fore-reef talus beds were not observed here in the transitional area between the reef section and the underlying Aurora lime mudstones. Therefore, it is most likely that a seaward reef-escarpment did not exist at this time. The sea bottom north of the shelf-edge was relatively flat but southward it sloped away at perhaps 1 to 2 degrees. Thus, the topography in northern Coahuila at the end of Glen Rose time consisted of two elements: (1) a relatively flat, shallow-water shelf that extended from the Sierra de San Gerónimo area northward for about 200 miles; and (2) a slope from the shelf-edge in the Sierra de San Gerónimo southward of perhaps 100 feet per mile to bathyal depths in the Cañón de la Alameda area, a distance of about 20 miles, where black lime muds were being deposited. Data are not yet available to demonstrate detailed relations between the inferred shelf-edge and the basinal area to the south.

The exact trend of the Glen Rose shelf-edge cannot be determined from the outcrop data presented here. Westward from the Rincón de María critical outcrops may be available but have not been investigated. Eastward, from the Sierra de San Gerónimo, all Lower Cretaceous formations are in the subsurface. About 50 miles eastward, Petroleos Mexicanos has drilled a series of wells along the axis of the Peyotes anticline (fig. 5). Analysis of sample data indicates the presence of a Glen Rose shelf-edge and probably reef deposits a few miles southeast of where the Piedras Negras–Nueva

Rosita highway crosses the fold. Eastward continuation of a line from the outcrop shelf-edge through this subsurface position connects with the "Deep Edwards" or Stuart City (Winter, 1962, p. 85) reef trend and shelf-edge in South Texas as shown on figure 17 (p. 48).

Fredericksburg and Washita Groups

REGIONAL RELATIONSHIPS AND NOMENCLATURE

The Fredericksburg and Washita Groups were named by R. T. Hill (1891) to include formations of the Comanche Series in Central Texas (table 2). Subsequently, Hill and Vaughan (1898a, b), and Vaughan (1900), without adequate proof of correlation, applied the formation names Comanche Peak, Edwards, Fort Worth (=Georgetown), Del Rio, and Buda to rock units of similar age in the southern Ed-

TABLE 2. *Generalized geologic column of the Fredericksburg and Washita Groups of Central Texas.* Modified after Lozo and Smith (1964, p. 287, fig. 2).

<table>
<tr><th colspan="4">TIME-ROCK UNITS</th><th>ROCK UNITS</th></tr>
<tr><th colspan="2">Standard Sequence</th><th colspan="2">Provincial Sequence</th><th>Central Texas Formations</th></tr>
<tr><td rowspan="2">Upper Cretaceous</td><td rowspan="2">Cenomanian</td><td rowspan="8">Comanche Cretaceous</td><td rowspan="5">Washita</td><td>Buda</td></tr>
<tr><td>Del Rio</td></tr>
<tr><td rowspan="6">Lower Cretaceous</td><td rowspan="6">Albian</td><td>(Main Street)</td></tr>
<tr><td>Georgetown</td></tr>
<tr><td>(Kiamichi)</td></tr>
<tr><td rowspan="3">Fredericksburg</td><td>Edwards</td></tr>
<tr><td>Comanche Peak</td></tr>
<tr><td>Walnut</td></tr>
</table>

wards Plateau region (fig. 2). Later, Udden (1907) coined a new name, Devils River Limestone, to apply to the same rocks for which Hill and Vaughan used Comanchee Peak, Edwards, and Fort Worth. Imlay (1944, 1945) used Edwards, Kiamichi, Georgetown, Del Rio, and Buda (Walnut and Comanche Peak were included in the Edwards) in the subsurface of South Texas and in the Serranía del Burro (here he also recognized a separate Walnut Formation but not a Comanche Peak). The unit he called Kiamichi had previously been informally called McKnight shale by South Texas subsurface geologists. During all this time, various other workers in South and Southwest Texas, involved in oil exploration, groundwater studies, etc., were using various combinations of names that suited their convenience.

Recently, Lozo and Smith (1964) published an extensive revision of Fredericksburg-Washita nomenclature applicable to Southwest Texas. Lozo (*in* Lozo and Smith, 1964, pp. 288–289) tabulated the usage of names by all previous investigators to illustrate the inconsistency and ambiguity of nomenclature that prevailed throughout the region. Figures 11, 12, and 13 (in pocket) taken from figures 6–8 of that report and based on field investigations by this writer, provide the stratigraphic framework and facies analysis on which the proposed revision was based. As shown on these diagrams, the Fredericksburg and lower Washita Groups are a genetically related series of formations, disconformably overlie the Trinity (Glen Rose), vary from 500 to 700 feet thick, and (Lozo and Smith, 1964, p. 291):

> . . . can be divided geographically into three geologically distinct areas—northern, central, and southern (Figure 6)—and the rocks in each area are divisible into distinct formations (Figure 7). The northern area sequence, divisible by a disconformity into two formations, is characterized by ease of subdivision, by distinctive faunal assemblages, and by a north-south facies change from marly mudstones to predominantly rudist-miliolid lime wackestones, mudstones, and minor grainstones which constitute the central area. The boundary between the central and southern areas is a line of abrupt facies change from the single mass of indivisible limestones to three formations of variable limestone facies (Figure 8). This line of facies change marks the northeastern boundary of the Maverick basin (Winter, 1961a-c),

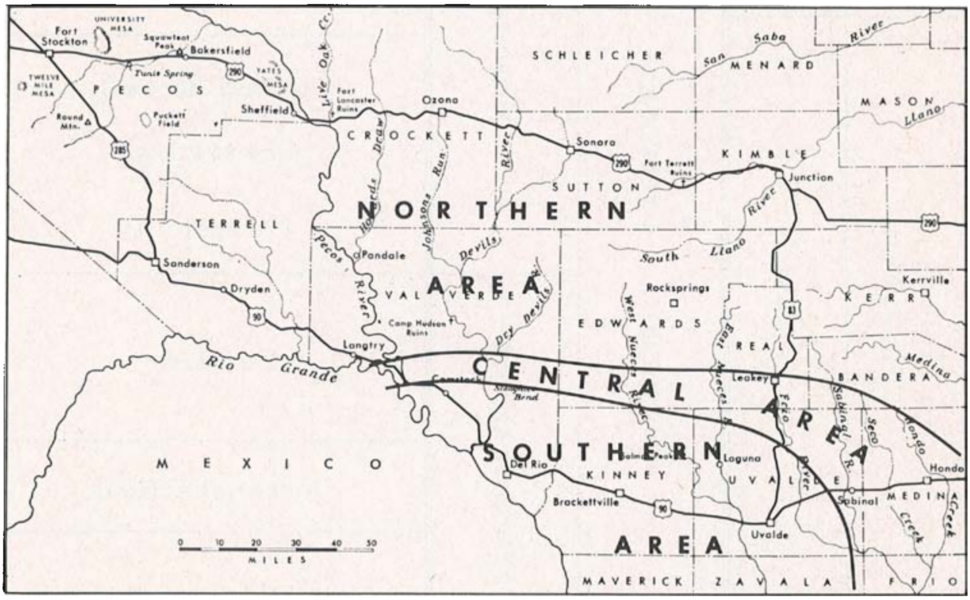


FIG. 11. Map of geologic provinces in the Edwards Plateau. (Modified after Lozo and Smith, 1964, p. 292, fig. 6.)

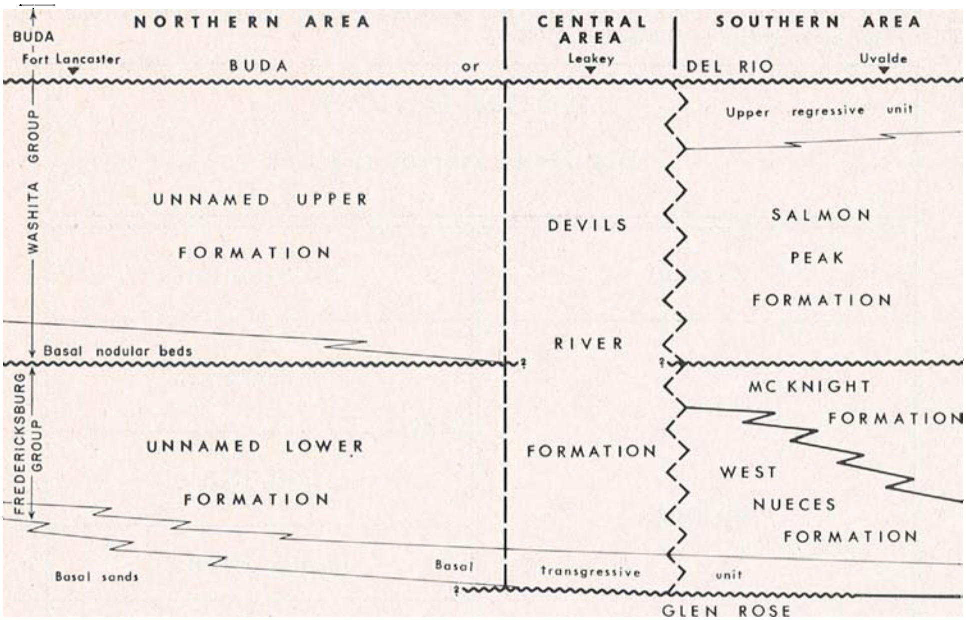


FIG. 12. Generalized northwest-southeast stratigraphic section of Devils River Formation and equivalents, Edwards Plateau. (Modified after Lozo and Smith, 1964, p. 292, fig. 7.)

and the three formations are characteristic of this basin.

The upper contact of this group of closely interrelated formations is a major unconformity exhibiting both truncation of the underlying beds and two separate onlaps of the overlying formation, the Del Rio and the Buda. In the southern area, 80–90 feet of Del Rio clays plus a basal 30 feet of interbedded clay and limestone overlies the unconformity. Northward these beds thin by onlap and truncation. Beyond the onlap-plus-truncation limit of the Del Rio, the Buda Limestone rests on the unconformity, and this relationship is present over most of the northern area investigated.

The recommendations made by Lozo and Smith are as follows:

(1) The names Walnut, Comanche Peak, Edwards, and Georgetown should be restricted in usage to Central and North Texas.
(2) The name Devils River should be retained but restricted to the central area as shown on figures 11–13.
(3) Del Rio and Buda should be retained as presently used.
(4) In the southern area (Maverick basin) the name West Nueces was proposed to replace Walnut and Comanche Peak and Edwards, and Salmon Peak was proposed to replace Georgetown.
(5) In the northern area, two formational units were recognized but nomenclature proposals were withheld pending additional field work.

The formations of the central and southern areas, recognized by Lozo and Smith, have been extended by the present study into the Serranía del Burro and southern Sierra del Carmen of northern Coahuila. Their areal distribution is shown on Plate 1 and figure 14.

In the Big Bend National Park in Texas, Maxwell et al. (1967) subdivided the Fredericksburg-Washita Groups as shown in table 3. Their basal Telephone Canyon Formation has been extended from the Rio Grande east and south over most of the area shown on the geologic map (Pl. 1). The overlying Del Carmen, Sue Peaks, and Santa Elena Formations have been extended as far east in Coahuila as the western limit of the Devils River Formation (central area, fig. 14) and north of the central Sierra del Carmen.

TABLE 3. *Formations of the Fredericksburg and Washita Groups in the Big Bend National Park, West Texas, as recognized by Maxwell et al. (1967).*

ROCK UNITS Big Bend National Park	
Group	Formation
Washita	Buda
	Del Rio
	Santa Elena
	Sue Peaks
Fredericksburg	Del Carmen
	Telephone Canyon

Recent surface work by the writer (unpublished report for Shell Development Company) between the Big Bend National Park and western Edwards Plateau has established that the Del Carmen Formation of Maxwell et al. (1967) is the "unnamed lower formation" in the northern area of Lozo and Smith (fig. 12) and that the Sue Peaks and Santa Elena comprise the "unnamed upper formation." The nomenclature proposed by Maxwell et al. is used here even though it is recognized that future work in northern Chihuahua and in Texas west of the Big Bend National Park may necessitate revision or abandonment of one or all of these new names.

Southeastward from the central Sierra del Carmen, formations of the Fredericksburg and lower Washita change facies to lime mudstones and become thinner as does the Glen Rose, between the Rincón de María and Cañón de la Alameda. In the Sierra del Orégano (in the extreme southwest part of the area mapped on Pl. 1) all of the upper Trinity (Glen Rose)—lower Washita (Santa Elena) is lime mudstone with the exception of an ammonite-bearing shale member equivalent in age to the lower Sue Peaks. This shale interval has been traced over most of the area covered by the paleogeographic Sabinas Gulf by Humphrey and Díaz (MS.) and referred to by

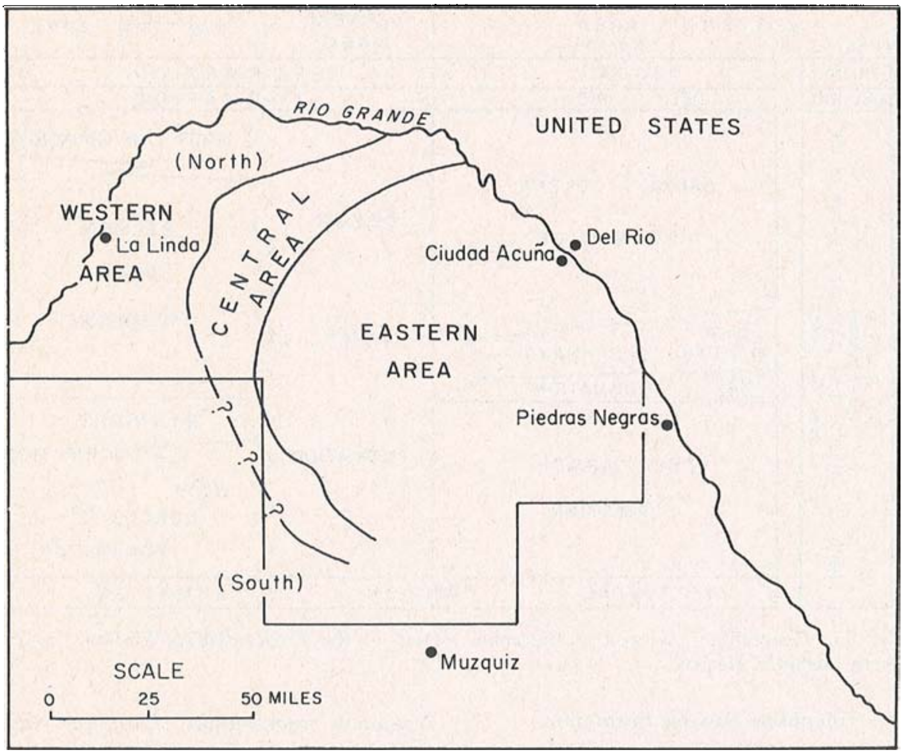


FIG. 14. Distribution of geologic province areas within the Fredericksburg-Washita groups in northern Coahuila, Mexico.

them as Kiamichi. They referred to the underlying indivisible upper Trinity and Fredericksburg as Aurora and to the overlying lime mudstone plus Del Rio and Buda as Washita Group undivided (Humphrey, 1956, p. 33). In the absence of a Kiamichi shale, as in Cañón de la Alameda (Pl. 5, section 24), the entire upper Trinity—lower Washita section was referred to as Aurora (Díaz, personal communication, 1962), although on correlation charts Humphrey and Díaz (Humphrey, 1956, pp. 32–34) indicated the Washita equivalents.

In the report, and on the geologic map (Pl. 1), the term "Aurora" is used informally to designate the lime mudstone equivalents of the upper Trinity—lower Washita formations. Where present, as in the Sierra del Orégano, the shaly lower Sue Peaks equivalents are mapped as a middle shale member of the Aurora (*Kars*, Pl. 1).

Northeastward from Cañón de la Alameda and Sierra del Orégano, the Aurora thickens rapidly and changes facies to Glen Rose limestone and to the Devils River limestones of the central area (Pls. 5 and 9).

Figures 14 and 15 summarize the distribution of geologic provinces, stratigraphic relations, and nomenclature used here for the formations of the Fredericksburg and Washita Groups in northern Coahuila. Since the Devils River Formation trends generally north-south through this area, the geographic subdivisions are referred to as western, central, and eastern.

DESCRIPTION

The following descriptions conform to the three-part geographic subdivision (western, central, and eastern) with the exception of the Telephone Canyon, Del Rio, and Buda Formations which are present in all three areas.

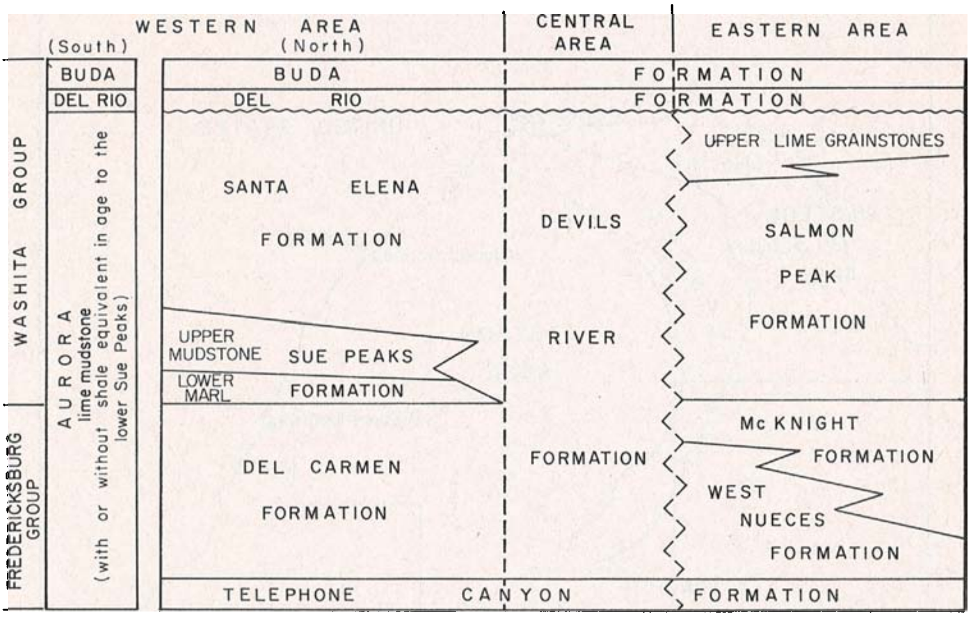


FIG. 15. Generalized east-west stratigraphic section of the Fredericksburg-Washita Groups in northern Coahuila, Mexico.

Telephone Canyon Formation

Occurrence, lithology, and thickness.—The type locality of this formation is in Texas, in Telephone Canyon about 7½ miles west of La Linda, Coahuila. From here the formation has been traced eastward across the Rio Grande, thence southeastward through the Serranía del Burro. The formation plunges underground around the northern and southeastern limits of the Serranía del Burro uplift (Pl. 1). The Telephone Canyon Formation can also be traced southeastward along the northeast escarpment of the southern Sierra del Carmen until it terminates by facies change to lower Devils River limestone (Pls. 5 and 9).

The formation averages about 130 feet in thickness. Both upper and lower contacts are transitional and arbitrary. However, at Cañón San Rosendo (Pl. 10, section 2) the top of a nodular limestone unit near the base of the formation has been extensively bored by clams. The characteristic lithology is of thick, receding beds of yellowish, fossiliferous marl and nodular marly lime wackestone, separated by thin *Gryphaea* lime packstones and shell fragment wackestones. *Exogyra texana*, *Gryphaea*, *Lunatia*, various burrowing clams, and echinoids are common to abundant throughout.

Near the southeastern limit of the Telephone Canyon Formation in the Serranía del Burro the facies is somewhat different. There is much less clay and the lithology is mainly nodular, marly lime wackestones with the same fauna as noted above. This facies of the Telephone Canyon Formation was noted by W. R. Fehr (1930) in the vicinity of Rancho El Trébol and referred to by him as the Trebol facies. The section in Cañón Las Calabazas (Pl. 5, section 17) is similar to those observed by Fehr.

In the section at Rancho El Melón (Pl. 5, section 19) near the southeastern limit of the formation in the Sierra del Carmen, the Telephone Canyon Formation is about 80 feet thick and contains only very minor amounts of marl (Trebol facies). From here southeastward along the escarpment the formation progressively thins or changes to limestone and within 2 to 3 miles disappears into the massive Devils River limestone.

Paleontology and age.—Fossil collections made from various localities in the Telephone Canyon Formation have been identified by L. B. Kellum as follows:

Exogyra texana Roemer (UM 51923, 51938, 51927, 51955, 51972, 51974, 51978, 52079)
Gryphaea mucronata Gabb (UM 51982, 51928, 51939, 51939, 51956, 51974, 51979, 52078)
Ostrea sp. (UM 52513)
Pecten subalpinus Böse (UM 52667)
Pecten occidentalis Conrad (UM 51980, 51940, 51958)
Cyprimeria texana (Roemer) (UM 51941)
Cardium sp. cf. *C. congestum* Böse (UM 52080)
Lima sp. (UM 52083, 51932)
Pteria pedernalis Roemer (UM 51930)
Tapes aldamensis Böse (UM 51959)
Tapes guadalupae Böse (UM 51960)
Anchura ? sp. (UM 51973, 51946)
Astarte ? sp. (UM 51977)
Pholadomya sp. cf. *P. sanctisabae* Roemer (UM 51942)
Pholadomya shattucki Böse (UM 51926)
Protocardia texana (Conrad) (UM 52508)
Cucullaea sp. (UM 51962)
Nucula ? sp. (UM 52512)
Meretrix ? sp. cf. *M. fortworthensis* Perkins (UM 51943)
Tylostoma sp. aff. *T. regina* (Cragin) (UM 51945)
Turritella sp. (UM 51933)
Nerinea ? sp. (UM 51934)
Pleurotomaria sp. (UM 52085)
Kingena sp. (UM 52086)
Phymosoma texanum (Roemer) (UM 51947)

None of these fossils has a sufficiently restricted stratigraphic range to determine the exact age of the Telephone Canyon Formation. They comprise a typical middle Albian fauna and are characteristic of the Walnut Formation of Texas. In all probability the Telephone Canyon Formation is about the same age as the Walnut and was deposited under similar environmental conditions.

Western Area Sequence

The three formations characteristic of the northern part of this area, Del Carmen, Sue Peaks, and Santa Elena, have been mapped to the west (in Texas) by Maxwell et al. (1967) throughout the Big Bend National Park and by B. E. St. John (1965, 1966) through the Black Gap game preserve (northeast of the Park and along the Rio Grande). Their distribution in northern Coahuila is shown on Plate 1 and figure 14. The Aurora, characteristic of the southern part of the western area, has been mapped only in the Sierra Hermosa de Santa Rosa and Sierra del Orégano (Pl. 1).

Del Carmen Formation

This formation overlies the Telephone Canyon and averages about 460 feet thick throughout the northern Serranía del Burro (Pl. 10, section 2; Pl. 11) and the Sierra del Bravo. To the west, across the Rio Grande, St. John (1965, p. 29) measured 455 feet of Del Carmen Formation. To the south, Santiago Charleston reported (personal communication) that the formation is only 270 feet thick at Cerro de Aguachile and 315 feet at Pico Puerto Rico.

The contact between the Del Carmen and Telephone Canyon Formations is transitional. The basal 10–20 feet of the Del Carmen usually consist of slightly nodular, medium-bedded, gray, miliolid, shell fragment lime wackestones. The remainder of the formation consists of thin to medium-bedded, miliolid, gastropod, *Toucasia* wackestone to grainstone commonly with thin layers or nodules of chert (Pl. 8, D-F). In the Black Gap (St. John, 1965, 1966)—San Rosendo canyon area two or more thick layers of caprinid rudist biostromes and bioherms are found within the sequence. Bioherms have not been found in this interval farther south or north.

Sue Peaks Formation

In the type area, R. A. Maxwell (oral communication, 1963) considered the Sue Peaks Formation to consist of a lower fossiliferous marl unit and an upper unit of limestone. Both units weather to form a long concave slope above cliffs of Del Carmen limestones and below cliffs of rudist-bearing Santa Elena limestone (Pl. 11, B). In the Black Gap preserve, St. John (1965, 1966) recognized both horizons but mapped only the lower marl as Sue Peaks, including the overlying unit with the Santa Elena limestone. Here, the original intent of Maxwell et al. (1967) has been followed and the Sue Peaks considered to consist of the entire slope-forming unit.

Occurrence, lithology, and thickness.—In Cañón San Rosendo (Pl. 10, section 2) the Sue Peaks is in sharp but conformable contact with the Del Carmen Formation and is about 236 feet thick. The lower marl unit is about 66 feet thick and consists of thick, receding, yellowish nodular marls with thin interbeds of *Gryphaea* lime packstones and wave-rippled small clam and gastropod lime packstones. Ammonites, *Lunatia*, various burrowing clams, *Gryphaea*, and echinoids are common throughout. The upper unit of the Sue Peaks is about 170 feet thick and consists of medium- to thick-bedded lime mudstone with abundant chert in the upper part. North of the Rio Grande the writer has observed abundant pelagic foraminifera (globigerinids) within equivalent mudstones.

To the south, in Cañón Ceferino (fig. 7, section 3) Santiago Charleston reported the Sue Peaks as 277 feet thick (79 feet lower unit; 198 feet upper unit). The lithology at this locality is very similar to that described above except for a 5-foot thick unit of dark gray, thin-bedded miliolid wackestone at the base. Westward, across the Rio Grande, the lower Sue Peaks as measured by St. John (1965, 1966) can almost be matched bed-by-bed with the Cañón Ceferino section.

Southeastward, the upper Sue Peaks lime mudstone rapidly changes facies to a rudist-bearing limestone. On the northwest wall of Cañón El Cíbolo (Pl. 11, C), the upper unit is not present and the lower unit has thinned to about 55 feet. Across the canyon, on the southeast wall (Pl. 11, A), the lower Sue Peaks thins and completely disappears northeastward.

Southwestward from the point where the Sue Peaks lenses out in Cañón El Cíbolo, the lower Sue Peaks thickens rapidly and within 4 miles (fig. 7, section 7) attains a thickness of about 105 feet. This is about 25 feet thicker than sections previously described to the northwest, and in addition the facies has changed somewhat. Here the lower 19 feet consist of thin-bedded, gray lime mudstone and wackestone with thin partings of marl and lenses of chert. The remainder of the unit consists of thick nodular, green to gray marls with thinner lime mudstone and wackestone interbeds. Burrowing clams, gastropods, and echinoids are common (as to the northwest) but ammonites and *Gryphaea* are rare. Also the thin, wave-rippled, small clam and gastropod packstones that were common to the northwest are *not found* here.

At Puerto Prieto (fig. 16, section 6) 8 miles west of Cañón El Cíbolo, the lower Sue Peaks has thickened to about 227 feet but the facies is the same. The upper Sue Peaks is also developed here and is about 286 feet thick (compared to 200 at Cañón Ceferino) and in the same facies as described previously—lime mudstone with chert. Comparison of the Puerto Prieto facies of the Sue Peaks with the more typical San Rosendo section is shown on figure 16.

From Puerto Prieto southward to Cerro de Aguachile and the Pico Puerto Rico section the facies of the Sue Peaks remains the same but the thickness varies. Santiago Charleston (personal communication, 1965) measured 550 feet of Sue Peaks at Aguachile (lower unit, 210 feet; upper unit, 330 feet) and a lower Sue Peaks thickness of 165 feet at Pico Puerto Rico. It is important to note here for interpretations to follow that in these areas of thick lower Sue Peaks development, the underlying Del Carmen Formation is from 135 to 180 feet thinner than it is to the northwest where the lower Sue Peaks is thinner by about the same amount (fig. 16).

Paleontology and age.—Fossils collected in both the normal and Puerto Prieto facies of the Sue Peaks Formation and identified by L. B. Kellum are:

Normal facies—
- Pelecypoda, 19 species—
  - *Exogyra texana* Roemer (UM 52504)
  - *Gryphaea corrugata* Gabb (UM 51993)
  - *Ostrea* sp. (UM 52070, 52049)
  - *Protocardia texana* (Conrad) (UM 52030, 52031)
  - *Cyprimeria texana* (Roemer) (UM 52032)

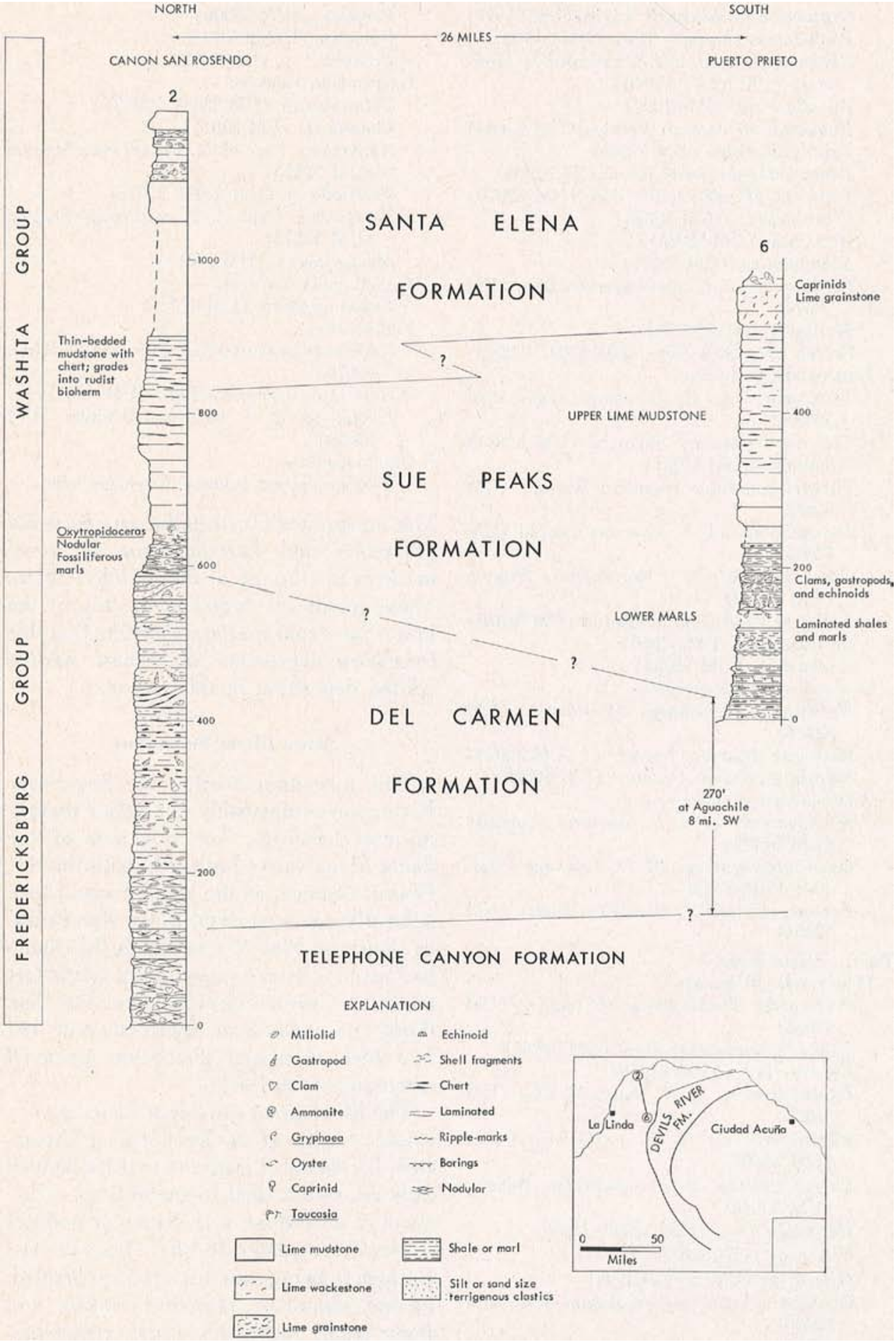


FIG. 16. Correlation diagram showing thickening and facies change in the lower Sue Peaks Formation.

Cyprimeria washitaensis Adkins (UM 51991)
Pholadomya shattucki Böse (UM 51988)
Pholadomya ? sp. aff. *P. sanctisabae* (Roemer) (UM 52041, 52040)
Cucullaea sp. (UM 51992)
Homomya tarrantensis Perkins (UM 52669)
Tapes gabbi Böse (UM 52043)
Tapes chihuahuaensis Böse (UM 52065)
Tapes sp. aff. *aldamensis* Böse (UM 52676)
Pleuromya sp. (UM 52045)
Arctica sp. (UM 52046)
Spondylus sp. (UM 52047)
Cardium sp. cf. *C. subcongestum* Böse (UM 52679)
Mytilus sp. (UM 52058)
Pecten irregularis Böse (UM 52042, 52029)

Gastropoda, 9 species—
Tylostoma ? sp. cf. *T. regina* Cragin (UM 52036)
Tylostoma elevatum Shumard (UM 52681)
Lunatia sp. (UM 52051)
Turritella seriatim-granulata Roemer (UM 52683)
Turritella sp. aff. *T. leonensis* Conrad (UM 52684)
Apporrhais sp. cf. *A. tarrantensis* Stanton (UM 52682)
Natica sp. cf. *N. collina* Conrad (UM 52680)
Cerithium sp. (UM 52050)
Anchura sp. (UM 52053)

Echinodermata, 3 species—
Heteraster mexicanus (Cotteau) (UM 52038)
Heteraster texanus (Roemer) ? (UM 52076)
Salenia mexicanus Schluter (UM 52686)

Ammonoidea, 3 species—
Pervinquieria sp. cf. *P. leonensis* (Conrad) (UM 51995)
Oxytropidoceras sp. aff. *O. belknapi* (Marcou) (UM 52039)
Engonoceras sp. cf. *E. stolleyi* Bohm (UM 52504)

Puerto Prieto facies—

Pelecypoda, 16 species—
Protocardia Denisonensis (Cragin) (UM 52064)
Tapes chihuahuaensis Böse (UM 52065)
Cyprimeria sp. (UM 52066)
Pholadomya sp. cf. *P. shattucki* Böse (UM 52007)
Pholadomya sp. cf. *P. toribioensis* Jones (UM 52008)
Pholadomya sp. cf. *P. sanctisabae* Roemer (UM 52023)
Homomya ? sp. (UM 52068, 52069)
Ostrea sp. (UM 52070)
Astarte sp. (UM 51995–51999)
Cardium sp. cf. *C. subcongestum* Böse (UM 52000)
Isocardia sp. cf. *I. washita* Marcou (UM 52003)
Meretrix sp. (UM 52004)
Nucula sp. (UM 52005)
Pecten sp. (UM 52006)
Pinna sp. (UM 52009)
Crenella ? sp. (UM 52022)

Gastropoda, 6 species—
Tylostoma sp. (UM 52071, 52072)
Lunatia sp. (UM 52011)
Apporrhais ? sp. cf. *A. tarrantensis* Stanton (UM 52073)
Turritella sp. (UM 52074, 52075)
Teinostoma ? sp. cf. *T. austinensis* Stanton (UM 52013)
Margarites sp. (UM 52012)

Cephalopoda, 1 species—
Engonoceras sp. (UM 52027)

Echinoidea—
Heteraster texanus (Roemer) ? (UM 52017, 52076)
Heteraster bravoensis Böse (UM 52077)
Salenia sp. cf. *S. mexicana* Schluter (UM 52019)

Brachiopoda—
Two specimens, genus and species indet.

The ammonites *Oxytropidoceras belknapi* (Marcou) and *Pervinquieria* are zonal markers for the top of the middle Albian. These fossils are found at the top of the lower Sue Peaks marls, suggesting that this formation represents uppermost middle Albian deposition in this region.

Santa Elena Formation

This formation overlies the Sue Peaks Formation conformably but rather sharply in most localities. The thickness of the Santa Elena varies indirectly with the Sue Peaks inasmuch as the lower Santa Elena is locally age equivalent to the Sue Peaks, as shown on Plate 10. In Cañón El Cíbolo the Santa Elena is more than 1,100 feet thick, at Cañón Ceferino about 808 feet thick, and at Cerro de Aguachile only 495 feet thick (Santiago Charleston, personal communication, 1963).

The lithology of the Santa Elena is very similar to that of the Del Carmen Formation. It consists of medium- to thick-bedded miliolid, rudist, shell fragment lime wackestone to grainstone with lenses or nodules of chert throughout. It differs from the Del Carmen in being somewhat thicker bedded, having abundant radiolitid rudists and fewer small gastropods. Large rudist bioherms are common and are usually surrounded by thin-bedded mudstones with abundant thin chert layers.

Aurora Lime Mudstone

That part of the Aurora equivalent in age to the Fredericksburg and lower Washita to the north has not been measured or described in detail. Generalized distribution of the facies is shown on figures 17 and 18. Santiago Reynolds measured the thickness of the total Aurora in Cañón de la Alameda. Díaz, Reynolds, the writer, and others reconnoitered this section and the outcrops in the Sierra del Oregano.

In Cañón de la Alameda, the Aurora is as described previously under the section on the Glen Rose—about 1,700 feet of dark gray or black, thick-bedded globigerinid lime mudstones with widely spaced, medium beds of brown dolomite and mixed mudstone and lithoclast (?) lime grainstone. In addition, the upper part of the section contains abundant chert in nodules and layers.

In the Sierra del Orégano, 40 to 50 feet of black shales with oxytropidoceratid ammonites (equivalent in age to the lower Sue Peaks) make a prominent slope break within the Aurora, and thin shale beds are found through the overlying 200 to 250 feet. Other differences here are that the upper Aurora is thin to medium bedded (rather than thick bedded as in Cañón de la Alameda) and beds of dolomite and mixed lithologies were not noted.

Central Area Sequence

The Fredericksburg—lower Washita Groups within this area are represented by two formations: the Telephone Canyon, previously described, and the Devils River Formation. A boundary between the two groups cannot be located and the definition of the central area and Devils River Formation is based upon this concept of indivisibility following the recommendations of Lozo and Smith (1964, figs. 6 and 7; figs. 11 and 12 of this paper).

Devils River Formation

The western boundary of the Devils River is considered to be the eastern limit of the Sue Peaks Formation to the north and the zone of facies change between the Devils River and Aurora on the south. This boundary can actually be seen only in the northern Serranía del Burro (Pl. 11, A). Elsewhere, surface exposures are not available and the contact shown (Pl. 1 and fig. 14) is arbitrarily placed between the Devils River and formations characteristic of the eastern area (figs. 14 and 15).

Thickness of the Devils River Formation ranges from more than 1,600 feet in the north to about 2,200 feet in the south. Lithologies and paleontologic character also change from north to south, and these changes are very important to paleoenvironmental interpretations.

In the north, as in Cañón El Cíbolo (Pl. 10, section 8) the Devils River is adequately described as Santa Elena resting on Del Carmen without the intervening Sue Peaks Formation. A practiced observer can recognize whether a particular outcrop is age equivalent to either the Santa Elena or Del Carmen in most instances by looking for the differences noted in the last paragraph describing the Santa Elena Formation (these differences are summarized on Pl. 10). However, subdivision for mapping purposes is not practicable.

Southward for some 50 to 60 miles, as far as the Santo Domingo and Ventana de la Encantada sections (fig. 7, sections 14 and 18), no major changes occur in the Devils River. However, this far south it is doubtful that the Del Carmen equivalents can be distinguished from Santa Elena equivalents, and the total thickness has probably increased.

South of the Rancho El Melón section the underlying Telephone Canyon marls disappear, as shown on Plates 5 and 9. This seems to be the critical point for major changes within the Devils River Formation. Just a few miles southeast of this point, the upper 125 to 285 feet of Glen Rose combine with the lower Devils River to form a 475-foot thick single reef mass (Pl. 9) consisting of several types of coral, stromatoporoids, rudists, and encrusting algae (Pl. 12, A, B). The overlying 1,725 feet of Devils River is also different from the northern area, here being dominated by thin- to medium-bedded, dark gray, miliolid and *Toucasia* lime mudstone to grainstone. The total increase in thickness of the Devils River limestone of Fredericksburg-Washita age, between Cañón El Cibolo and the Rincón de María, a distance of almost 75 miles, is between 115 and 275 feet. The exact amount depends on how the base of the Telephone Canyon Formation is correlated with the Rincón de María section, as discussed previously (p. 38). This sequence of reef and associated beds can be seen in the Rincón de María (Pl. 12, C) and from the Puerto de Aguacate southward along the front of the Sierra de San Gerónimo (fig. 7, section 22). The line of outcrops apparently parallels the orientation of the reef front since the inter-relations of the sequence persist in this direction.

The only other known outcrop of the Devils River Formation regarded as reef-related is on the northeast flank of the Loma Gorda anticline about 15 miles southeast of the Sierra de San Gerónimo (Pl. 1). Here 400 to 500 feet of section is exposed below the Del Rio clay. The lower 200 to 300 feet are mostly lime grainstones. The overlying section is mostly caprinid biostromes.

In the Pemex wells along the Peyotes anticline, Fredericksburg-Washita reef-beds have not been found. Probable equivalent strata are dark, miliolid, pellet, *Toucasia* facies similar to the Sierra de San Gerónimo outcrop section.

In the Sierra de San Gerónimo, about 850 feet above the base of the reef (Pl. 9, section 22), there is a 60-foot slope-forming section of nodular marls with *Exogyra texana* and *Gryphaea* below and lime mudstones with *Gryphaea* above. This unit is shown on the geologic map (Pl. 1) as Sue Peaks Formation because it is about the right place in the section and has the same lithology and the same general fauna as the northern Sue Peaks. The nearest known Sue Peaks in this facies is almost 75 miles northwest, although the middle Aurora Sue Peaks (*Kars*, Pl. 1) occurs 35 miles to the southwest in the Sierra del Orégano. The presence of these outcrops in the Sierra de San Gerónimo is very unexpected because of the distance from typical outcrop areas and their designation as Sue Peaks is subject to question.

Eastern Area Sequence

The distribution of the three formations characteristic of this area (West Nueces, McKnight, and Salmon Peak) in northern Coahuila is shown on Plate 1 and figure 14. The only other outcrop area is in southwest Texas (Kinney and Uvalde counties) and has been mapped by Lozo and Smith (1964, fig. 15). Generalized stratigraphic relations of these formations with each other and with the Devils River Formation are shown on figure 15 and details on Plates 9 and 10.

West Nueces Formation

The West Nueces is an eastward-thinning, wedge-like continuation of the lower Devils River limestone under the McKnight Formation. The formation varies in thickness from about 600 feet on the west side of the area to about 150 feet in the easternmost outcrops. As shown on the stratigraphic diagram (Pl. 10) this thinning is a result of facies change to the McKnight Formation which thickens correspondingly. The contact between the West Nueces and McKnight Formations is ordinarily transitional and arbitrarily located but at some localities is sharp.

In the western part of the area, the lithology of the West Nueces is almost identical with the lower Devils River and Del Carmen Formations. As shown on Plate 10 a single summary description suffices for all three units. Eastward, however, in the Cañón Las Calabazas (Pl. 10, section 17), the formation consists of medium- to thin-bedded pelleted lime mudstones with small gastropods and chert layers. A similar change was shown in the West Nueces Formation in Texas (fig. 13). About 12 miles to the south, in Cañón San Francisco, caprinid and *Toucasia* mounds occur in this interval. In Cañón El Mulato, 12 miles farther southwest (fig. 7, section 16), the West Nueces has a thickness of about 170 feet and is composed of thick, rudist bioherms and intermound beds.

McKnight Formation

The McKnight varies in thickness from zero in the west to about 243 feet in Cañón Las Calabazas. However, this does not represent a true maximum thickness of the formation, as is indicated on Plate 10. The McKnight in the subsurface of Southwest Texas consists in large part of anhydrite or gypsum, although 20 to 40 feet of salt has been reported from two wells near the center of the basin (Getzendaner, 1930, pp. 1426, 1426; Imlay, 1945, p. 1459). At the outcrop, both here and in Texas (Lozo and Smith, 1964, p. 297) these evaporites have been removed by ground water, resulting in collapse and brecciation of interbedded thin limestone layers (Pl. 12, E). The thickness of the McKnight at Cañón Las Calabazas, prior to evaporite removal, is estimated to have been a maximum of 500 feet (Pl. 10). A thickness of about 505 feet has been recorded in the subsurface 60 miles to the east in Texas (Winter, 1962, p. 106; fig. 17, p. 111).

In Cañón Las Calabazas (Pl. 10, section 17) the McKnight can be divided into three lithologically distinct parts.

Lower McKnight.—The lower part of the McKnight Formation is approximately 150 feet thick and consists of gray to dark-gray, thin-bedded, miliolid, gastropod and clam lime wackestone to grainstone interbedded with *Gryphaea*, lithoclast, pellet lime grainstones to wackestones (Pl. 13, A). Intervals of laminated, fecal pellet lime mudstone to grainstone (Pl. 13, B) and chert in thin nodular layers are common. No breccia zones indicative of evaporite removal have been found in the lower McKnight, but pseudomorphs of salt crystals have been noted in thin sections of the laminated, fecal pellet beds (Pl. 13, C). North and eastward, in the subsurface, the lower McKnight is almost 50 percent anhydrite or gypsum (Lozo and Smith, 1964, p. 300, fig. 12). At Rancho San Miguel, 35 miles northwest of Cañón Las Calabazas, the middle McKnight is exposed and is crumpled as if collapse may have occurred in the lower McKnight (Pl. 12, E).

Middle McKnight.—The middle McKnight, at Cañón Las Calabazas, consists of about 37 feet of brown to black, thin-bedded to laminated, fissile, petroliferous, clayey lime mudstone with common oxytropidoceratid ammonites. This same horizon is found in the middle McKnight in Texas (Lozo and Smith, 1964). Samples analyzed from there by Shell Development Company contained 68.7 percent calcium carbonate, 8.5 percent petroleum, and 22.8 percent clay. The unit weathers to a whitish color and does not support vegetation. All around the southeastern end of the Serranía del Burro it appears as a broad, white band on aerial photographs.

Upper McKnight.—The upper McKnight in Cañón Las Calabazas is about 56 feet thick; the upper 30 feet are covered. The lower 26 feet consist of breccia layers separated by thin-bedded, fecal pellet lime mudstone to grainstone. Individual clasts within the breccia are comprised of similar lithologies. Chert occurs as thin, nodular layers and as broken pieces within the breccia layers. The upper McKnight, both here and in Texas, is characterized by the fecal pellet beds and by the occurrence of unusual *ribbon pellets* (Pl. 13, B). In Texas these peculiar pellets are confined to the upper McKnight, but in Mexico they range throughout the formation. They are not known from other stratigraphic levels of the Cretaceous in Texas or northern Mexico.

Facies change.—Northwestward from Cañón Las Calabazas the McKnight thins by progressive change from the base upward to the West Nueces facies. The facies change in the lower and upper units occurs by a gradual decrease in fecal pellet lithoclast type beds, an increase in bed thickness, and a slight but perceptible color change from dark to light gray. In the upper McKnight there is apparently a decrease in the percentage of evaporites relative to other rock types since beds of breccia are less common. The change is ordinarily considered complete when the rudistid *Toucasia* is found. This progressive change may be observed either vertically or laterally on Plates 9 and 10, but in any one section the formation boundary is arbitrarily placed.

Salmon Peak Formation

The Salmon Peak overlies the McKnight conformably but there is a sharp lithologic change at the contact. In Texas the contact is disconformable in up-dip outcrops (Lozo and Smith, 1964). The formation is almost 900 feet thick at Cañón La Palma (Pl. 10, section 10) and about 800 feet thick in the Sierra El Cedral (Pl. 9, section 15), the only two complete sections measured. The formation can be divided into upper and lower units that could be mapped at a scale of 1:50,000 and named as members.

Lower Salmon Peak.—The lower unit ranges from about 375 feet thick in the Sierra El Cedral to 575 feet in Cañón La Palma. The thickness increases eastward and a maximum of about 700 feet has been recorded in the subsurface of Texas (Winter, 1962). It consists of thick-bedded, white, globigerinid lime mudstone to wackestone (Pl. 13, D). Chert occurs in nodular layers near the top of the exposed section at Cerro El Palomo and is very abundant in large irregular masses in the upper part of the unit in Texas (Lozo and Smith, 1964).

Upper Salmon Peak.—The upper unit of the Salmon Peak is about 435 feet thick in the Sierra El Cedral. It thins to about 325 feet in Cañón La Palma and disappears eastward. It is, in effect, a tongue of the Devils River facies extending eastward overlapping and changing into the lower Salmon Peak mudstone facies. Here, the tongue is arbitrarily cut off where the lower unit of the Salmon Peak Formation changes facies, rather abruptly, to Devils River limestone.

In the Sierra El Cedral (Pl. 9, section 15), the lower 175 feet of the unit consists of rounded and coated, oriented-pellet, shell fragment lime grainstone, grading from very fine at the base to coarse at the top (Pl. 13, E), with beds inclined 10°–15° easterly (Pl. 12, D). This is considered to be depositional dip since beds above and below are horizontal. These inclined grainstones are overlain by about 127 feet of irregularly bedded grainstones and by an upper 135 feet of radiolitid, shell fragment, miliolid lime wackestones to grainstones with common large gastropods. In the upper 35 feet the radiolitids are unbroken and in growth position whereas below all shells are fragmented.

At Cañón La Palma (Pl. 10, section 10), the interval is about 100 feet thinner than in the Sierra El Cedral, but the same lithologic relations maintain except that inclined bedding was not noted in the lower grainstones.

In the Salmon Peak outcrop area of Texas, the same two lithologic members are present (fig. 13) and have the same relation as in northern Coahuila. Inclined beds have not been noted in Texas but the outcrops are poor.

Del Rio Formation

The Del Rio rests disconformably on Santa Elena, Devils River, or Salmon Peak across northernmost Coahuila. The top of the underlying formation is commonly iron-stained and bored by clams. The lithology is dominantly clay with abundant nodules of pyrite, weathered reddish to buff; *Exogyra arietina, Haplostiche texana* (a large, uniserial, arenaceous foraminiferan), and various echinoids are common. Across the Devils River trend, the formation is only 6 to 8 feet thick and commonly contains numerous thin interbeds of wave-rippled fine sandstones. To the west, thicknesses vary erratically from a few feet to as much as 75 or 100 feet. West of the Rio Grande, St. John (1965, p. 35) measured thickness changes from zero to 185 feet within 8 miles, and he suggested (p. 34) that these variations are the result of local tectonic activity during deposition of the formation. Southwestward, in the Sierra del Orégano the Del Rio thickens to about 150 feet and is conformable with Aurora lime mudstones. Eastward, in the subsurface of South Texas, the formation thickens to about 400 feet and is conformable on Salmon Peak lime mudstones.

Buda Formation

The Buda Formation is apparently conformable on the Del Rio in northern Coahuila but unconformable in the Edwards Plateau region (fig. 12). The formation thickness varies from 75 feet on the Agua Verde anticline (fig. 7, section 1) to 130 feet in the Sierra El Cedral and is divisible into three units: a lower 10 to 20 feet of nodular marly lime wackestone; a middle 30 to 50 feet of soft, nodular marly lime wackestone; and an upper 35 to 60 feet of medium- and even-bedded, brittle, white lime mudstone.

To the south, over Aurora lime mudstone depositional areas, these three subdivisions are not recognizable. In these regions the entire formation is thin- to medium-bedded, brittle lime mudstone.

INTERPRETATION

Sedimentary-Tectonic Framework

At the end of Trinity (Glen Rose) deposition, a continental shelf and slope deposition topography was present in northern Coahuila. The shelf-edge trended approximately east-west, extended eastward across the Texas Gulf Coast, and was covered by an environmental complex of reefs, bars, and banks. As described above, this shelf-edge is believed to be the result of southward offlap of shallow-water sediments during upper Glen Rose deposition. After Glen Rose deposition the relief at the edge probably became greater and the rate of offlap slowed so that throughout Fredericksburg-Washita deposition the position of the shelf-edge was fairly stable, as shown on Plate 9.

Northward from the shelf-edge in Mexico, toward the shoreline, a distance of about 200 miles, upper Glen Rose miliolid, gastropod marls and lime wackestones were being deposited in shallow, well-circulated, but quiet water. At this time, the Marathon region (fig. 2) was uplifted and a wedge of sandstone, the Maxon Formation (King, 1930, p. 92), was deposited to the south in regressive offlap relation with the Glen Rose. King (1930) believed the Maxon sand to be wholly Fredericksburg in age, but St. John (1965, p. 22) has shown that it spans the Trinity-Fredericksburg boundary, the time of maximum sand influx being latest Trinity. Clay-size material was carried farther out and distributed over the broad, shallow, shelf sea as far as the shelf-edge. Initial deposition of the clay marks the base of the Fredericksburg Group.

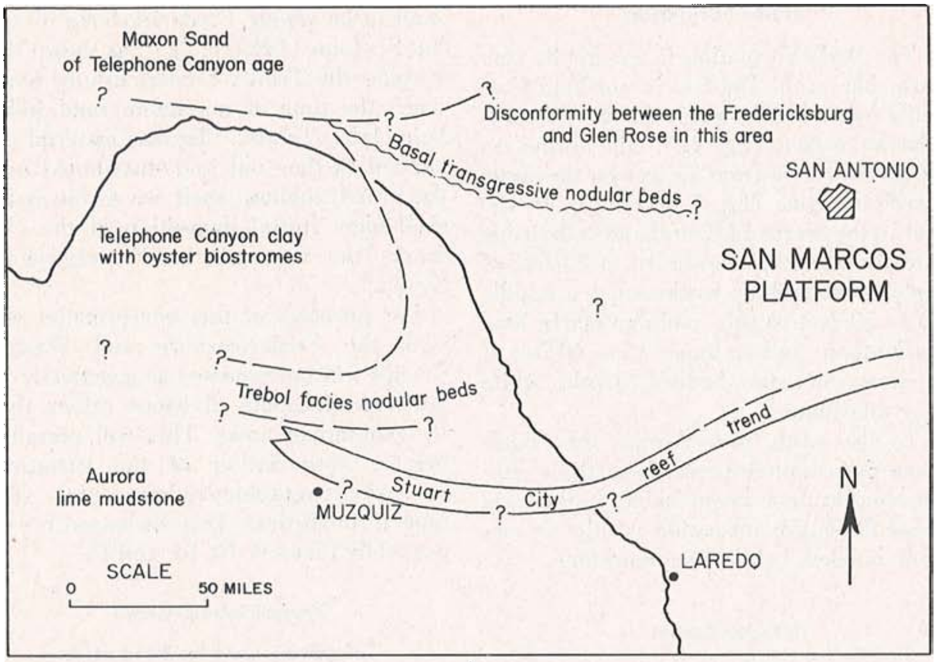
For purposes of this interpretative section, the Fredericksburg and Washita Groups will be discussed as genetically related stratigraphic divisions rather than by geographic areas. This will permit a greater appreciation of the variations in paleogeographic-environmental relations through time. This discussion is supported by Plates 9, 10, 14, and 15.

Fredericksburg Group

Telephone Canyon Formation

Terrigenous clays of the Telephone Canyon Formation were probably derived from the Marathon source area (as noted above) and distributed rather evenly over a large part of northern Coahuila (fig. 17, A). These clays were deposited in layers alternating with marly lime wackestones and oyster biostromes. Bottom environments were ideal to support a large population of mud-burrowing and plowing mollusks. The area of deposition, between the shelf-edge and the shoreline, was probably quite shallow but oxygenated and not subject to large waves and strong currents. Southward and eastward the percentage of clays decreases and the nodular, burrowed lime wackestones of the Trebol facies were deposited. The southernmost exposures of the "Basal transgressive unit" of the West Nueces Formation in Texas (Lozo and Smith, 1964) are probably correlative with the Telephone Canyon and Trebol facies.

Inundation of the Marathon region source area shut off the supply of terrigenous clay and terminated deposition of the Telephone Canyon Formation. Carbonate sediments deposited in the new clay-free environment initiated the sequence that includes the Del Carmen, Devils River, and



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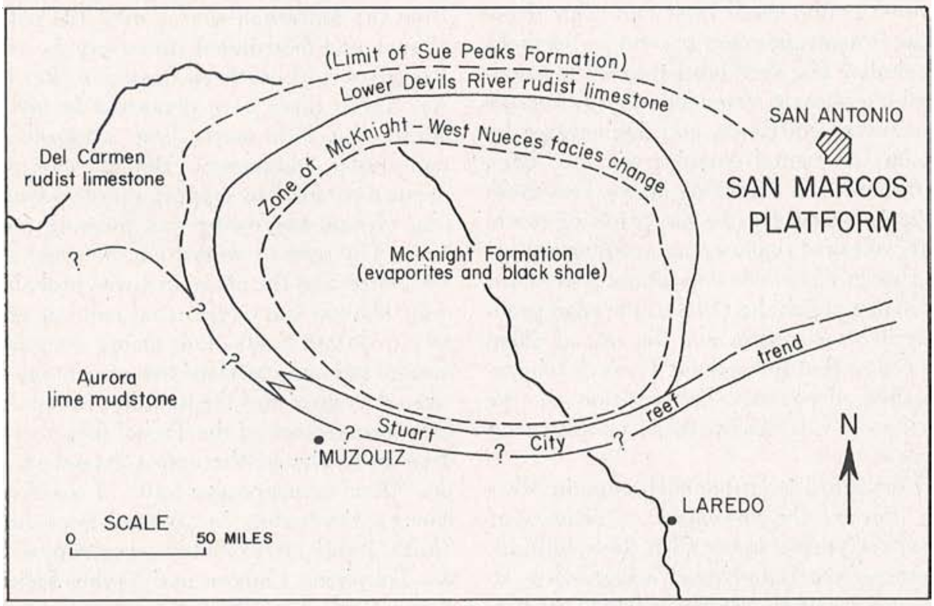


B

FIG. 17. Facies distribution maps of the Fredericksburg Group in northern Coahuila, Mexico. A, Lower Fredericksburg—Telephone Canyon Formation and equivalents. B, Middle Fredericksburg formations.

West Nueces Formations. Since the inundation was progressive through time, the environmental change occurred first to the south and later in the north nearer the source area.

Del Carmen, Lower Devils River, West Nueces, and McKnight Formations

The controlling element in environmental variations leading to deposition of this series of formations was the barrier effect of the reefs and other shallow-water to supra-tidal environments along the shelf-edge (fig. 17, B). Sea waters behind the shelf-edge began to clear, as the Telephone Canyon source area was reduced, and fine-grained, medium-bedded, pelleted lime mud, with slender gastropods and small clams, was deposited (Pl. 10, section 17). These beds form the base of the West Nueces Formation. This environment probably resembled the modern Florida Bay as similar sediment and faunal types are currently being deposited there (Ginsburg, 1956). As in Florida Bay the primary factor in this environment was protection from wind-driven waves and currents by the shallow-water barriers to the south. Northward, at the same time, lime muds were also being deposited but some terrigenous clay was still present here, and burrowing and plowing mollusks were common along with slender gastropods and miliolids. The resulting nodular lime wackestones form basal deposits of the northern West Nueces, lower Devils River, and Del Carmen Formations (Pl. 10, sections 2, 8, 10, and 12).

When the clay source area to the north was completely submerged, waters in this region became exceptionally clear and filter-feeding rudists comprised the dominant bottom fauna north and west of Cañón Las Calabazas (Pl. 10, section 17). They formed biostromes or bioherms interbedded with miliolid, gastropod lime wackestones to mudstones and, locally, grainstones. Rocks of this facies form the bulk of Del Carmen, lower Devils River, and West Nueces Formations (Pl. 10). Bioherms are common in the Del Carmen in the Black Gap and Cañón San Rosendo area but have not been found in the lower Devils River. It is probable that these Del Carmen bioherms were developed in waters that were transitional in depth between the very shallow biostromal facies of the Del Carmen on the north or lower Devils River on the east and deeper waters of the Aurora lime mudstone depositional area to the south (fig. 17). If the bioherms are related to such a transitional depth zone, then a belt of bioherms may trend southward coincident with the boundary between the lower Devils River and the Aurora and eventually grade into the shelf-edge facies in the Sierra de San Gerónimo. This facies change would be at the western end of the Stuart City reef trend that extends eastward for at least 250 miles into Central Texas (fig. 17). Time was not available to study the lower Devils River—Aurora facies boundary, but the known distribution of the Aurora (fig. 17), the change in thickness of the Del Carmen from north to south (fig. 16), and the spatial distribution of facies in the overlying Sue Peaks Formation, all support the hypothesis presented above.

The West Nueces, on the other hand, has abundant large bioherms below and grades up to *Toucasia, Gryphaea* biostromes (Pl. 10), indicating an environmental change with time. This change is genetically related to deposition of the McKnight Formation. The lower McKnight at Cañón Las Calabazas is mainly dark, thin-bedded to laminated lime wackestones and fecal-pellet grainstone with lithoclasts. Halite pseudomorphs were noted but no evaporite beds nor collapse breccias to record their former presence were found. These beds were apparently deposited in shallow waters and represent an increase in the restriction and salinity of this shelf area. East and northward thick evaporites were deposited contemporaneously. This general environment persisted throughout the deposition of this formation except that during the middle McKnight a considerable amount of terrigenous clay from an unknown source was introduced. This clay was apparently by-passed across the Devils

River depositional area since that formation surrounds the Maverick basin and does not contain clayey horizons. The resulting organic shales are interbedded with thin evaporites in the subsurface to the east. In the upper McKnight conditions of restriction and evaporation apparently reached a maximum. Outcrops of this part of the formation are mostly collapse breccias resulting from ground water removal of evaporites.

Interpretation of the data on lithology and facies relations of the McKnight has led to the following explanation for the origin of the environment and spatial distribution of the facies. As bioherms and biostromes were constructed by rudists in the clear, well-circulated waters north and west of Cañón Las Calabazas and in the southern Edwards Plateau in Texas (Lozo and Smith, 1964, p. 293), circulation in the waters between there and the shelf-edge, to the south, was increasingly restricted. In all probability, this area closely resembled modern back-reef lagoons at that time. Deposition of the McKnight Formation was initiated in this euxenic, high-salinity environment. From comparison of outcrop data in Coahuila and in Texas (fig. 13) with subsurface data (Winter, 1962) it appears that McKnight deposition began at approximately the same time over an area of about 15,000 square miles (100 miles north-south by 150 miles east-west; fig. 17, B).

Influx of normal marine water into the restricted area was apparently from all directions or at least from north, south, and west since normal marine limestones were deposited in those areas contemporaneous with McKnight evaporite deposits. Furthermore, the occurrence of salt in the center of the basin surrounded by halos of anhydrite and limestones implies circulation and increasing brine concentration in that direction. The areal expansion and overlap of the McKnight Formation on the West Nueces probably resulted from a progressive decrease in rate of influx of normal marine waters into the restricted area or increased rate of evaporation and a corresponding expansion of high salinity areas. As salinities in the lagoonal area increased, the surrounding rudist banks were killed and overridden by McKnight deposits. This is probably the reason that the upper West Nueces deposits are characterized by *Toucasia* and *Gryphaea* rather than caprinid rudists. The former apparently had greater tolerance for high salinities as well as for turbid water (B. F. Perkins, personal communication, 1964). By the end of McKnight time the area measured about 150 by 200 miles. Isopach maps of the McKnight Formation clearly show this environmental-facies expansion (Winter, 1962, p. 111).

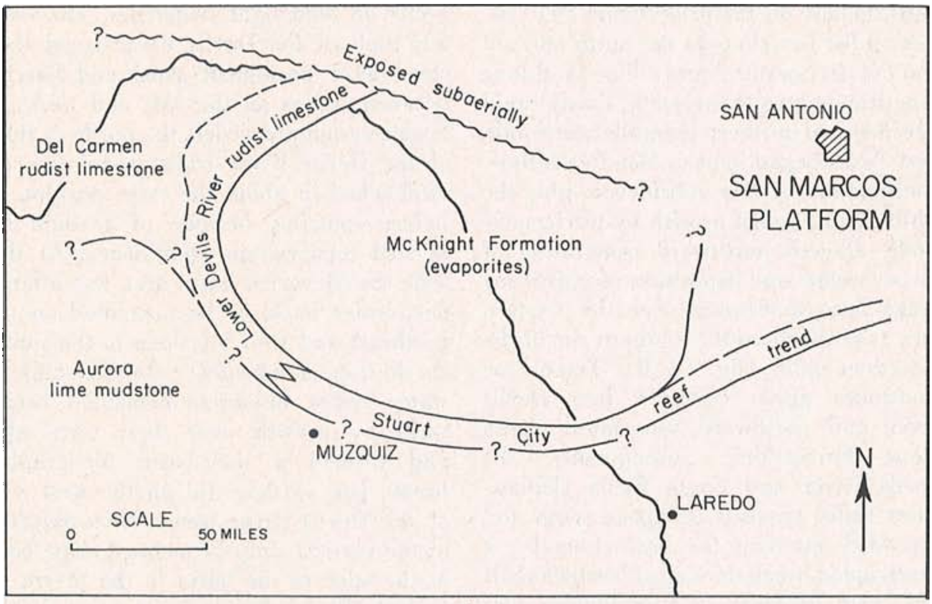
The facies patterns described above were terminated by regional uplift and tilting that caused southward regression of the Fredericksburg sea to the approximate position shown on figure 18, A. This uplift was probably in progress during upper McKnight deposition. Restriction of the McKnight depositional area may have increased as land barriers developed to the north and east during the initial stages in the uplift, thus accounting, in part, for extended development of upper McKnight evaporites.

Washita Group

Sue Peaks, Santa Elena, Upper Devils River and Salmon Peak Formations

As uplift and shoreline regression occurred and terminated Fredericksburg deposition, the northern limb of the Devils River rudist trend and adjacent parts of the Maverick basin were subaerially exposed (fig. 18, A). However, the western limb of the Devils River depositional environment (in Mexico) persisted and formed an elongate, north-south shallow-water bank between the shoreline and the Stuart City reef trend.

Terrigenous clastics of the Sue Peaks Formation, derived from rejuvenated source areas to the west, were transported into northern Coahuila by eastward-flowing longshore currents. The north-south shoal formed by the Devils River trend diverted these currents southward. Lower Sue Peaks terrigenous clays were deposited



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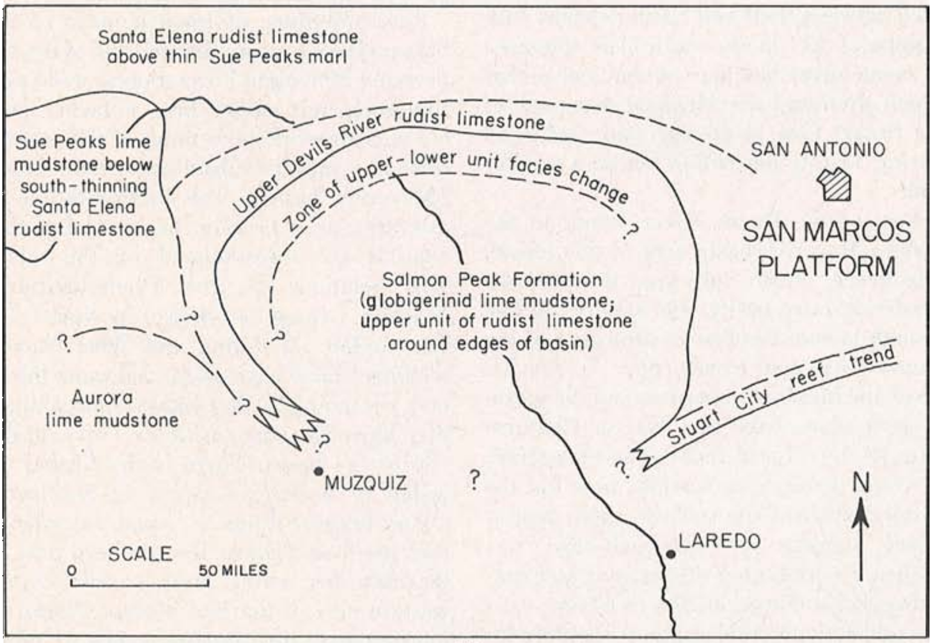

B

FIG. 18. Facies distribution maps of the uppermost Fredericksburg Group (A) and of the lower and middle Washita Group (B).

transitionally on the pre-existing Del Carmen rudist limestone to the north and out into the deep-water Aurora lime mudstone depositional area to the south. Fairly rapid subsidence of northern Coahuila and Southwest Texas began in early Sue Peaks time. Continuation of this subsidence, plus the inhibition of rudist growth by terrigenous muds, allowed northward penetration of deeper waters and deposition of upper Sue Peaks lime mudstones over the western area as far north as the southern rim of the Marathon uplift (fig. 18, B). These lime mudstones grade eastward into Devils River and northward into lower Santa Elena Formations. Subsequently, the Devils River and Santa Elena shallow-water rudist deposits offlapped south and westward out over the basinal muds. A topographic break developed between shelf and basin domains as progradation continued. In the Marathon rim region of Texas, the northernmost edge of lime mud deposition, 110 feet of relief has been measured between shelf and basin deposits with a slope of 13° to the south. The sequence of events described here is identical to that which produced the Mexican extension of the Stuart City shelf-edge and reef-trend during Trinity deposition but on a smaller scale.

East of the Devils River trend, in the eastern Maverick basin area of this report, subsidence, closely following the terminal Fredericksburg uplift, was apparently fast enough to cause extensive drowning of the Stuart City reef trend (fig. 17, A) between the Mexican exposures and the southwestern edge of the San Marcos Platform (fig. 18, B).[6] Local reef patches may have survived throughout Washita time but the barrier effect of the shallow-water depositional complex at the shelf-edge was broken. Continuation of shallow-water conditions in the Sierra de San Gerónimo area was aided by the stable support provided by the western limb of the Devils River trend. Deeper waters rapidly filled the old lagoonal area and globigerinid lime muds of the Salmon Peak Formation were deposited directly on McKnight evaporites. The western limb of the Devils River trend then stood as a prominent shoal and barrier between basins on the east and west. As transgression proceeded, the northern limb of the Devils River rudist trend was reestablished in about the same position as before—possibly because of a slight inherited topographic prominence. At this time the Maverick basin area was a large deep-water basin or bay enclosed on the northeast and west but open to the south. As the rate of subsidence slowed, shallow-water rudist limestone expanded basinward by growth over their own talus and formed a shelf-basin topographic break, just as they did on the west side of the Devils River trend. Measurements of the vertical drop of inclined slope beds at the edge of the basin in the Sierra El Cedral (Pl. 12, D), indicate water depths of about 175 feet (below the shelf-edge). Depths in the center of the basin may have been as much as 400 to 600 feet.

Interpretations of isopach maps of the Salmon Peak lime mudstone (and of the underlying McKnight Formation as well) as a time-rock unit rather than a facies have led various workers to think of the eastern area as a rapidly subsiding tectonic basin (Maverick basin). The interpretation of this area as a tectonic basin during this time is not substantiated by the thickness relations of the Fredericksburg-Washita Groups as shown in figure 19. The Cañón La Palma and West Nueces sections would have about the same thickness according to that interpretation since they have the same position relative to the rim of the basin. There is the further illusion of a basinal aspect in Southwest Texas because lines of equal subsidence rate trend east across the northern part of the area then swing south parallel to the western side of the San Marcos Platform. Isopach maps do, therefore, when properly constructed, show an arcuate pattern which can be interpreted as one segment of a basin.

[6] This possibility was first suggested to the writer by T. D. Cook, Shell Oil Company geologist, 1964.

Del Rio and Buda Formations

Regional uplift ended Santa Elena,

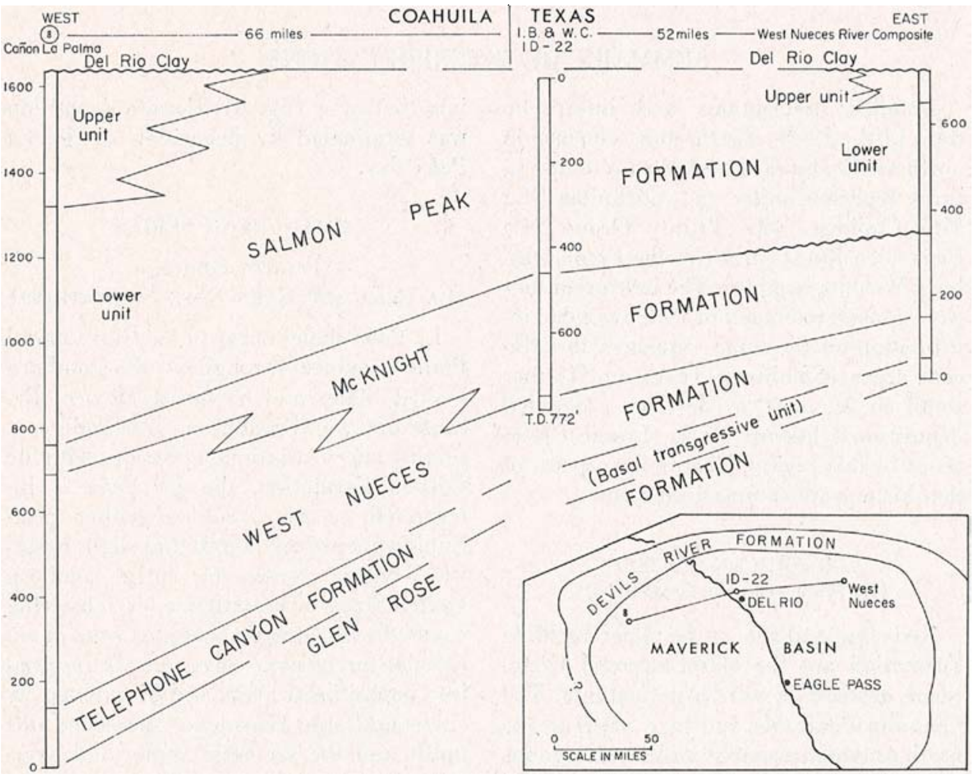

FIG. 19. Generalized east-west stratigraphic section demonstrating thickness relationships of Washita formations across the northern part of the Maverick basin.

Devils River, and Salmon Peak deposition as it did Fredericksburg deposition. However, the results of this uplift did not just modify environmental patterns but completely terminated rudist limestone, shelf deposition in northern Mexico and South Texas. Vast quantities of terrigenous clay were spread across the western Gulf to form the Del Rio clay. Among Lower Cretaceous formations the areal distribution of the Del Rio is exceeded only by the La Peña. In the center of the eastern (Maverick) basin the Del Rio is about 400 feet thick and has a gradational contact with the underlying Salmon Peak. Northward, onto the Devils River trend, it thins to zero by overlap and truncation (Lozo and Smith, 1964, p. 291). Westward, it thins to a minimum of about 6 feet over the Devils River trend and is disconformable on that formation. These thickness figures and stratigraphic relations are an indication of the topography of the area prior to influx of the Del Rio clay.

Near the end of Del Rio deposition minor uplift exposed the top of the Del Rio in the Edwards Plateau region (Lozo and Smith, 1964) but apparently not in northern Coahuila. Subsequently, the area rapidly subsided and lime mudstones and wackestones of the Buda Formation were deposited over the entire region. The Buda Formation varies from 50 to 150 feet and is the upper unit of the Washita Group and of the Comanche Series. With the beginning of Gulfian deposition (Boquillas or Eagle Ford) an entirely new and different regimé of sedimentation was established.

SUMMARY OF INTERPRETATIONS

Detailed descriptions and interpretations of the Lower Cretaceous sequence in northern Coahuila have been presented in three separate units: (1) Coahuilan (La Mula-Cupido), (2) Trinity Group (La Peña-Glen Rose), and (3) the Fredericksburg-Washita complex. The interpretations were considered together with available information on the same sequences in adjacent areas (Southwest Texas and farther south in Mexico) to develop a detailed depositional history of the Lower Cretaceous in this region. The major aspects of that history are summarized below.

COAHUILAN SERIES
(La Mula—Cupido Formations)

Red clays and silts of the upper La Mula Formation are the oldest exposed Cretaceous deposits in northern Coahuila. The Coahuila Peninsula and land areas to the north provided a source for the terrigenous clastics which were deposited in littoral and sublittoral environments across the Sabinas Gulf and Tamaulipas Peninsula (fig. 6). Deposition of the La Mula was terminated and Cupido deposition initiated as the influx of terrigenous clastics decreased and calcium carbonate sedimentation predominated. At the beginning of Cupido limestone deposition, the shoreline position was approximately as shown on figure 10, and it probably extended westward across the upper end of the old peninsula.

Cupido sedimentation was transgressive but characterized by numerous minor fluctuations so that the preserved sedimentary record consists entirely of littoral and shallow sublittoral deposits. The total amount of shoreline transgression during Cupido time was 25 to 30 miles (fig. 10) with most of this occurring toward the end of the depositional history. Depositional and tectonic strike lines were parallel and trended east-west, but terrigenous clastics increase eastward at the expense of limestones, indicating a greater rate of influx into that area (fig. 9). Cupido deposition was terminated by deposition of the La Peña clay.

COMANCHEAN SERIES

Trinity Group
(La Peña and Glen Rose Formations)

La Peña shales occur in the Gulf Coastal Plain province throughout the southern United States and northeast Mexico. Because of wide distribution, lithologic continuity, and stratigraphic relations with the Cupido Formation, the La Peña is interpreted as the result of either post-Cupido epeirogenic uplift and slight basinward tilting across the entire southern United States or eustatic sea level lowering coupled with climatic change. Large quantities of terrigenous clays were introduced into depositional areas and distributed by currents. Rapid subsidence succeeded this uplift and the La Peña shales and overlying Aurora globigerinid lime mudstones of Glen Rose age were deposited in rather deep, open marine waters in areas where littoral environments had prevailed during Cupido deposition. Subsequently, this rate of subsidence slowed and shallow neritic and littoral deposits of the middle and upper Glen Rose expanded seaward, building a depositional shelf or platform southward out into deeper water areas where lime muds of the Aurora were being deposited. Near the end of the Glen Rose, as the shelf-edge was extended southward into clearer, more open waters, reef-building organisms constructed reefs in many places along a line from northern Coahuila into Central Texas, a distance of some 250 to 300 miles. This line has been referred to as the Stuart City reef-trend (Winter, 1962). This reef-tract probably did not extend west of the Sierra de San Gerónimo area, possibly because of turbid water conditions in that direction. Seaward from the shelf-edge, water depths increased to perhaps as much as 2,000 to 4,000 feet during Washita deposition.

FREDERICKSBURG GROUP (TELEPHONE CANYON, DEL CARMEN, LOWER DEVILS RIVER, WEST NUECES, AND MCKNIGHT FORMATIONS)

The Telephone Canyon clays are initial deposits of the Fredericksburg Group. These clays were derived from source areas in the Marathon region of Texas, uplifted during late Trinity deposition. They were deposited across northern Coahuila in sublittoral waters shoreward from the shallow-water shelf-edge (fig. 17, A). Along the southern edge of the shelf, seaward from the limit of the Telephone Canyon, the Trinity and Fredericksburg deposits of the trend form a continuous shallow-water depositional complex that has not been subdivided stratigraphically.

As the influx of Telephone Canyon clays diminished, a secondary bank of rudist bioherms and biostromes (lower Devils River) developed in a north-south direction, connecting the western end of the Stuart City reef trend with the broad depositional area of the Del Carmen Formation. Southwestward this bank sloped into deeper waters where Aurora lime mudstones were deposited (fig. 17, B). The area to the east was then encircled as a lagoon behind the Stuart City reef-trend (shelf-edge) to the south, the lower Devils River rudist banks to the west and north, and the San Marcos Platform area to the east. Circulation in the lagoon was thus restricted. Initially, pelleted lime mudstones of the lower West Nueces Formation were deposited in the lagoon. Then, as restriction increased, the evaporites and black shales of the McKnight Formation were laid down. Through time, the area of evaporite deposition expanded by onlap of the surrounding *Toucasia,* miliolid limestones. The western and northern limit of McKnight deposition forms the inner boundary of the arbitrarily designated Devils River Formation.

Fredericksburg deposition was terminated by uplift to the north, in Texas, which subaerially exposed the northern part of the McKnight depositional area and northern arm of the Devils River Formation (fig. 18, A). At the same time, terrigenous clays were transported into the northern Edwards Plateau and northwestern Coahuila from source areas to the northwest. The beginning of deposition of these clays, the Sue Peaks Formation, marks the Fredericksburg-Washita contact in the western area of this report. The southern and eastern limit of the Sue Peaks defines the north and western boundary of the Devils River Formation.

WASHITA GROUP (SUE PEAKS, SANTA ELENA, UPPER DEVILS RIVER, SALMON PEAK, DEL RIO, AND BUDA FORMATIONS)

Subsidence of the region began with the initiation of Washita deposition and must have been fairly rapid. Deep-water globigerinid lime mudstones of the upper Sue Peaks were deposited far to the north over previous areas of shallow-water Del Carmen limestone (fig. 18, B). At the same time, the Stuart City reef trend and shelf margin to the southeast were inundated by deeper water and the Salmon Peak lime mudstones were deposited over the McKnight evaporites. During this time the western limb of the Devils River rudist trend extended southward as a shallow-water bank or shoal, bordered by basins on either side and terminating in a south-facing escarpment. As the rate of subsidence slowed, Santa Elena shelf deposits expanded southward by offlap over the Sue Peaks in the western area and upper Salmon Peak lime grainstones and rudist banks expanded inward over the mudstones of the eastern basin. The sequence of events was very similar or identical to that which produced the late Trinity (Glen Rose) shelf but on a smaller scale.

Epeirogenic uplift and influx of the Del Rio clays, on the same order of magnitude as the La Peña influx, ended the long history of rudist shelf-limestone deposition in this region. Deposition of these clays tended to reduce the relief of pre-existing submarine topography. The Del Rio Formation is thicker in previous basinal areas and thinner over highs (Devils River trend), although local tectonic movements complicate this relation to the west. Another uplift at the end of Del Rio deposition subaerially exposed most of the Edwards Plateau region in Texas. The succeeding transgression again seems to have been quite rapid, and the Buda limestone (particularly the upper brittle lime mudstone) was deposited in relatively deep, open sublittoral waters.

CONCLUSIONS

Preliminary studies of the Lower Cretaceous formations in northern Coahuila have established the interrelations between the sedimentary sequences of a continental shelf and those of the contiguous ocean basin. They have both scientific and economic significance. Their scientific significance derives from the interpretation of the processes that produced these topographic elements, and of the horizontal and vertical variations within the stratigraphic succession. Their economic significance derives from their bearing on the distribution of potential oil and gas reservoirs of the continental shelves where much of the world's petroleum reserves are to be found.

This Lower Cretaceous continental shelf and primary variations within the stratigraphic succession were the result of sedimentary response to tectonic movements or to eustatic-climatic factors and suitable environmental conditions for the growth of lime-secreting organisms. The principal changes and their sedimentary effects were:

(1) shoreline regression as a result of epeiorogenic uplift or eustatic change; deposition of terrigenous clastics (La Peña clays).

(2) rapid subsidence accompanied by northward transgression of the shoreline; onlap of shallow-water sediments by deeper water lime mud deposition (lower Glen Rose).

(3) progressive decrease in rate of subsidence; seaward offlap of shallow-water limestones over deeper water lime muds (middle and upper Glen Rose).

Reef growth along the seaward edge of the offlapping shallow-water deposits was primarily responsible for the change in sea bottom slope that separated the continental shelf and ocean basin at the end of Trinity deposition.

Principal variations during accumulation of the Fredericksburg and lower Washita sequence on the continental shelf were evaporite deposition (McKnight) and creation of a deeper water shelf-basin or embayment (Maverick basin) rimmed by a shallow water rudist bank (upper Devils River). The evaporites resulted from restriction of waters by the shelf-margin barrier. The topographic basin was formed by small-scale repetition of the tectonic-sedimentary processes that caused development of the continental shelf.

A second major tectonic uplift during late Lower Cretaceous time initiated the influx and deposition of terrigenous clastics (Del Rio clay) that stopped reef growth and reduced relief of topographic features on the shelf. Rapid subsidence followed the uplift, and deeper water deposits (Buda limestone) overlapped far northward bringing an end to Lower Cretaceous shallow-water shelf and bank deposition in northern Coahuila and southwestern Texas.

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APPENDICES

A. GEOGRAPHY

In addition to a variety of interesting and superbly exposed geologic features, northern Coahuila offers the only spectacular mountain scenery for over 300 miles in any direction. In spite of these geologic and scenic attributes and proximity to the Texas border, the region has remained almost totally unknown to the general public. The principal reason for this isolation has been the lack of accurate road maps or general geographic description of the region. The geologic map (Pl. 1) accompanying this report accurately depicts the roads and culture of the entire area. The following descriptions of the principal mountain ranges, culture, climate, and accessibility are given here in the belief that they will assist any geologist contemplating field work in the area and may stimulate the interest of the general public.

Principal Mountain Ranges[7]

SERRANÍA DEL BURRO

The Serranía del Burro covers the northeastern half of the area studied and is divisible into three topographically distinct parts—northern, central, and southern.

The northern end of the range begins just south of the Rio Grande at an elevation of about 1,600 feet and rises to around 4,700 feet at Pico El Cíbolo along the northwest side of Cañón El Cíbolo (Pl. 11, C) where the range is only 15 miles wide. The eastern front of the range is formed by a long narrow fold, the Sierra del Consuelo, which is slightly separated from the main range by a narrow valley. The western flank slopes gently into the Llano de los Buras.

The central part of the Serranía del Burro extends from the east side of Cañón El Cíbolo (Pl. 11, A) southeastward to Arroyo de la Zorra and broadens from 15 miles on the northwest to 30 miles on the southeast. Both the eastern and western flanks rise gently from the plains to a high, plateau-like area lying mostly between 4,000 and 4,500 feet in elevation but rising to around 6,000 feet in the southwest corner (Pl. 14, A). The most conspicuous landmarks of the central Serranía del Burro are three igneous intrusions aligned east-west (Pl. 1); Cerro El Burro, the smallest, on the east flank; Cerro Nevado near the middle, and Cerro Colorado (Pl. 14, B), the largest, on the west side. Cerro Colorado is encircled by a deep, moat-like valley. The surrounding sedimentary formations dip into this valley. Dikes and sills are abundant throughout this region.

The southern part of the Serranía del Burro begins at the north rim of the large valley of Arroyo de la Zorra and extends to the plain on the southeast end. It is a highly dissected, broad swell, 40 miles wide and 50 miles long, gently rising from about 2,300 feet on the east, west, and south sides to about 4,700 feet at Cerro Oso Blanco near the heart of the range.

SIERRA EL CEDRAL

The Sierra El Cedral is a sharply defined range lying along the southwestern side of the Serranía del Burro and is separated from it by the Valle El Infante. This range has previously been considered as part of the Serranía del Burro. However, it has strikingly different topographic form, strongly resembling the tilted-block mountains of Nevada. The northeastern front is a steep scarp rising more than 2,600 feet abruptly above the Valle El Infante. The southwestern side slopes smoothly and gently into the valley of Arroyo de la Babia. The range is about 40 miles long, from 4 to 8 miles wide, and has the same variation in elevation as the southern Serranía del Burro—2,300 to 4,700 feet.

[7] The ranges described are labeled on the physiographic diagram of figure 4.

SIERRA DEL CARMEN

The Sierra del Carmen crosses the Rio Grande north of Boquillas del Carmen on the eastern side of the Big Bend National Park (fig. 2) and extends parallel to the Serranía del Burro for some 80 miles (fig. 4). The range does not exceed 10 miles in width and is much narrower in most places. The northeastern flank borders the Pico Etéreo region and Valle Las Norias in the north and the valley of Arroyo de la Babia on the south. The southwestern flank borders the large valley south of Boquillas in the north and various ranges and valleys on the south.

As with the Serranía del Burro, the Sierra del Carmen is divisible into three distinctly different parts. The northern part is a tilted-block range with an escarpment facing to the southwest nearly 2,000 feet high (Pl. 15, A). This is the spectacular Carmen front seen from the Big Bend National Park. The central Sierra del Carmen is offset slightly eastward from the northern part. At the north end is the 9,500+-foot high igneous mass of Pico Centinela (Pl. 15, A and C) which slopes southeastward to the high lava fields of the Mesa de los Fresnos (Pl. 15, C). The southwestern side of the range in this part is also an escarpment, but the northeast side breaks off into very rugged terrain which gradually descends into the Valle Las Norias. The southern Sierra del Carmen[8] is also a tilted block but the escarpment face is to the northeast overlooking the valley of Arroyo de la Babia (Pl. 15, B). This southern part of the Sierra is even more spectacular than the northern part. Here the scarp front rises some 3,500 feet above the valley floor with vertical cliffs of limestone 1,000 feet high in some places. The southeastern end of the range is marked by a deep re-entrant, the Rincón de María.

RANGES SOUTH OF THE SIERRA DEL CARMEN

The southern Sierra del Carmen merges with a series of ranges and valleys having a more southerly trend. From west to east (fig. 4), these are the Sierra de la Gorriona, the great, elongate Valle El Fortín, and the closely adjacent Sierra de los Ojos and Sierra de Berruguero. The latter two ranges merge southward. South of Cañón de la Alameda, a cross-canyon some 30 miles south of the Sierra del Carmen, they become the Sierra Hermosa de Santa Rosa (fig. 5). The latter range curves eastward for about 20 miles toward Muzquiz. To the southeast of Muzquiz, it resumes the regional southeast trend parallel to the Sierra del Carmen.

East of the Sierra de Berruguero is the Valle de Agua Dulce and the Sierra de San Gerónimo. This range is 30 miles long, less than 4 miles wide, and is asymmetrical with a steep eastern front and gently dipping western flank. The eastern front faces the plains to the east and on a clear day may be seen from the Piedras Negras highway 50 miles due east.

The west flank of the Sierra de la Gorriona and the southwest flank of the southern Sierra del Carmen descend gradually into the great Valle de la Encantada—Valle Columbia depression. Bordering these valleys on the west is the Sierra de la Encantada which has a scarp front on the southwest similar to the northern Sierra del Carmen.

Climate, Culture, and Accessibility

Northern Coahuila lies within the subtropical high-pressure atmospheric belt and has a predominantly arid climate. However, these mountains are the first encountered by easterly winds from the Gulf of Mexico and their eastern slopes and higher parts receive considerably more moisture than ranges farther west (Muller, 1947, pp. 37–38).

Vegetation varies widely according to elevation (rainfall) and, to a lesser degree, soil types. Muller (1947) described the vegetation types and outlined their distribution. The following is a synopsis of his types; their distribution in this area is shown on figure 20: (1) Chihuahuan desert shrub—a strictly desert vegetation

[8] Referred to as Sierra del Agua de las Cabras by Bose (1927, p. 19) and Humphrey (1956, p. 33).

dominated in this region by *Larrea* (creosote bush), *Agave lechuguilla, Forquieria splendens* (ocotillo), *Prosopis* (mesquite), and *Acacia.* (2) Grasslands. (3) Transitional grasslands—true grasslands occur only on the deep soils of the high valleys of the area; transitional grasslands are those areas with a mixture of grasses and desert vegetation including *Yucca, Nolina* (beargrass), *Agave,* and *Dasylirion* (sotol). (4) Montane chaparral and low forest—shrub oak (chaparral) and low, open oak forests. (5) Montane mesic forest—open pine forest occurring only in the high

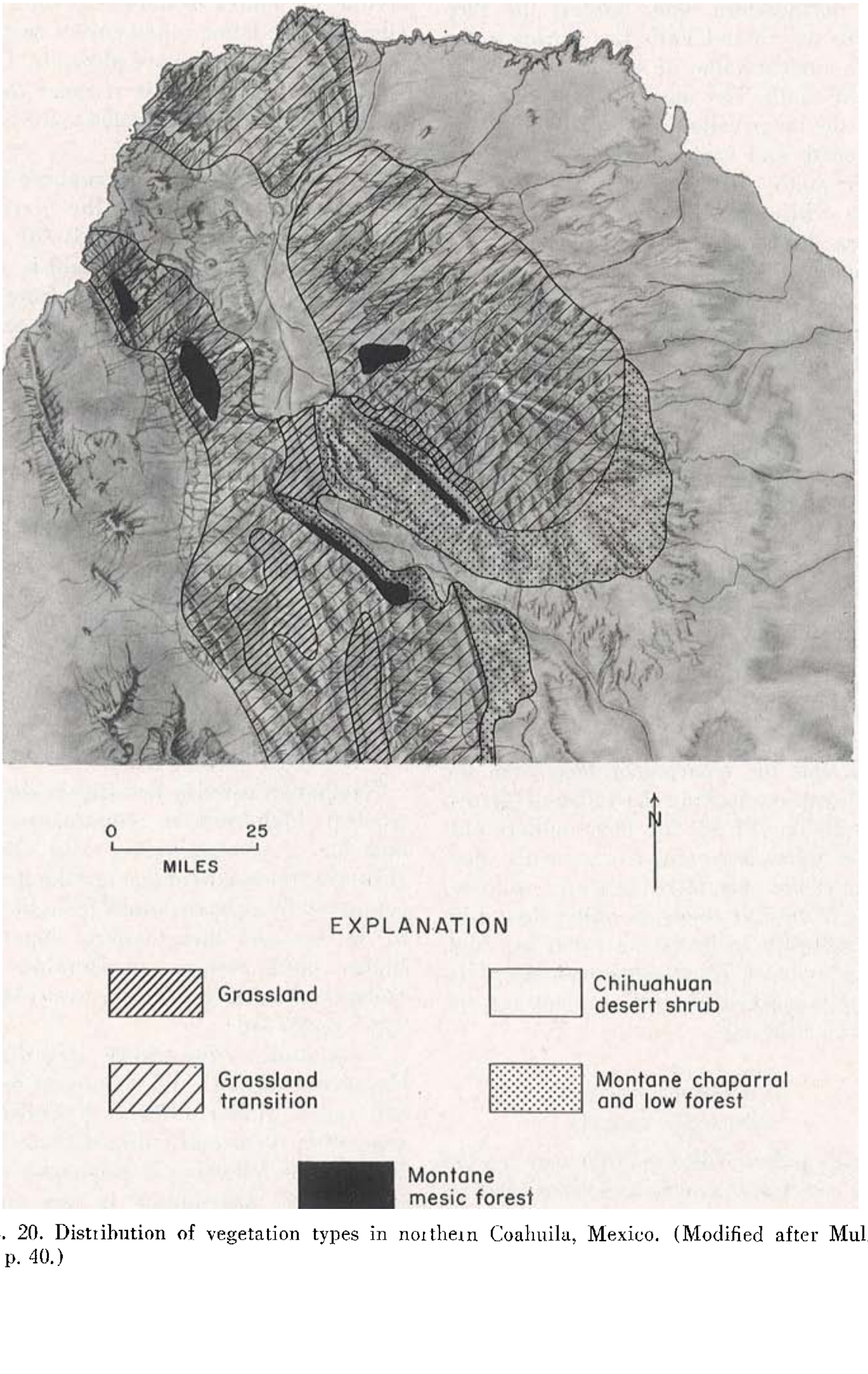

FIG. 20. Distribution of vegetation types in northern Coahuila, Mexico. (Modified after Muller, 1947, p. 40.)

Sierras. These small areas are the remnants of once vast forests that covered this region in a cooler more humid time.

The economy of the region is based on ranching and mining. Because of the grasses and vast areal extent of the grasslands and grassland transition described above, this part of northern Coahuila has long been one of the major beef-producing areas of the North American continent. More recently, discovery of large fluorspar deposits in the Pico Etéreo district and Mesa de los Fresnos has added to the economy.

The accessibility of the area has been greatly facilitated by recent road improvement necessitated by mining development. A good gravel road has been built from Muzquiz to the central Sierra del Carmen via the Arroyo de la Babia and improvements have been made in the Acuña-La Linda road which passes through Cañón Colorado. The connecting road between these two, the Santo Domingo-Las Norias road, has not been noticeably improved but is still considered a primary thoroughfare. A third road improvement, not related to mining, was the reconstruction of the Acuña-Zaragoza road. These three roads provide primary access to various parts of the area from Acuña, Zaragoza, Muzquiz, and La Linda. Secondary or ranch roads extend from these to ranches and ejidos. Almost any part of the area is easily accessible by vehicle with the exception of the heart of the southern Serranía del Burro—Oso Blanco area (fig. 4). This region is accessible only by foot or horseback.

B. SYNOPSIS OF R. J. DUNHAM'S LIMESTONE CLASSIFICATION SCHEME

R. J. Dunham's "Classification of Carbonate Rocks According to Depositional Texture" (1962, pp. 108–121) was used in both field and laboratory description of rock specimens. This classification scheme is most useful in stratigraphic-facies analysis studies in that it emphasizes those rock characteristics which may be directly interpreted in terms of depositional environment of the sediment. Dunham's classification chart is shown in table 4.

The boundstone class (table 4) is distinguished from the non-bound classes by presence of an organic, sediment-binding agent or by physical features related to a bound framework. Depending on identification of the binding agent, a particular specimen may be designated coral lime boundstone, algal-laminated lime boundstone, etc. Additional descriptive terms or phrases may be added before or after the class name to complete the description. The basis of subdivision within the non-bound group is the total absence versus the presence of mud (20 microns) between grains and on the bulk ratio of grains to mud. Identification of grain-kind, sedimentary structures, diagenetic and weathering features, etc., may be added as adjectival modifiers to the textural class name to provide a complete description (i.e., white, brittle, globigerinid lime mudstone; cross-bedded, oolite lime grainstone; and nodular, gastropod lime wackestone).

The crystalline carbonate class (table 4) includes those rocks retaining too little of their depositional texture to be classified in the scheme outlined above. In the measured sections accompanying this report, these rocks are described as recrystalized.

TABLE 4. *Classification of carbonate rocks according to depositional texture.* After Dunham (1961,p. 117).

DEPOSITIONAL TEXTURE RECOGNIZABLE					DEPOSITIONAL TEXTURE NOT RECOGNIZABLE
Original components not bound together during deposition				Original components were bound together during deposition as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices	
Contains mud (particles of clay and fine silt size)			Lacks mud and is grain-supported		
Mud-supported		Grain-supported			
Less than 10 percent grains	More than 10 percent grains				
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	Crystalline carbonate (Subdivide according to classifications designed to bear on physical texture or diagenesis.)

C. MEASURED SECTIONS

The location of each of these measured sections is shown on figure 7. With the exception of the Del Rio clay, all sedimentary rocks described in these sections are limestones, marly limestones, or limy marls. For this reason the adjective "lime," which would ordinarily precede the Dunham classification categories (mudstone, wackestone, and grainstone) is considered unnecessarily repetitious and has been omitted here.

Section 1. Agua Verde

Unit		*Feet*
Del Carmen Formation (incomplete)—		
1.	*Toucasia,* miliolid, shell fragment wackestone with chert at the base; two layers of *Monopleura* and a thin, miliolid grainstone in the middle	29.2
2.	Shell fragment wackestone with radiolitids and caprinids above, *Toucasia* at top and bottom, and miliolids at the base	30.3
	Total	59.5
Sue Peaks Formation—		
3.	Nodular, shell fragment wackestone alternating with miliolid, shell fragment wackestone containing *Toucasia* and *Monopleura*	16.1
4.	Nodular, shell fragment wackestone with heart clams and large gastropods; *Toucasia* common near base	25.4
	Total	41.5
Santa Elena Formation—		
5.	Partly recrystallized, shell fragment wackestone with common *Toucasia*; irregular chert abundant below overlain by a solutioned, recrystallized zone	15.4
6.	Mudstone with "finger" chert above and stylolitic seams below; two thin layers of wackestone	38.6
7.	Recrystallized with miliolid grainstone at the base	16.0
8.	Rudist fragment wackestone with abundant *Chondrodonta* and *Toucasia* at top	9.8
9.	Thin- to thick-bedded mudstone with chert and two solutioned zones below	34.7
10.	Mudstone with chert below, grading up to shell fragment wackestone with *Toucasia* and radiolitids at the top	35.0
11.	Shell fragment wackestone with *Toucasia, Chondrodonta,* and miliolids	16.8
12.	Recrystallized	8.5
13.	Shell fragment wackestone with rudists at top and bottom; chert at base	23.0
14.	Shell fragment wackestone grading up to recrystallized grainstone (?) at top; chert at base	20.5
15.	Mudstone below grading up to fine, sorted grainstone with few shell fragments; one cross-bedded layer and irregular large silicified areas	101.4
16.	Miliolid, shell fragment wackestone with two levels of abundant silicified radiolitids and *Chondrodonta*	29.8
17.	Shell fragment wackestone with miliolids throughout; slender gastropods and *Pecten* below	16.0
18.	Miliolid grainstone with chert below	9.0
19.	Shell fragment wackestone with radiolitids	11.0
20.	Shell fragment wackestone with miliolids at the base	45.0
21.	Alternating nodular, shell fragment wackestone and thin, marl beds; *Gryphaea* common to abundant	34.9
	Total	465.4
Del Rio Formation—		
22.	Partly covered yellowish-weathering clay with abundant iron nodules; fossils rare; *Exogyra arietina* at base and top; *Haplostiche* common at the top in thin beds of shell fragment, lithoclast, rippled, silty grainstone	61.0
	Total	61.0
Buda Formation—		
23.	Shell fragment wackestone; nodular and burrowed above lower 2 feet	10.0

24.	Partly covered, soft, nodular marl and marly wackestone	31.0
25.	Even-bedded, hard, brittle, white mudstone	34.0
	Total	75.0
	Base Boquillas Formation.	
	TOTAL SECTION MEASURED	702.4

Section 2. Cañón San Rosendo

Unit		*Feet*
	Top Glen Rose Formation.	
	Telephone Canyon Formation—	
1.	Covered below; soft, nodular, shell fragment wackestone with *Exogyra texana* and heart clams at top; sand bed at base	12.5
2.	Slightly nodular, shell fragment, gastropod wackestone; miliolid, shell fragment grainstone at top with bored surface	25.0
3.	Partly covered, nodular, shell fragment wackestone to mudstone with *Exogyra texana* and heart clams	91.4
	Total	128.9
	Del Carmen Formation—	
4.	Nodular to slightly nodular, miliolid wackestone to mudstone	78.0
5.	Miliolid, shell fragment wackestone; slightly thin bedded and with chert below; nodular at top	63.0
6.	Gastropod, shell fragment wackestone to grainstone with abundant *Gryphaea* at top	25.0
7.	Mudstone	15.0
8.	Gastropod, *Gryphaea* wackestone to mudstone with chert	42.7
9.	Shell fragment wackestone to mudstone with chert	62.0
10.	Rudist mound; mostly recrystallized, shell fragment grainstone (?) with chert on flanks	28.5
11.	Gastropod, shell fragment grainstone to wackestone	22.5
12.	Mudstone with wackestone near middle	45.6
13.	Shell fragment wackestone; upper part nodular	21.8
14.	Shell fragment wackestone with *Toucasia* in upper part	24.0
15.	Mound level with *Toucasia* overlain by recrystallized limestone with chert	35.0
	Total	463.1
	Sue Peaks Formation—	
	Lower unit—	
16.	Yellowish, soft, nodular, marly, shell fragment wackestone with thin, rippled, gastropod and small clam wackestone-grainstones; heart clams, *Gryphaea*, and echinoids common; *Oxytropidoceras* scattered	66.0
	Upper unit—	
17.	Mostly covered mudstone slope	85.5
18.	Even-bedded, recrystallized limestone with chert	85.0
	Total	236.5
	Santa Elena Formation (incomplete)—	
19.	Mostly covered, recrystallized, thin-bedded limestone with chert	70.0
20.	Covered	155.0
21.	Not seen; base of this bed forms excellent mapping horizon	50.0±
22.	Miliolid wackestone to grainstone with caprinids near middle	26.8
	Total	344.0±
	TOTAL SECTION MEASURED	1,173.0±

Section 6. Puerto Prieto

Unit		*Feet*
	Del Carmen Formation (incomplete)—	
1.	Shell fragment, gastropod wackestone with common *Gryphaea*	9.4
	Total	9.4

	Sue Peaks Formation—	
	Lower marly unit—	
2.	Very thin-bedded and laminated mudstone with a few slightly marly layers	10.4
3.	Very thin-bedded and laminated mudstone with marly interbeds; scattered chert	18.0
4.	Yellow to buff, argillaceous, blocky-weathering mudstone with two laminated mudstone interbeds	19.5
5.	Marl	4.4
6.	Yellowish, nodular mudstone	8.4
7.	Covered below; marl at top	19.6
8.	Ledges of gastropod, shell fragment wackestone alternating with marls and nodular, marly mudstones and wackestones with common clams, echinoids, and gastropods; thin-bedded mudstone at top	28.7
9.	Covered	21.0
10.	Hard ledges of shell fragment wackestone alternating with marly mudstones and nodular wackestones	41.0
11.	Nodular, shell fragment wackestones alternating with marly wackestones; common gastropods and clams	20.5
12.	Thin-bedded mudstones and good marl with scattered fossils	25.8
13.	Mudstone with chert	5.0
14.	Covered	15.8
	Upper lime mustone—	
15.	Mudstone with chert in upper three-fourths	265.2
	Total	503.3
	Santa Elena Formation—	
16.	Grainstone (?) with caprinids at top	50.0±
	Total	50.0±
	TOTAL SECTION MEASURED	562.0±

Section 7. Cañón El Cíbolo Section III

Unit		*Feet*
	Top Del Carmen Formation.	
	Sue Peaks Formation—	
1.	Buff, laminated, silty marl and marly mudstone with scattered shell fragments	4.2
2.	Thin-bedded, gray mudstone with small miliolids below grading up to slightly burrowed, small clam, gastropod, and miliolid wackestone above; chert in thin layers throughout	14.5
3.	Slightly nodular and marly to thin-bedded, burrowed mudstone and wackestone	10.4
4.	Nodular, green to gray, marly mudstone with scattered clams and gastropods	27.0
5.	Medium-bedded, shell fragment, miliolid wackestone	8.0
6.	Nodular, marly mudstone with clams, gastropods, and echinoids alternating with mudstone ledges	20.8
7.	Hard, miliolid, shell fragment wackestone	5.2
8.	Covered	15.0±
	Total	105.0±
	Base Santa Elena Formation.	
	TOTAL SECTION MEASURED	105.0±

Section 8. Cañón El Cíbolo

Unit		*Feet*
	Glen Rose Formation (incomplete)—	
1.	Sill	5.8
2.	Covered	26.5
3.	Dark gray, brittle mudstone with shell fragments; slightly metamorphosed with abundant pyrite and small round white spheres	14.0
4.	Covered	15.9
5.	Dark gray to black, brittle mudstone with abundant small sills and dikelets; shell fragments common	84.8

6.	Partly covered, shell fragment wackestone with heart clams; burrows in resistant ledges	26.5
7.	Covered	16.0
8.	Dark gray, shell fragment wackestone and mudstone with large *Nerinea* and heart clams	51.7
9.	Mostly covered, shell fragment wackestone with *Toucasia* and large oysters	48.6
10.	Alternating hard and soft beds of slightly nodular, shell fragment wackestone with abundant gastropods, heart clams, and *Gryphaea*	42.4
11.	Shell fragment mudstone and wackestone with *Toucasia, Monopleura,* and miliolids	15.6
12.	Covered	42.4
13.	Nodular, *Orbitolina texana, Gryphaea,* shell fragment wackestone with common heart clams and echinoids	159.7
14.	Mudstone; nodular below with scattered *Orbitolina;* thin bedded with miliolid wackestone at top	22.5
15.	Shell fragment wackestones with *Orbitolina texana* and miliolids	42.3
16.	Hard, miliolid, shell fragment wackestone to grainstone with monopleurids alternating with mostly covered, receding, nodular, marly mudstones	101.2
17.	Partly covered, *Orbitolina texana* wackestone	67.0
18.	Mostly covered, receding, shell fragment wackestones with thin ledges of miliolid, shell fragment, burrowed wackestone	189.4
19.	Resistant ledges of miliolid, gastropod, shell fragment wackestone to packstone with partly covered marly beds between	41.8
20.	Miliolid, shell fragment wackestones and soft marl layers with common heart clams; two bored surfaces	34.5
21.	Miliolid, shell fragment wackestone with marls and nodular marls; bored surface near top; *Toucasia* below	84.5
22.	Mostly covered, miliolid, shell fragment wackestone with a thin *Gryphaea* ledge near middle	80.0
	Total	1,213.1
	Telephone Canyon Formation—	
23.	Mostly covered, soft, nodular, marly wackestones and marls with abundant *Exogyra texana, Gryphaea,* heart clams, and small oysters	126.7
	Total	126.7
	Devils River Formation (incomplete)—	
24.	Nodular, miliolid, shell fragment wackestones and marly wackestones with a few *Exogyra texana*	58.2
25.	Mudstone; nodular above	11.4
26.	*Toucasia,* miliolid, shell fragment wackestone; chert below	44.6
27.	Partly covered and recrystallized, miliolid, shell fragment, gastropod wackestone to mudstone with common chert; two thin, miliolid grainstones; common *Gryphaea* near middle	152.2
28.	Shell fragment wackestone with *Toucasia* and a few silicified caprinids; two thick chert layers	38.3
29.	Very distinctive, miliolid, shell fragment grainstone	25.0
30.	Partly covered mudstones and shell fragment wackestones	112.0
31.	Massive, almost vertical cliff of recrystallized limestone; shell fragments common; inclined bedding visible in places	107.0
32.	Alternating *Toucasia,* shell fragment wackestones and radiolitid, *Chondrodonta* wackestones; *Monopleura* near the middle and at the top; chert common in the upper part	220.0
33.	Miliolid, *Toucasia* wackestone and recrystallized mudstone (?) with chert below grading upward to radiolitid, *Toucasia* wackestone at the top	120.0
34.	Partly recrystallized; shell fragment wackestones and mudstones with miliolids at several levels; chert common throughout	360.0
35.	Partly recrystallized, shell fragment mudstone to miliolid wackestone to grainstone	143.0
36.	Slope forming, even-bedded, shell fragment mudstone with one caprinid and one *Gryphaea* at top	235.5
	Total	1,626.4
	TOTAL SECTION MEASURED	2,966.2

Section 10. Cañón La Palma

Unit	Feet
Glen Rose Formation (incomplete)—	
1. Miliolid, shell fragment wackestone below and small gastropod and clam wackestone above; two good marl breaks near middle	12.6
2. Alternating marls and thin, gastropod, shell fragment wackestone ledges; *Exogyra texana* common at base; top ledge bored	17.2
3. Burrowed, nodular, shell fragment wackestones and marly mudstone; *Gryphaea* common above; bored surface near middle	20.5
Total	50.3
Telephone Canyon Formation—	
4. Barren, platy marl	17.5
5. Soft, platy marl with ledges of nodular, burrowed, shell fragment wackestone; *Exogyra texana,* heart clams, *Tylostoma, Lunatia,* and *Gryphaea* scattered throughout	127.5
Total	145.0
West Nueces Formation—	
6. Nodular mudstone with small gastropods and clams above and miliolids below	117.1
7. Burrowed mudstone; slightly nodular below with small gastropods and clams; dolostone near middle and dolomitized burrows above	35.0
8. Sill	25.0
9. *Dictyoconus,* shell fragment wackestone	16.5
10. Miliolid, shell fragment wackestone; recrystallized in middle; *Toucasia* at top	24.5
11. Thin-bedded dolostone and mudstone with chert; *Gryphaea* at base	13.5
12. Miliolid, *Toucasia* wackestone with *Monopleura* at top	30.5
13. Shell fragment wackestone with chert; grainstone to packstone near middle	32.5
14. Recrystallized with chert	11.0
15. *Toucasia, Monopleura* wackestone with dolostone near middle	24.2
16. Recrystallized and dolomitized with large-oyster wackestone near middle	39.4
17. Miliolid, *Toucasia* wackestone with chert and a few caprinids; grainstone at base	18.5
18. Alternating miliolid, pellet grainstones with wackestones; scattered chert and a few *Toucasia* and large oysters above	162.5
Total	550.2
McKnight Formation—	
19. Mostly covered, thin-bedded to laminated mudstone and miliolid mudstone with common ribbon and fecal pellets; lithoclasts common particularly at top and base	70.0
Total	70.0
Salmon Peak Formation—	
Lower unit—	
20. White, thick-bedded mudstone with fine shell fragments and globigerinids	419.0
Upper unit—	
21. Fine, shell fragment wackestone at the base becoming coated-pellet, shell fragment grainstone upward; grain size increases upward	192.4
22. Well-bedded, miliolid, shell fragment wackestone with abundant chert and radiolitids at top	124.8
23. Shell fragment wackestone with silicified caprinids and radiolitids at top	26.0
24. Recrystallized with chert	17.5
25. *Toucasia,* shell fragment wackestone	18.9
Total	798.6
Del Rio Formation—	
26. Mostly covered, soft, yellowish clay with *Exogyra arietina* and thin, brown beds with *Haplostiche texana*	23.3
Total	23.3
Buda Formation (incomplete)—	
27. Buda	9.0
TOTAL SECTION MEASURED	1,646.4

Section 14. Rancho Santo Domingo

Unit	*Feet*
Telephone Canyon Formation (incomplete)—	
1. Nodular, slightly marly, shell fragment wackestone to mudstone becoming more marly downward; common heart clams, *Gryphaea*, and gastropods	31.2
2. Slightly nodular with shell fragments and scattered miliolids	22.8
Total	54.0
Devils River Formation (incomplete)—	
3. Mottled mudstone with oyster and *Toucasia* fragments	35.4
4. Miliolid, pellet, shell fragment grainstone	10.6
5. *Gryphaea* wackestone to mudstone with chert above; two covered zones	32.7
6. Thin- to medium-bedded mudstone with chert; recrystallized below	43.8
7. Shell fragment wackestone with radiolitids	10.0
8. Shell fragment wackestone with chert; *Toucasia* at the top and recrystallized below	52.4
9. Miliolid, shell fragment wackestone with chert; large oysters at the top and recrystallized below	45.2
10. Miliolid, pellet, shell fragment grainstone; *Dictyoconus* near the base; upper 100 feet very fine grained and upper 50 feet with stylolitic bedding planes	286.0
11. Slightly nodular above with *Gryphaea;* covered zone below appears to be "punky" recrystallized or dolomitized	33.8
12. Dark brown, completely recrystallized thin beds with chert	30.0
13. Medium to coarse, shell fragment grainstone with cross-bedding	52.0
14. Miliolid wackestone and mudstone to grainstone with scattered *Toucasia* fragments; chert throughout; two dolostone layers	322.4
15. Mudstone with fecal pellets (?); chert scattered throughout	171.6
16. Very fine pellet, small miliolid (?) grainstone; slightly coarse above and thin-bedded zone near middle	218.4
17. Estimated 250± feet of radiolitid, miliolid grainstone beds	250.0±
Total	1,594.0±
TOTAL SECTION MEASURED	1,648.0±

Section 16. Cañón El Mulato

Unit	*Feet*
Glen Rose Formation (incomplete)—	
1. Miliolid, shell fragment wackestone burrowed at top	10.8
2. Nodular, marly, shell fragment, miliolid wackestone to mudstone with scattered heart clams	11.5
3. Dark gray mudstone with scattered miliolids; burrowed, shell fragments and miliolids	10.1
4. Nodular, marly mudstone with shell fragments and miliolids	14.3
5. Gastropod, shell fragment wackestone at top and bottom; shell fragment mudstone in middle	17.3
6. Mudstone with chert	17.2
7. Small gastropod, miliolid, shell fragment wackestone to grainstone	124.7
8. Soft, nodular, marly mudstone with burrows near base	15.3
9. Miliolid, gastropod, shell fragment grainstone	15.3
10. Miliolid wackestone to mudstone with *Toucasia* above	22.3
11. Miliolid, small gastropod, shell fragment, pellet grainstone with *Gryphaea* at top	33.9
12. Miliolid wackestone	15.0
13. Cross-bedded, miliolid, shell fragment grainstone with *Toucasia*	20.0
14. Miliolid wackestone and nodular mudstone	70.6
15. Resistant, shell fragment wackestones and nodular, marly, yellowish mudstones becoming more nodular upward; heart clams and *Lunatia* common at base	67.1
Total	405.4
Telephone Canyon Formation—	
16. Nodular, yellowish marl and marly mudstone slope with *Exogyra texana, Gryphaea,* heart clams, *Lunatia,* and echinoids	90.0
Total	90.0

West Nueces Formation—	
17. Hard, thin, *Gryphaea* wackestone	8.2
18. Solutioned, recrystallized limestone with fluorite; lower part dolomitized and with *Gryphaea;* upper part has grumose texture or is a pellet grainstone	36.1
19. Rudist fragment wackestone below and whole caprinid wackestone above	21.7
20. *Toucasia* fragment wackestone with chert at top. The whole unit is massively bedded and expands and contracts along exposure	54.0
21. Miliolid grainstone below grading up to wackestone with shell fragments and *Toucasia;* chert near top	33.3
22. Miliolid, *Toucasia,* shell fragment wackestones and grainstones with chert; abundant *Gryphaea* at top	22.9
Total	176.2
McKnight Formation—	
23. Thin-bedded, recrystallized beds below; *Gryphaea* biostrome with chert at top	11.5
24. Thin-bedded to laminated mudstone partly recrystallized and with abundant chert	35.0
25. Thin-bedded to laminated, alternating mudstone and miliolid, gastropod wackestone to grainstone; chert in thin layers abundant and *Gryphaea* in a few layers	60.0
26. Thin-bedded to laminated mudstone, miliolid wackestone and miliolid, gastropod grainstone with chert in thin layers; lower 6 feet "ribbon" pellet, pellet, and miliolid grainstone	46.3
27. Partly covered, soft, yellowish when weathered, dark and laminated when fresh, organic (?) mudstone alternating with *Gryphaea,* gastropod wackestones	51.0
28. Partly covered and recrystallized, thin-bedded mudstone and shell fragment mudstone; variable dips common on outcrop	48.5
Total	252.3
Salmon Peak Formation (incomplete)—	
29. Massive, thick-bedded, light gray, dense, brittle mudstone with scattered to common globigerinids and small shell fragments	290.7
Total	290.7
TOTAL SECTION MEASURED	1,214.6

Section 17. Cañón Las Calabazas

Unit	*Feet*
Glen Rose Formation (incomplete)—	
1. Gastropod, miliolid, shell fragment wackestone to mudstone and some grainstone ledges alternating with mostly covered, nodular, marly, shell fragment mudstone to wackestone; oysters and oyster shell fragments very common	183.4
2. Marl and marly mudstone with thin, nodular, marly, oyster fragment wackestone and mudstone beds; a thick, miliolid, shell fragment wackestone near the middle and a burrowed wackestone at the top; heart clams scattered throughout	68.1
Total	251.5
Telephone Canyon Formation—	
3. Marl and nodular, marly, shell fragment wackestones with very abundant *Gryphaea, Exogyra texana,* and heart clams	58.4
4. Mudstone	7.1
5. Nodular wackestones	22.4
6. Thin-bedded to laminated, black mudstones and *Gryphaea* wackestones; slightly nodular in lower part	21.5
Total	109.4
West Nueces Formation—	
7. Creamy, mollusk and oyster fragment wackestone to mudstone with stylolitic bedding planes	48.2
8. Very thin-bedded mudstone and shell fragment, miliolid wackestone to grainstone with abundant thin, dark, chert layers. Slightly thicker bedded and with small clams and fecal pellets above	48.9

9. Three to 4-foot thick beds of mudstone with large, nodular chert	30.6
Total	127.7
McKnight Formation—	
10. One to 2-foot thick beds of slightly laminated mudstone and wackestone with layered chert	12.3
11. Ribbon-pellet and pellet wackestone at the base and grainstone at the top with *Gryphaea*, lithoclast, miliolid, pellet wackestone in the middle	13.7
12. Shell fragment, miliolid wackestone to grainstone with *Gryphaea* and chert	37.4
13. Recrystallized	13.6
14. Miliolid, gastropod, shell fragment grainstone with abundant lithoclasts at top	5.1
15. Gastropod, *Gryphaea*, miliolid grainstone to mudstone alternating with thin mudstone and very fine, miliolid, pellet grainstone; chert common	54.6
16. Thin, alternating beds of fecal-pellet grainstone to mudstone and gastropod, clam, and miliolid wackestone; *Gryphaea* in upper part; chert common throughout	26.5
17. Mostly covered, dark gray to black, fissile mudstone with *Oxytropidoceras*	36.7
18. Gray to black mudstone below with *Oxytropidoceras*; thin-bedded mudstone and pellet grainstone above with chert	12.1
19. Solutioned and recrystallized with thin, fecal-pellet beds near middle and collapse breccia at top	13.1
20. Covered	30.6
Total	255.7
Salmon Peak Formation (incomplete)—	
21. White mudstone	10.0±
Total	10.0±
TOTAL SECTION MEASURED	754.0±

Section 18. La Ventana De La Encantada

Unit	*Feet*
Top Glen Rose Formation.	
Telephone Canyon Formation—	
1. Alternating nodular, shell fragment wackestone and yellowish marls; *Exogyra texana*, *Gryphaea*, and heart clams common to very abundant; upper 15 feet covered	49.8
2. Nodular to slightly nodular, shell fragment wackestone to mudstone with common *Gryphaea*	33.5
Total	83.3
Devils River Formation (incomplete)—	
3. Nodular, shell fragment wackestone; slightly recrystallized, hard and with brown mottles near top	46.8
4. Mottled, miliolid wackestone to mudstone with caprinids and *Toucasia* above; slightly recrystallized below	46.0
5. *Gryphaea* wackestone and mudstone at the base; covered above	35.0
6. *Dictyoconus*, shell fragment wackestone with abundant chert	41.7
7. Caprinid, *Toucasia*, shell fragment wackestone to mudstone; grainstone in dipping beds at base	85.8
8. Thin mudstones with miliolids and *Gryphaea*; abundant chert	35.0
9. Miliolid, shell fragment wackestone to grainstone with abundant chert; partly covered throughout	53.0
10. Recrystallized and dolomitized with chert	37.0
11. Miliolid, shell fragment grainstone to wackestone with abundant chert; partly covered throughout	64.6
12. Slope forming, miliolid mudstone to wackestone with chert	88.4
13. Miliolid, shell fragment grainstone	39.0
14. Partly recrystallized, *Toucasia* fragment wackestone	46.1
15. Miliolid, *Toucasia*, shell fragment grainstone and wackestone with abundant chert; partly covered and recrystallized throughout	97.0
16. Radiolitid fragment wackestone	13.0
17. Miliolid mudstone to miliolid, *Toucasia* fragment wackestone with chert	50.0

18.	*Toucasia* fragment grainstone with chert at base	15.0
19.	Miliolid, *Toucasia* mudstone to wackestone to grainstone with chert; radiolitids with *Gryphaea* at top and two *Gryphaea* levels below	235.0
20.	Thin-bedded, laminated, black mudstone with thin chert layers	135.0
21.	*Gryphaea* wackestone	20.0
	Total	1,183.4
	TOTAL SECTION MEASURED	1,266.7

22. Above here there is at least 200 feet of rudist limestone up to the Del Rio Formation.

Plates 3, 4, 7, 8, 11–15

PLATE 3

Photomicrographs of thin sections[9] of typical lithologies of the Cupido Formation in the Sierra El Cedral section

A. Oolite, mollusk fragment lime wackestone, x25. EC-IIA-8, Plate 2.

B. Algal laminated, pellet lime grainstone and ostracod lime mudstone, x10. EC-IIA-10, Plate 2.

C. Oolite lime grainstone, x25. EC-IIA-12, Plate 2.

D. Fine quartz sand, lithoclast, shell fragment lime packstone, x25. EC-IIA-13, Plate 2.

E. Shell fragment, lithoclast lime grainstone with quartz grains and scattered oolites, x10. EC-IIA-14, Plate 2.

F. Pellet lime grainstone, x25. EC-IIB-17, Plate 2.

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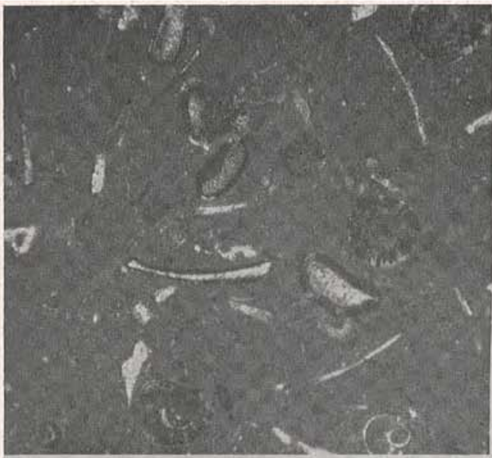
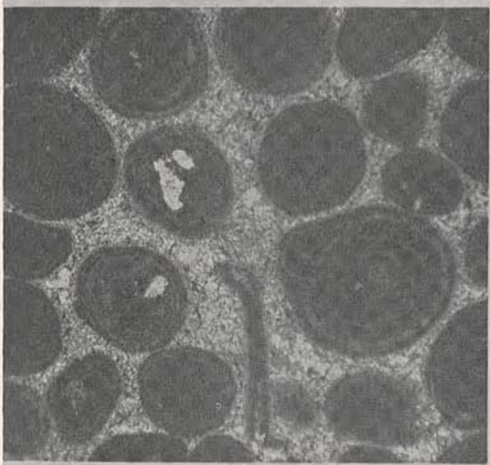
[9] Photomicrographs on this plate and other plates made in plane polarized light. A thin-section identification number and a graphic-section plate number on which each thin section is located are given after each description in the figure caption. Thin sections from localities not illustrated in detail in the text are located verbally.



A

B



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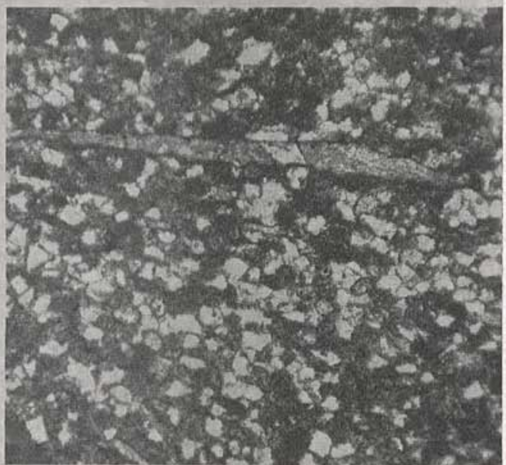

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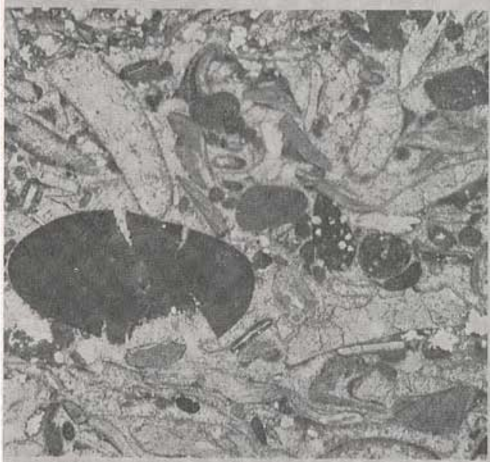


E

F

PLATE 4

Views of outcrops of the La Peña and Glen Rose Formations

A. Contact between the La Peña and Cupido Formations; Cañón de los Locos, Sierra El Cedral section.

B. Outcrop of the La Peña Formation in Cañón de los Locos, Sierra El Cedral section.

C. View of the Glen Rose Formation looking northwest along the front of the Sierra El Cedral. The upper part of the Glen Rose Formation shown on Plate 2 was measured on the mountain slopes in the background.

D. An upper Glen Rose rudist bioherm in tthe Sierra El Cedral section. The same bioherm may be seen at the base of the mountain shown in (C).

E. Bored, iron-stained, disconformity (?) surface at the base of the exposed Glen Rose Formation at Cerro El Palomo, Plate 6.

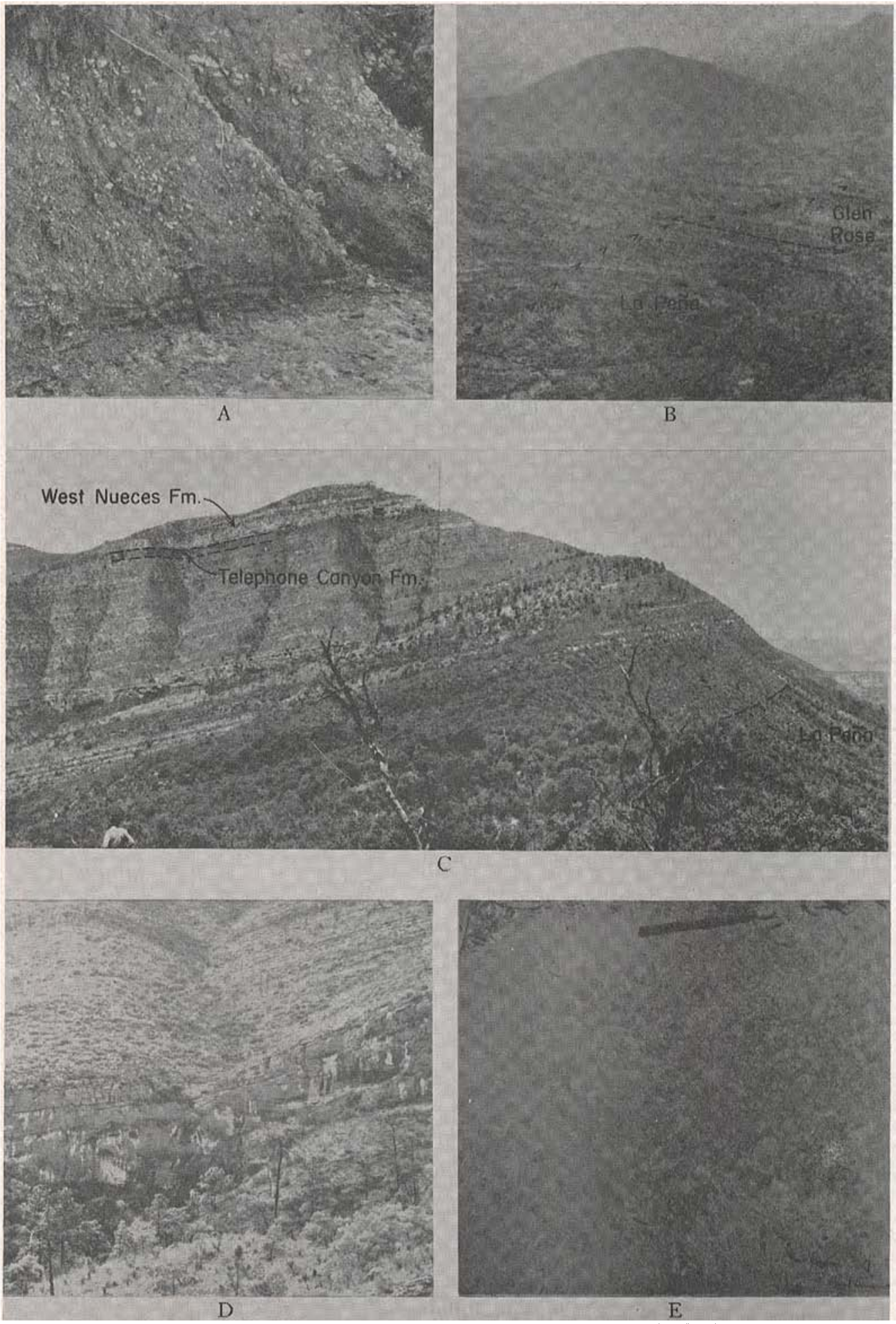

Glen Rose
La Peña
West Nueces Fm.
Telephone Canyon Fm.
La Peña
A
B
C
D
E

PLATE 7

Photomicrographs of thin sections of typical lithologies of the Glen Rose Formation in the Cerro El Palomo section

A. Coated pellet, oolite lime grainstone, x25. CP-I-1, Plate 6.

B. *Orbitolina texana* in miliolid, pellet lime grainstone, x10. CP-I-10, Plate 6.

C. Globigerinid, echinoid fragment lime mudstone, x50. CP-IV-21, Plate 6.

D. *Dictyoconus* (?), miliolid lime wackestone, x20. CP-IV-21, Plate 6.

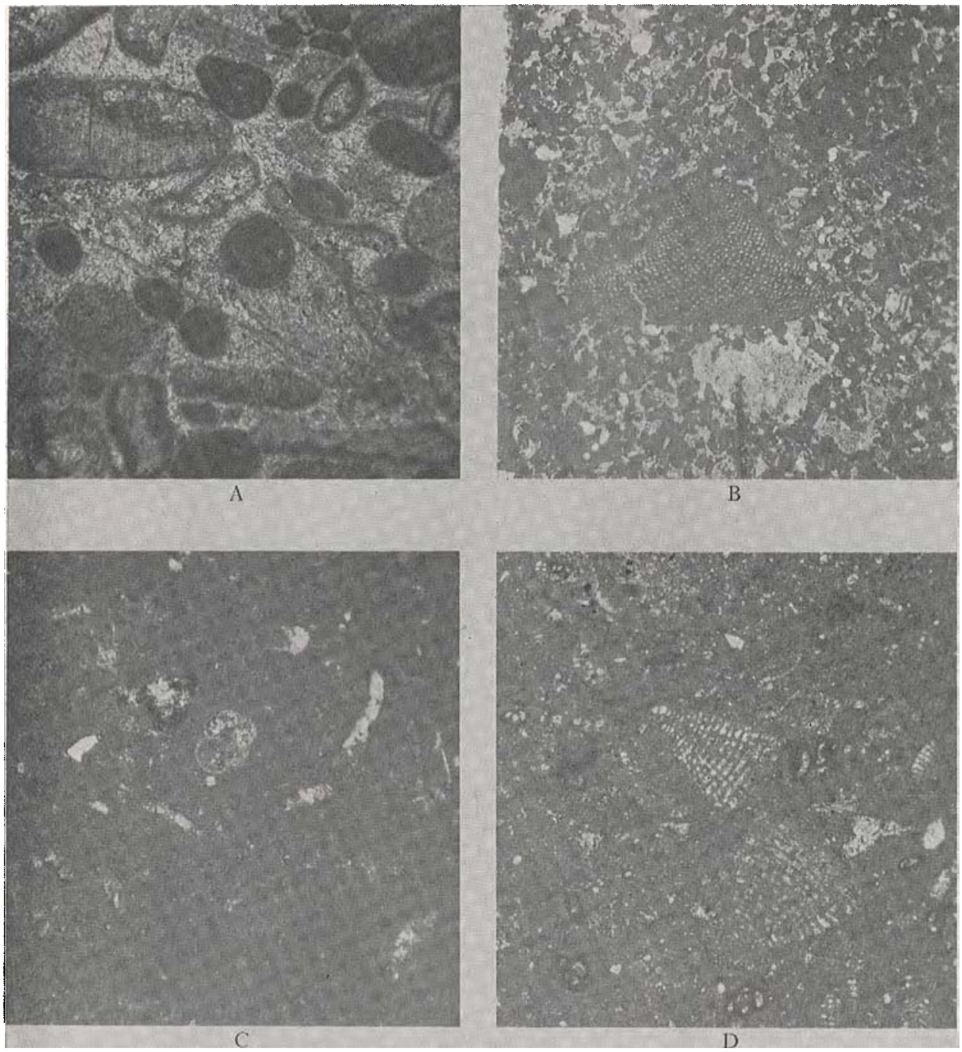

A
B
C
D

PLATE 8

Photomicrographs of thin sections of the Aurora lime mudstone (A-C) and of the Del Carmen Formation (D-F)

A. Globigerinid lime mudstone, x50. Aurora from the Rincón de María.

B. 25–50-micron crystalline dolomite, x50. Aurora from the Sierra de San Gerónimo.

C. Globigerinid lime mudstone to lithoclast (?) lime grainstone, x10. Aurora from the Sierra de San Gerónimo.

D. Miliolid, mollusk fragment lime wackestone to grainstone, x50. Del Carmen Formation from the Cañón El Cíbolo.

E. *Gryphaea* fragment lime wackestone, x10. From the Del Carmen Formation in the Cañón El Cíbolo.

F. Miliolid, pellet, gastropod lime grainstone, x10. From the Del Carmen Formation in the Cañón El Cíbolo.

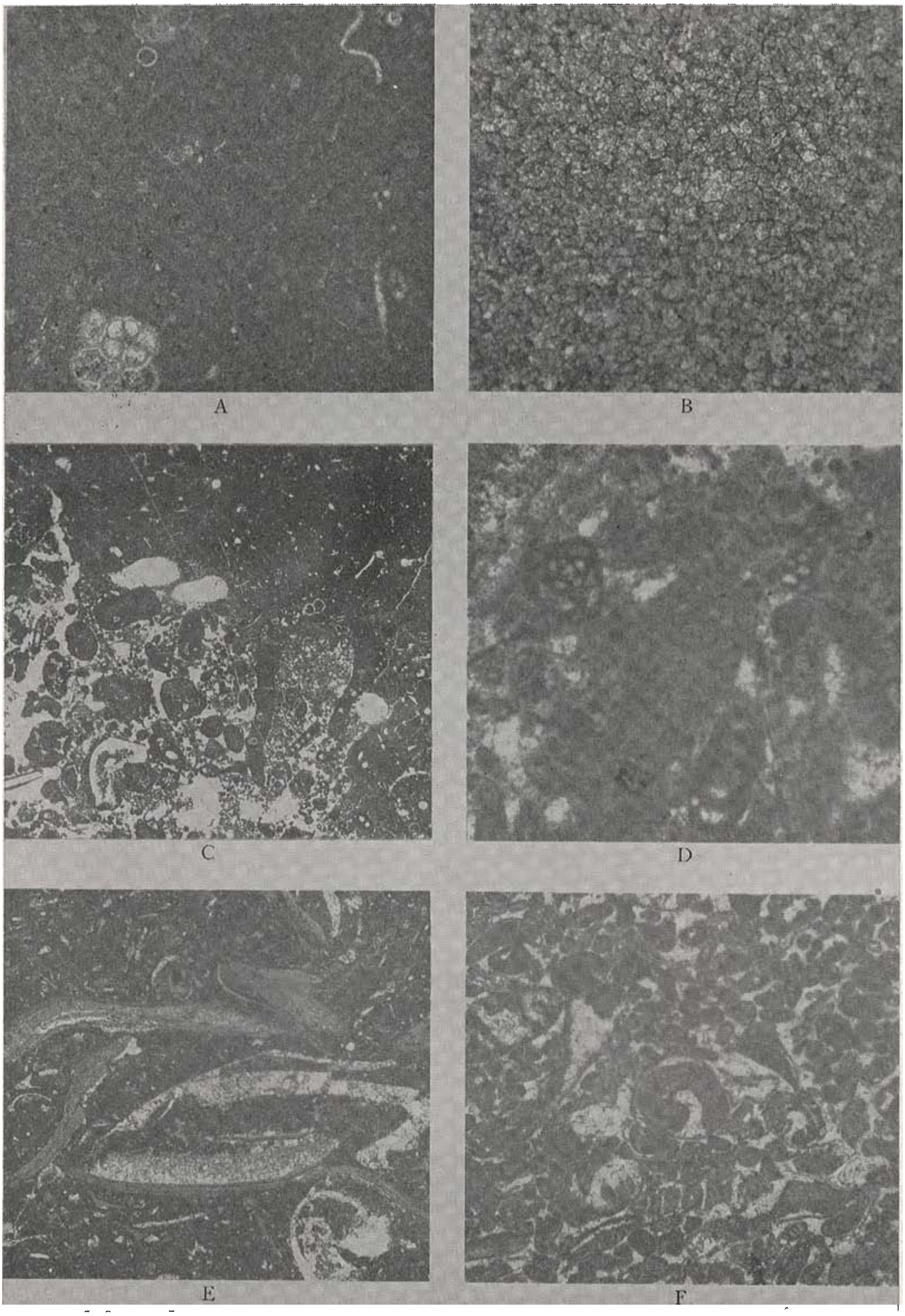

A
B
C
D
E
F

PLATE 11

Views of outcrops of the Fredericksburg and Washita Groups
in the western geologic province area

A. Panorama of the southeast side of Cañón El Cíbolo showing northward termination of the Sue Peaks Formation.

B. Sue Peaks Formation in Cañón Ceferino. A typical exposure in the northern part of the western area.

C. View of the northwest side of Cañón El Cíbolo. Pico El Cíbolo on the left.

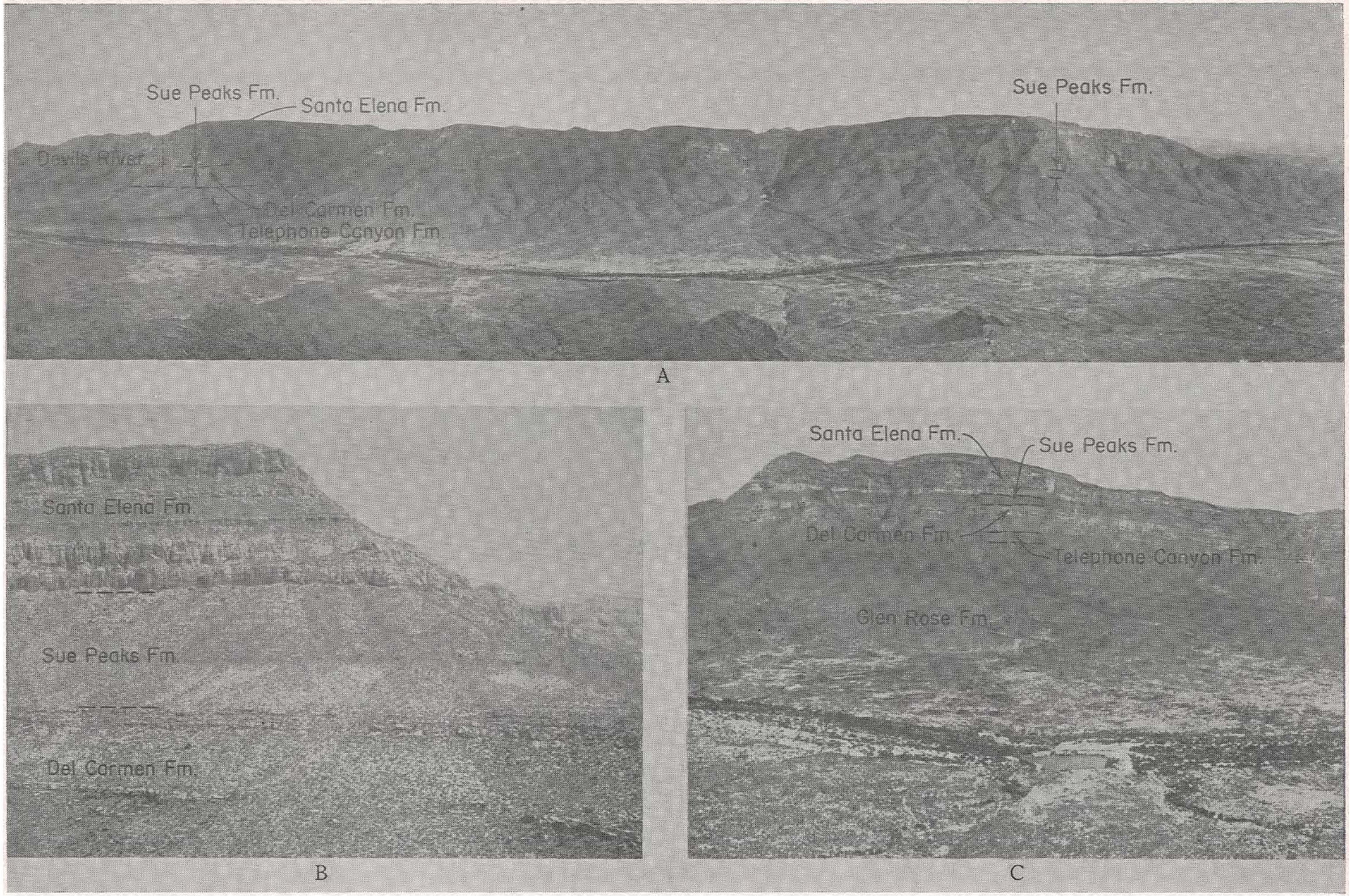

Sue Peaks Fm.
Santa Elena Fm.
Sue Peaks Fm.
Devils River
Del Carmen Fm.
Telephone Canyon Fm.
A
Santa Elena Fm.
Sue Peaks Fm.
Del Carmen Fm.
B
Santa Elena Fm.
Sue Peaks Fm.
Del Carmen Fm.
Telephone Canyon Fm.
Glen Rose Fm.
C

Plate 11

PLATE 12

Views of outcrops of the Fredericksburg and Washita Groups
in the central and eastern geologic province areas

A. Large branching coral in the Devils River Formation; Puerto de Aguacate in the Sierra de San Gerónimo.

B. Radiolitids in growth position in the Devils River Formation; Puerto de Aguacate in the Sierra de San Gerónimo.

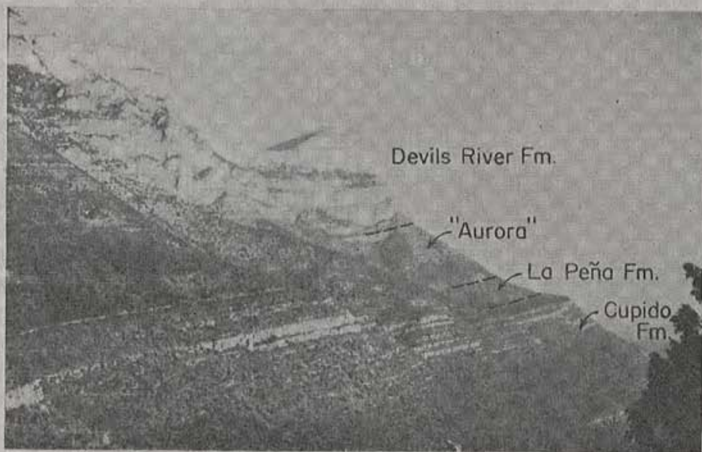
C. Devils River (upper cliff) overlying the Aurora and the La Peña Formation of the Trinity Group (middle slope) and the Cupido Formation of the Coahuilan Series (lower cliff); west wall of the Rincón de María.

D. Upper Salmon Peak inclined grainstones overlying lower Salmon Peak lime mudstones, McKnight Formation and the West Nueces Formation; Cañón Pacheco on Rancho El Cedral.

E. Folded and collapsed McKnight Formation at Rancho San Miguel.

A

B



C

D

E

PLATE 13

Photomicrographs of thin sections of typical lithologies
of the McKnight and Salmon Peak Formations

A. *Gryphaea* fragment, lithoclast, pellet lime grainstone, x10. McKnight Formation from Cañón Las Calabazas.

B. Laminated, fecal-pellet lime grainstone and ostracod lime wackestone, x12. McKnight Formation from Cañón Las Calabazas.

C. Halite pseudomorphs in lime mudstone, interlaminated with coated pellet lime grainstone, x10. McKnight Formation from Cañón Las Calabazas.

D. Globigerinid lime mudstone, x50. Lower unit of the Salmon Peak Formation from Rancho El Mulato.

E. Oriented, pellet lime grainstone, x4. Upper unit of the Salmon Peak Formation from Cañón La Palma.

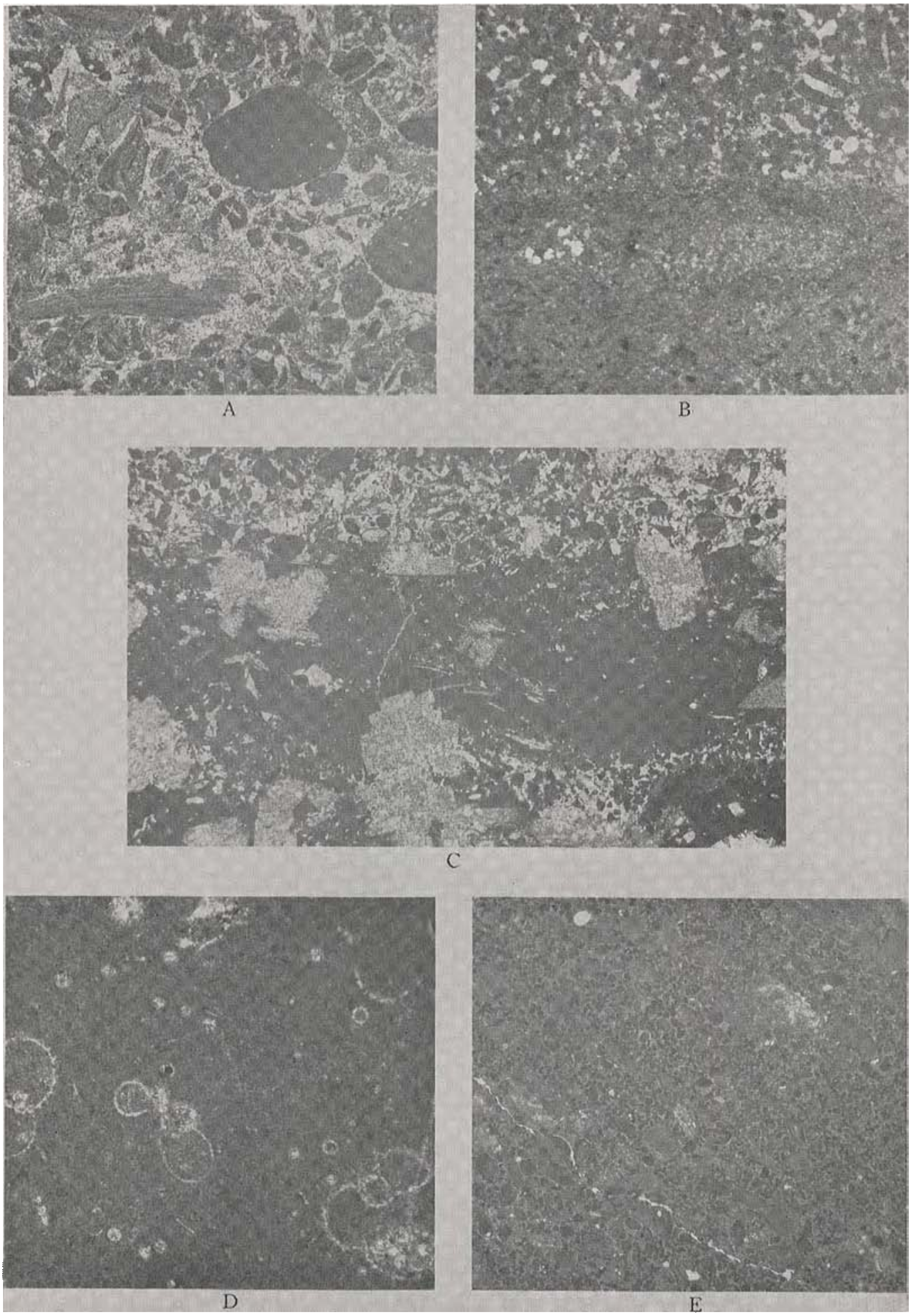
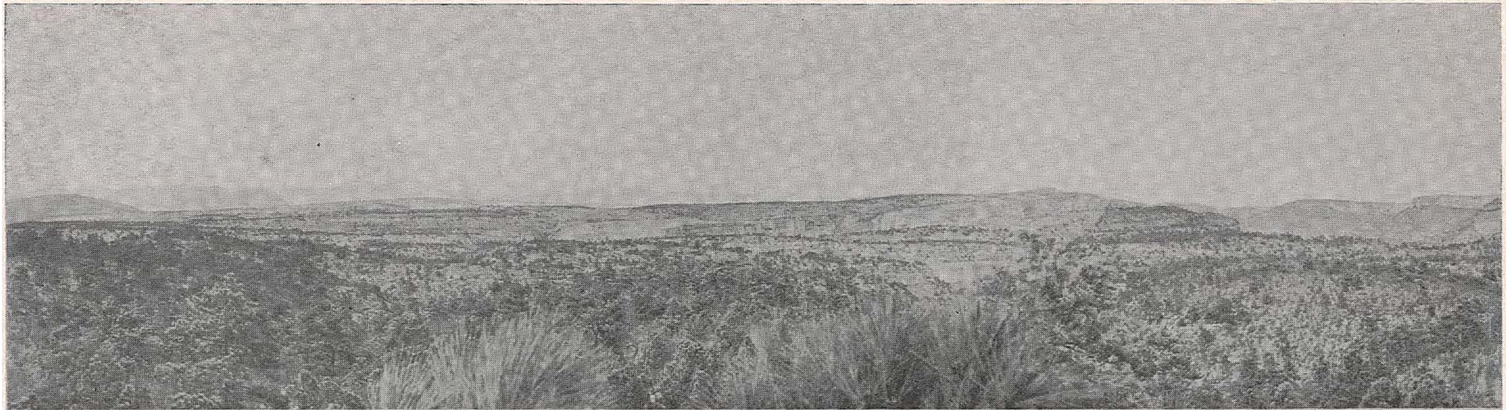

A
B
C
D
E

PLATE 14

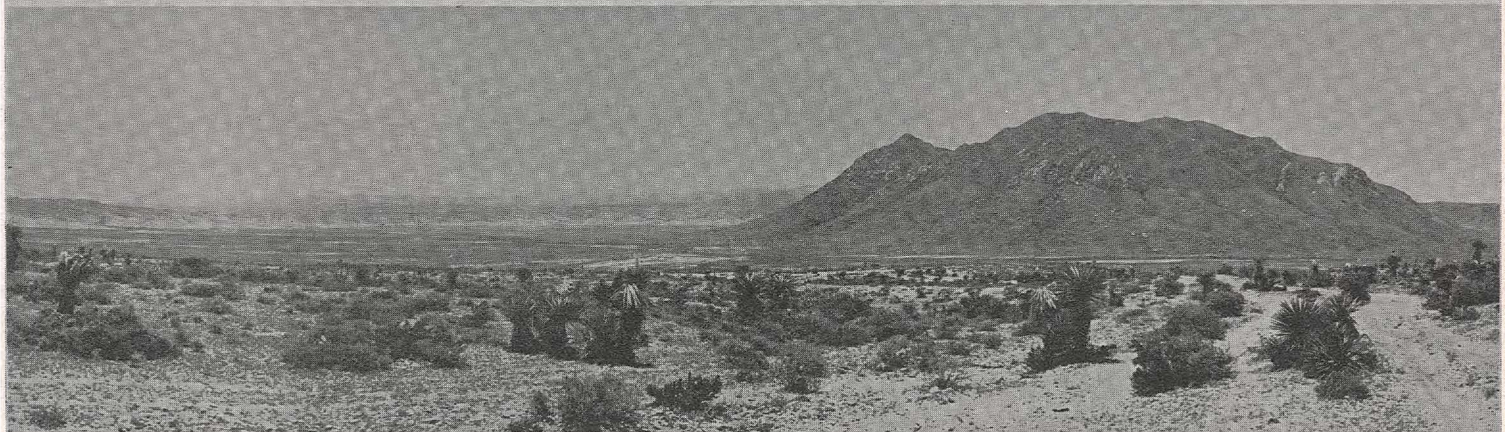
Views of the central Serranía del Burro, northern Coahuila, Mexico

A. Panorama across the central Serranía del Burro, extending from Cerro Colorado on the left to Cañón Cuatralbo on the right; view northwestward taken from a tree in the high southeast corner of the central part of the range.

B. Panorama of Cerro Colorado and surrounding valley from the west; Cerro Nevado faintly visible on the left.



A



B

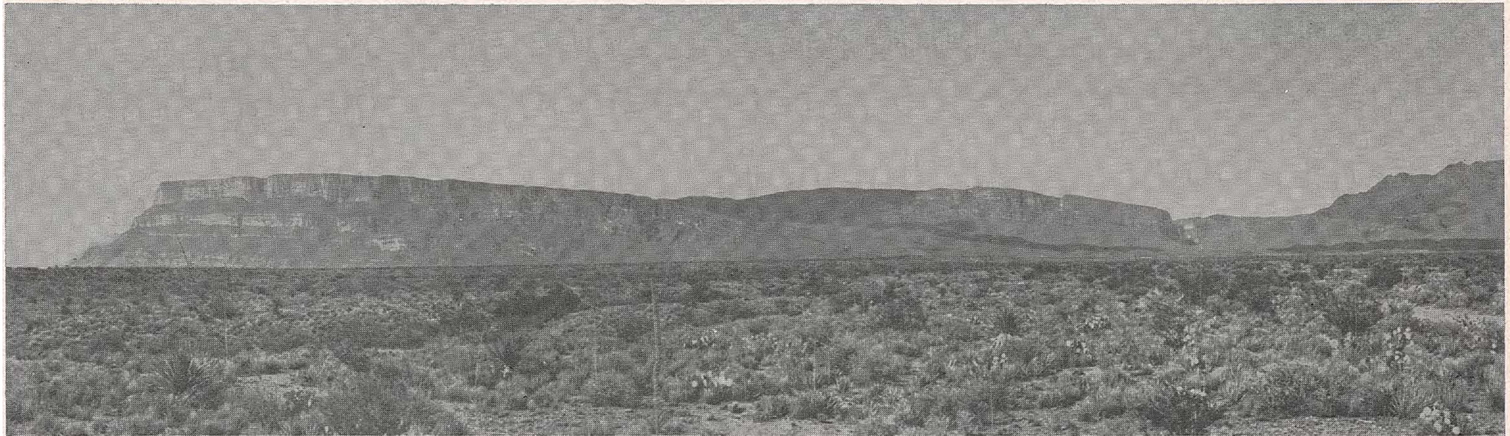
PLATE 15

Views of the Sierra del Carmen, northern Coahuila, Mexico

A. Panorama of the northern Sierra del Carmen (left), Cañón del Jardín (right center), and Pico Centinela (far right); northward view from the Jaboncillos-Boquillas road.

B. Escarpment of the southern Sierra del Carmen; view southeast from hill above La Ventana (canyon in foreground).

C. Panorama across the central Sierra del Carmen; view northwest from the Muzquiz-La Encantada mineral road across the Mesa de los Fresnos to Pico Centinela.



A

B

C

Index

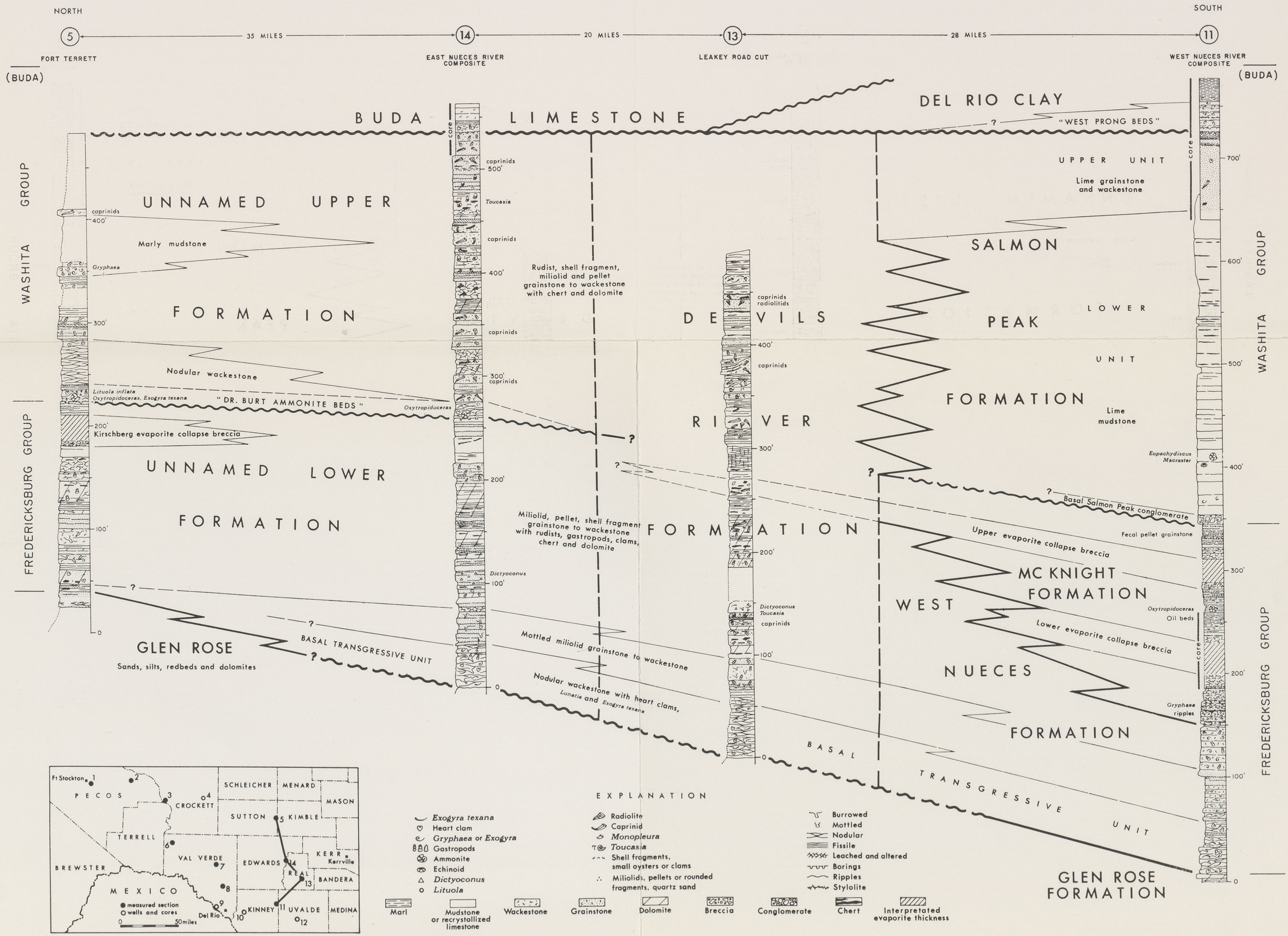


FIG. 13. North-south correlation cross section, southern Edwards Plateau, Southwest Texas. (After Lozo and Smith, 1964, p. 293, fig. 8.)

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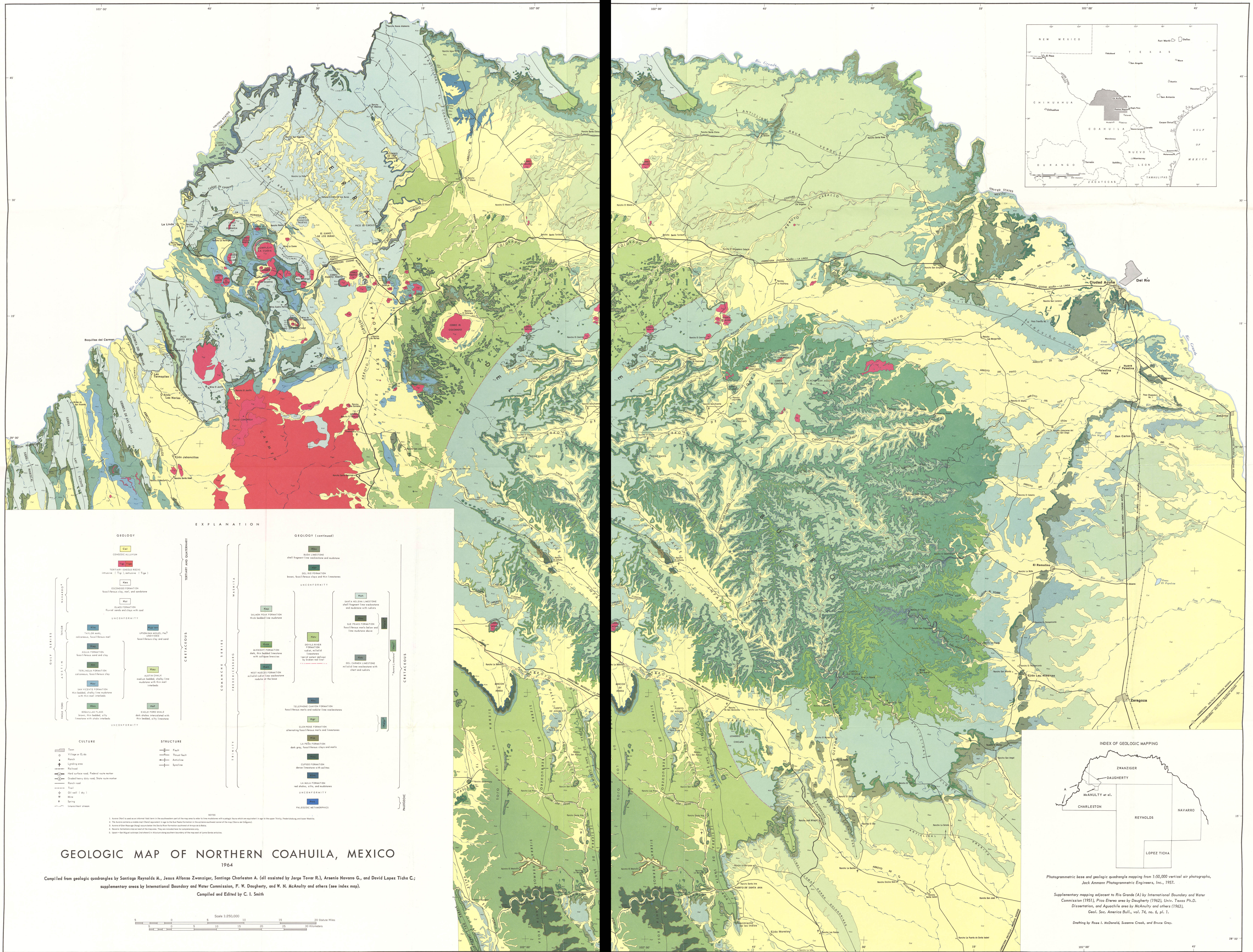

GEOLOGIC MAP OF NORTHERN COAHUILA, MEXICO

1964

Compiled from geologic quadrangles by Santiago Reynolds M., Jesus Alfonso Zwanziger, Santiago Charleston A. (all assisted by Jorge Tovar R.), Arsenio Navarro G., and David Lopez Ticha C.; supplementary areas by International Boundary and Water Commission, F. W. Daugherty, and W. N. McAnulty and others (see index map).

Compiled and Edited by C. I. Smith

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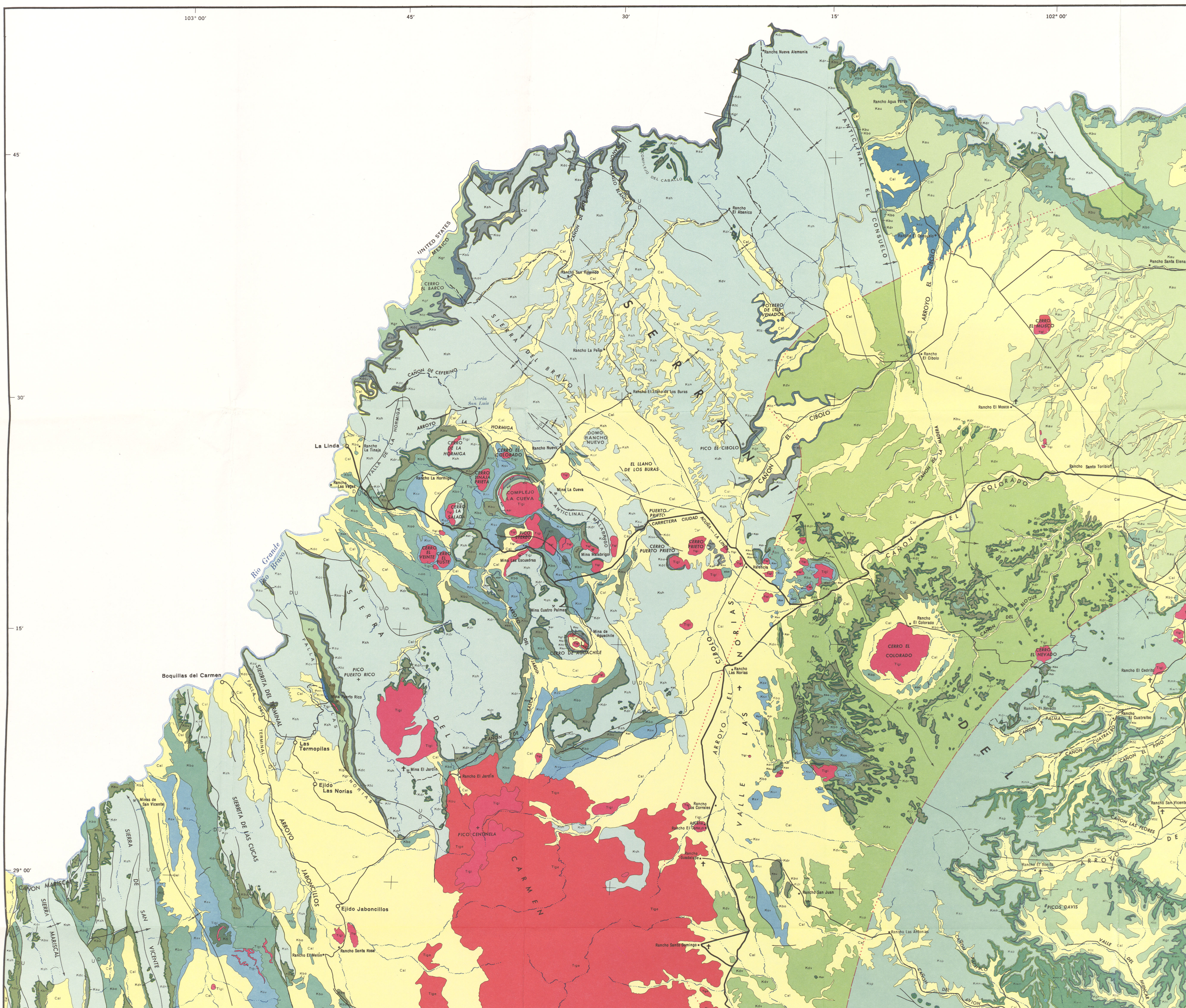

EXPLANATION

GEOLOGY

TERTIARY AND QUATERNARY

Cal — CENOZOIC ALLUVIUM

Tigi, Tige — TERTIARY IGNEOUS ROCKS intrusive (Tigi), extrusive (Tige)

CRETACEOUS

GULF SERIES

NAVARRO[4]

Kes — ESCONDIDO FORMATION fossiliferous clay, marl, and sandstone

Kol — OLMOS FORMATION fluvial sands and clays with coal

UNCONFORMITY

TAYLOR

Kta — TAYLOR MARL calcareous, fossiliferous marl

Kup-sm — UPSON-SAN MIGUEL FM.[5] UNDIVIDED fossiliferous clay and sand

AUSTIN

Kag — AGUJA FORMATION fossiliferous sand and clay

Ktl — TERLINGUA FORMATION calcareous, fossiliferous clay

Ksv — SAN VICENTE FORMATION thin bedded, chalky lime mudstone with thin marl interbeds

Kau — AUSTIN CHALK medium bedded, chalky lime mudstone with thin marl interbeds

EAGLE FORD

Kbo — BOQUILLAS FLAGS brown, thin bedded, silty limestone with shale interbeds

Kef — EAGLE FORD SHALE dark shales intercalated with thin bedded, silty limestone

UNCONFORMITY

GEOLOGY (continued)

CRETACEOUS

COMANCHE SERIES

WASHITA

Kbu — BUDA LIMESTONE shell fragment lime wackestone and mudstone

Kdr — DEL RIO FORMATION brown, fossiliferous clays and thin limestones

UNCONFORMITY

FREDERICKSBURG

Ksp — SALMON PEAK FORMATION thick bedded lime mudstone

Kmk — McKNIGHT FORMATION dark, thin bedded limestone with collapse breccias

Kwn — WEST NUECES FORMATION miliolid rudist lime wackestone nodular at the base

Kdv — DEVILS RIVER FORMATION rudist, miliolid limestones (aerial extent defined by broken red line)

Ksh — SANTA HELENA LIMESTONE shell fragment lime wackestone and mudstone with rudists

Ksu — SUE PEAKS FORMATION fossiliferous marls below and lime mudstone above — (Kars)[2]

Kdc — DEL CARMEN LIMESTONE miliolid lime wackestone with chert and rudists

"Aurora Limestone" (Kar)[1]

Ktc — TELEPHONE CANYON FORMATION fossiliferous marls and nodular lime wackestones

TRINITY

Kgr — GLEN ROSE FORMATION alternating fossiliferous marls and limestones — (Karg)[3]

Klp — LA PEÑA FORMATION dark gray, fossiliferous clays and marls

Kcu — CUPIDO FORMATION dense limestone with oolites

Klm — LA MULA FORMATION red shales, silts, and mudstones

UNCONFORMITY

PALEOZOIC

Pmt — PALEOZOIC METAMORPHICS

CULTURE

- Town
- Village or Ejido
- Ranch
- Landing area
- Railroad
- Hard surface road; Federal route marker (57)
- Graded heavy duty road; State route marker (22)
- Ranch road
- Trail
- Oil well (dry)
- Mine
- Spring
- Intermittent stream

STRUCTURE

- Fault (U D)
- Thrust fault
- Anticline
- Syncline

NOTES

1. Aurora (Kar) is used as an informal field term in the southwestern part of the map area to refer to lime mudstones with a pelagic fauna which are equivalent in age to the upper Trinity, Fredericksburg, and lower Washita.
2. The Aurora contains a middle marl (Kars) equivalent in age to the Sue Peaks Formation in the extreme southwest corner of the map (Sierra del Orégano).
3. Aurora of Glen Rose age (Karg) occurs below the Devils River Formation southwest of Arroyo de la Babia.
4. Navarro formations crop out east of the map area. They are included here for completeness only.
5. Upson — San Miguel outcrops (not shown) in Alluvium along southern boundary of the map east of Loma Gorda anticline.

GEOLOGIC MAP OF NORTHERN COAHUILA, MEXICO

1964

Compiled from geologic quadrangles by Santiago Reynolds M., Jesus Alfonso Zwanziger, Santiago Charleston A. (all assisted by Jorge Tovar R.), Arsenio Novarro G., and David Lopez Ticha C.; supplementary areas by International Boundary and Water Commission, F. W. Daugherty, and W. N. McAnulty and others (see index map).

Compiled and Edited by C. I. Smith

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

Photogrammetric base and geologic quadrangle mapping from 1:50,000 vertical air photographs, Jack Ammann Photogrammetric Engineers, Inc., 1957.

Supplementary mapping adjacent to Rio Grande (A) by International Boundary and Water Commission (1951), Pico Etereo area by Daugherty (1962), Univ. Texas Ph.D. Dissertation, and Aguachile area by McAnulty and others (1963), Geol. Soc. America Bull., vol. 74, no. 6, pl. 1.

Drafting by Rose I. McDonald, Suzanne Crook, and Bruce Gray.

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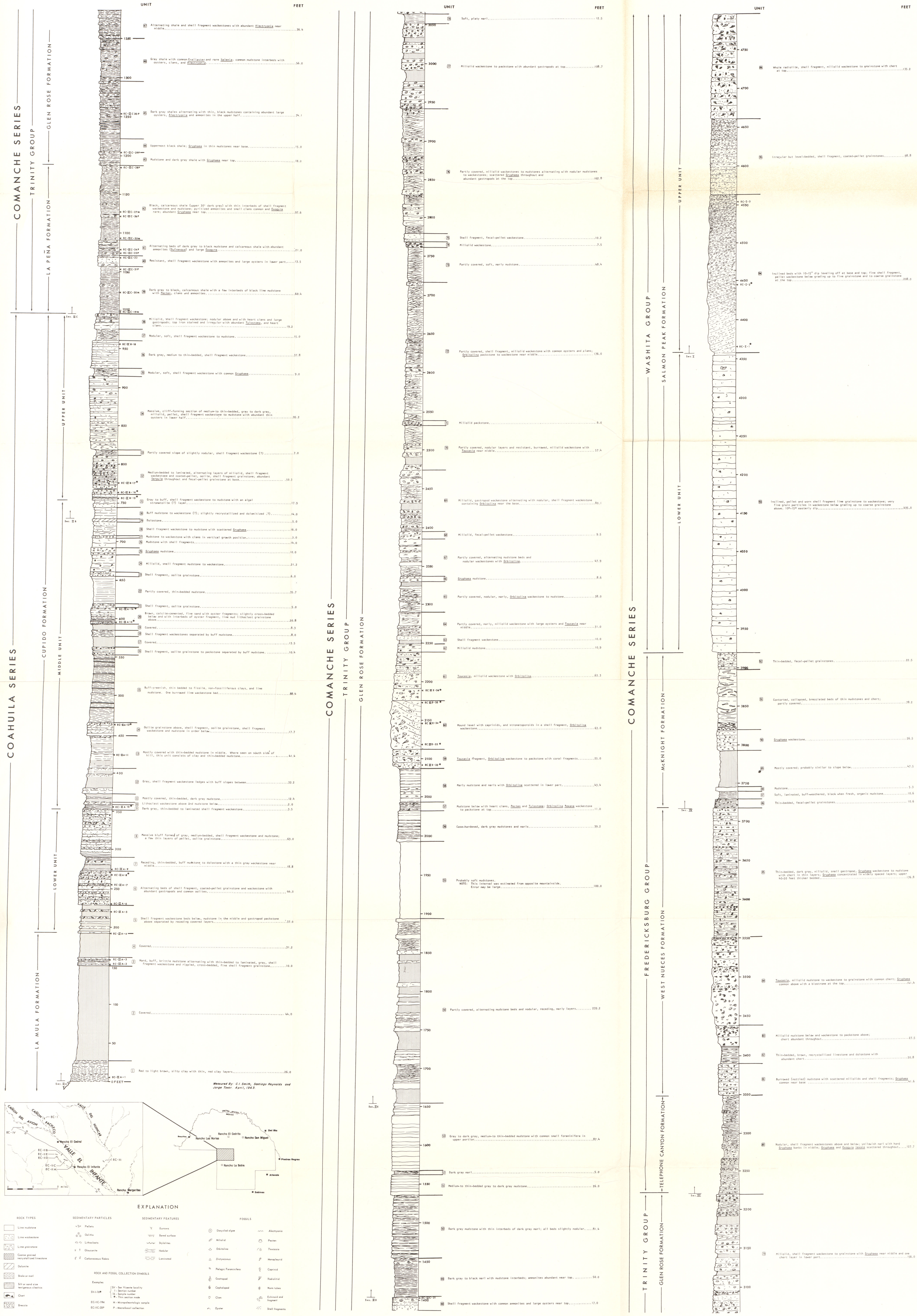
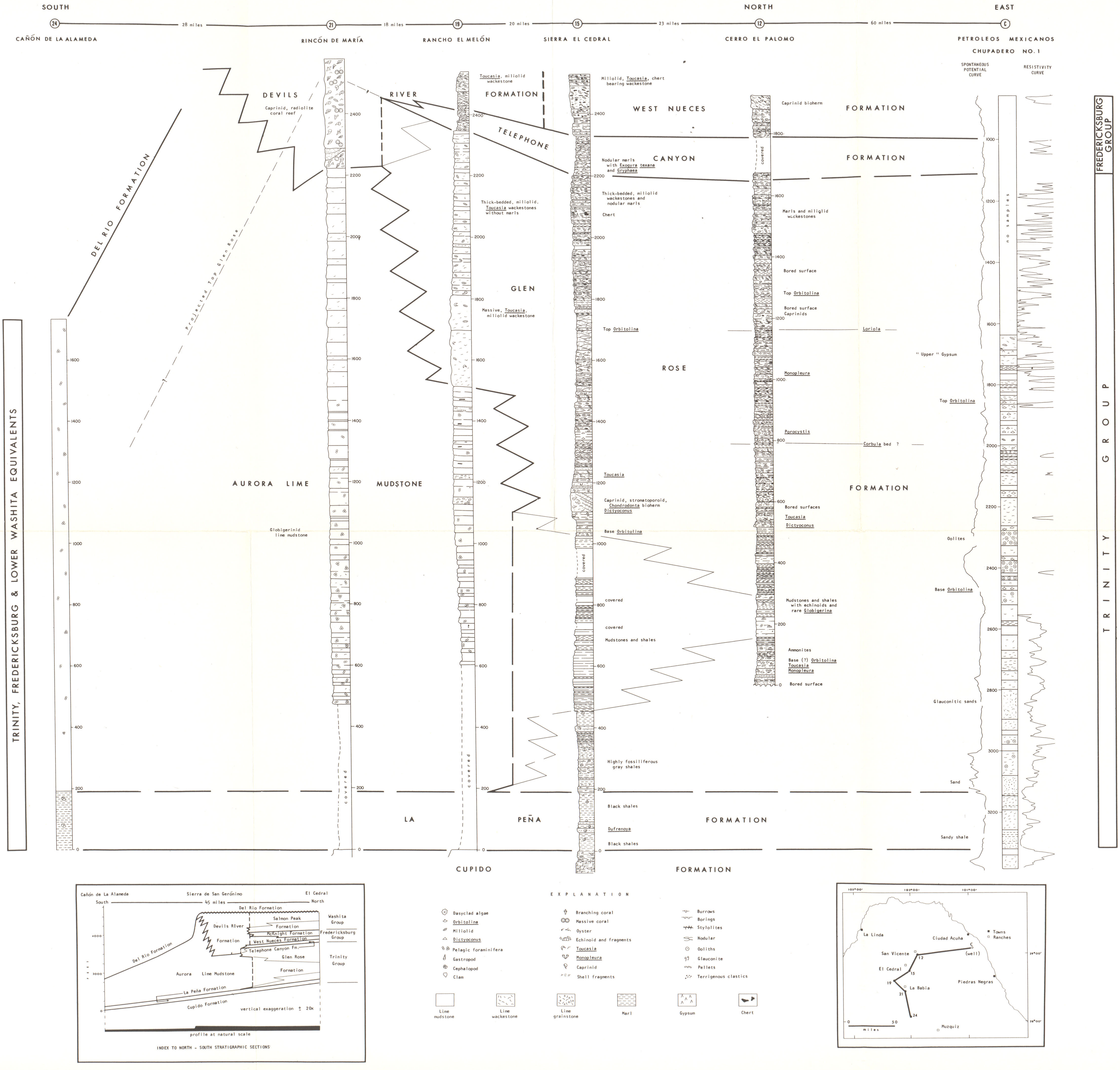


Graphic section: Sierra El Cedral



North-south stratigraphic cross section of the Trinity Group

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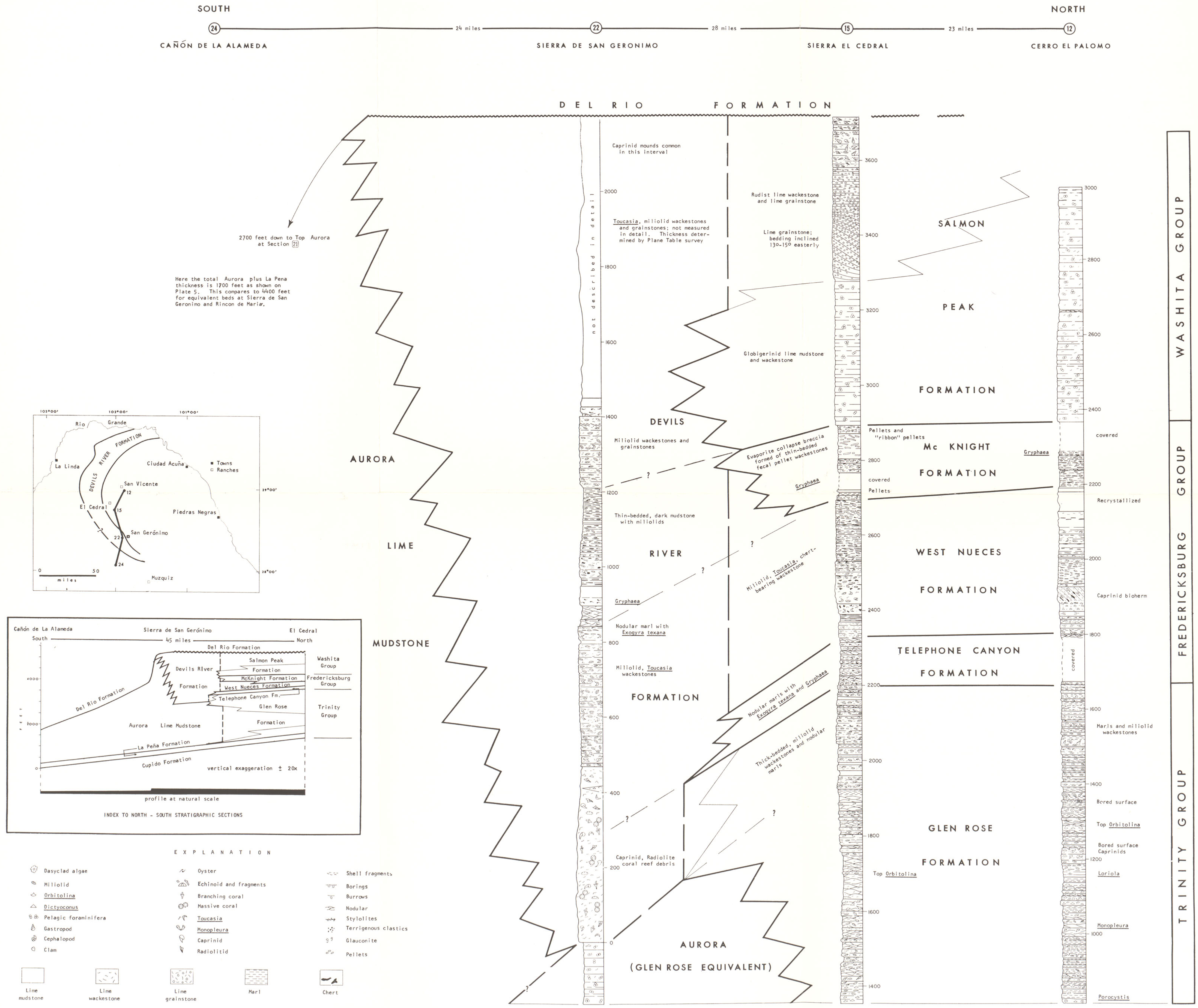
LOWER CRETACEOUS STRATIGRAPHY
NORTHERN COAHUILA, MEXICO
PLATE 6

Graphic section: Cerro El Palomo



North-south stratigraphic cross section of the Fredericksburg and Washita Groups

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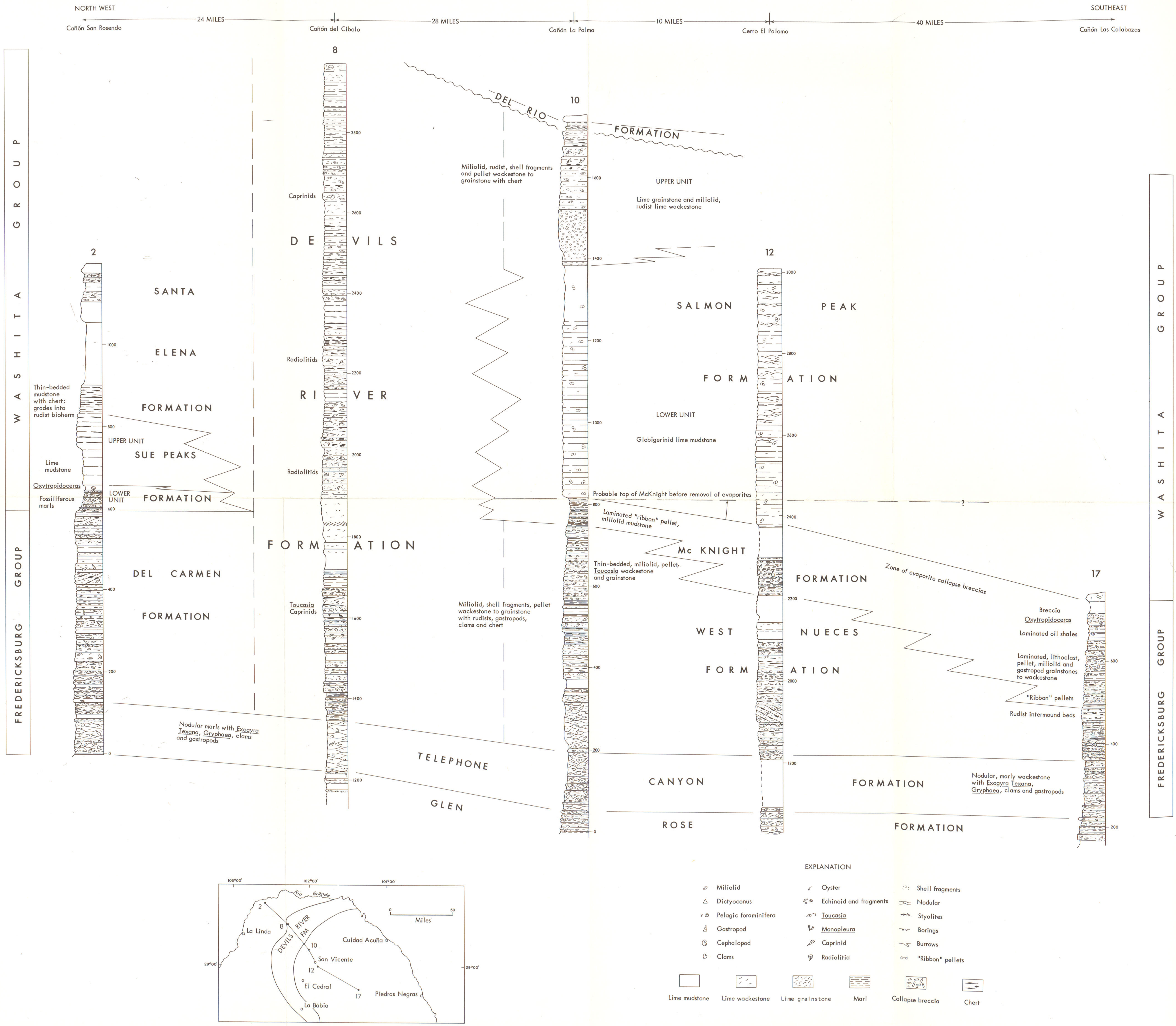
LOWER CRETACEOUS STRATIGRAPHY
NORTHERN COAHUILA, MEXICO
PLATE 10



East-west stratigraphic cross section of the Fredericksburg and Washita Groups