U.S. GEOLOGICAL SURVEY CIRCULAR 943

Petroleum Geology and Resources of Northeastern Mexico

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By James A. Peterson

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Potentially major petroleum deposits, primarily gas, in northeastern Mexico occur in carbonate and clastic reservoirs of Cretaceous and Jurassic age

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
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PREFACE

The World Energy Resources Program of the U.S. Geological Survey (USGS) intends to develop reliable and credible estimates of undiscovered recoverable petroleum resources throughout the world. Initial program efforts have focused on the major producing areas of the world in order to gain a broad understanding of the geologic characteristics of petroleum occurrence for purposes of resource assessment as well as for analysis of production potential. Investigations of production potential are carried out in cooperation with other U.S. Government agencies; specifically, the studies of the main free-world exporting nations, of which this study is a part, are carried out in cooperation with the Foreign Energy Supply Assessment Program of the Department of Energy. The estimates represent the views of a U.S. Geological Survey study team and should not be regarded as an official position of the U.S. Government.

The program seeks to investigate resource potential at the basin level, primarily through analogy with other petroleum regions, and does not necessarily require, therefore, current exploration information that is commonly held proprietary. In conducting the geological investigations, we intend to build a support base of publicly available data and regional geologic synthesis against which to measure the progress of exploration and thereby validate the assessment. Most of these investigations will lead directly to quantitative resource assessments; to be effective, resource assessment, like exploration, must be an ongoing process taking advantage of changing ideas and data availability—the results produced being progress reports reflecting a state of knowledge at a point in time. Because the program is coordinated with the USGS domestic assessment program and both utilize similar techniques for assessment, the user can be assured of a thread of consistency permitting comparisons between the various petroleum basins of the world, including those of the United States, that have been assessed in the overall USGS program.

In addition to resource estimates, the program provides a regional base of understanding for in-country exploration analysis and for analysis of media reports regarding the exploratory success or failure of ventures in studied areas.

USGS open-file reports related to the assessment of undiscovered conventionally recoverable petroleum resources include:

81-0986—Assessment of conventionally recoverable petroleum resources of Persian Gulf basin and Zagros fold belt (Arabian-Iranian basin)

81-1027—Assessment of conventionally recoverable petroleum resources, Volga-Urals basin, U.S.S.R.

81-1142—Assessment of conventionally recoverable petroleum resources of Indonesia

81-1143—Assessment of conventionally recoverable petroleum resources of northeastern Mexico

81-1144—Assessment of conventionally recoverable petroleum resources of southeastern Mexico, northern Guatemala, and Belize

81-1145—Assessment of conventionally recoverable petroleum resources of Trinidad

81-1146—Assessment of conventionally recoverable petroleum resources of Venezuela

81-1147—Assessment of conventionally recoverable petroleum resources of the West Siberian Basin and Kara Sea Basin, U.S.S.R.

81-0296—Assessment of undiscovered conventionally recoverable petroleum resources of the Middle Caspian basin, U.S.S.R.

82-1027—Assessment of undiscovered conventionally recoverable petroleum resources of the East Siberian Basin, U.S.S.R.

82-1056—Assessment of undiscovered conventionally recoverable petroleum resources of North Africa

82-1057—Assessment of undiscovered conventionally recoverable petroleum resources of the Timan–Pechora basin, U.S.S.R., and Barents–northern Kara shelf

83-0598—Assessment of undiscovered conventionally recoverable petroleum resources of northwestern, central, and northeastern Africa

83-0801—Assessment of undiscovered conventionally recoverable petroleum resources of on-shore China

84–0094—Assessment of undiscovered conventionally recoverable petroleum resources of the northwest European assessment region

84–0158—Assessment of undiscovered conventionally recoverable petroleum resources of New Zealand

84–0214—Assessment of undiscovered conventionally recoverable petroleum resources of Australia

84–0328—Assessment of undiscovered conventionally recoverable petroleum resources in Tertiary sedimentary basins of Malaysia, Brunei

84–0329—Assessment of undiscovered conventionally recoverable petroleum resources in offshore Tertiary sedimentary basins of The People's Republic of China

84–0330—Assessment of undiscovered conventionally recoverable petroleum resources in Tertiary sedimentary basins of Thailand

84–0852—Assessment of undiscovered conventionally recoverable petroleum resources of South Asia

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C–922-A—Assessment of undiscovered conventionally recoverable petroleum resources of the Northwest European Region

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ILLUSTRATIONS

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ABBREVIATIONS USED IN THIS REPORT

BBO—Billion barrels of oil
BBOE—Billion barrels of oil equivalent
BCF—Billion cubic feet
BD—Barrels per day
BOE—Barrels of oil equivalent
CFD—Cubic feet per day
MMBO—Million barrels of oil
MMCF—Million cubic feet
TCF—Trillion cubic feet

Petroleum Geology and Resources of Northeastern Mexico

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ABSTRACT

Petroleum deposits (primarily gas) in northeastern Mexico occur in two main basins, the Tertiary Burgos basin and the Mesozoic Sabinas basin. About 90 gas fields are present in the Burgos basin, which has undergone active exploration for the past 30–40 years. Production in this basin is from Oligocene and Eocene nearshore marine and deltaic sandstone reservoirs. Most of the fields are small to medium in size on faulted anticlinal or domal structures, some of which may be related to deep-seated salt intrusion. Cumulative production from these fields is about 4 trillion cubic feet gas and 100 million barrels condensate and oil. Since 1975, about 10 gas fields, some with large production rates, have been discovered in Cretaceous carbonate and Jurassic sandstone reservoirs in the Sabinas basin and adjacent Burro-Picachos platform areas. The Sabinas basin, which is in the early stages of exploration and development, may have potential for very large gas reserves.

The Sabinas basin is oriented northwesterly with a large number of elongate northwest- or west-trending asymmetric and overturned Laramide anticlines, most of which are faulted. Some of the structures may be related to movement of Jurassic salt or gypsum. Lower Cretaceous and in some cases Jurassic rocks are exposed in the centers of the larger anticlines, and Upper Cretaceous rocks are exposed in much of the remainder of the basin. A thick section of Upper Cretaceous clastic rocks is partly exposed in tightly folded and thrust-faulted structures of the west-east oriented, deeply subsided Parras basin, which lies south of the Sabinas basin and north of the Sierra Madre Oriental fold and thrust belt south and west of Monterrey.

The sedimentary cover of Cretaceous and Jurassic rocks in the Sabinas and Parras basins ranges from about 1,550 m (5,000 ft) to 9,000 m (30,000 ft) in thickness. Upper Jurassic rocks are composed of carbonate and dark organic shaly or sandy beds underlain by an unknown thickness of Late Jurassic and older redbed clastics and evaporites, including halite. Lower Cretaceous rocks are mainly platform carbonate and fine clastic beds with some evaporites (gypsum or anhydrite) deposited in two main rudist reef-bearing carbonate cycles. Upper Cretaceous rocks are mainly continental and marine clastic beds related to early development of the Laramide orogeny. This Upper Cretaceous sequence contains a marine shale and deltaic clastic complex as much as 6,000 m (20,000 ft) or more thick in the Parras basin, which grades northward and eastward to open marine, fine clastic beds. The Burgos basin, which is an extension of the Rio Grande embayment of the western Gulf of Mexico basin province, contains an eastward-thickening wedge of Tertiary continental and marine clastics. These beds are about 1,550 to 3,000 m (5,000–10,000 ft) thick in the outcrop belt on the west side of the basin and thicken to more than 16,000 m (50,000 ft) near the Gulf Coast.

INTRODUCTION

GEOGRAPHY

The assessment area considered in this report covers about 330,000 km² (125,000 mi²) in the northeastern part of Mexico. The area includes the Burgos basin (primarily a Tertiary gas province), including its offshore part to the 1,000-m depth; the Sabinas basin where recent Mesozoic gas discoveries have been made; the adjacent Sierra Madre frontal basins (Parras and Magiscatzin basins); and the northern part of the Sierra Madre Oriental fold and thrust belt (fig. 1). Topography of the area is characterized by the flat-lying Gulf of Mexico coastal plain, the plateau regions along the Rio Grande and in western Coahuila State, the isolated ranges or sierras of central Nuevo Leon and eastern Coahuila (basins and ranges provinces of Humphrey, 1956), the rugged mountain belt along the front of the Sierra Madre Oriental, and the northern part of the Central Mesa region south of the Sierra Madre front.

The climate is semiarid to arid in most of the region. Annual precipitation is about 25 to 50 cm (10–20 inches) in most parts of Coahuila State and part of Nuevo Leon State and about 50 to 75 cm (20–30 inches) in the coastal plain region of Tamaulipas State. In the high sierras south of Monterrey, precipitation may be to 100 cm (40 inches) or more in places.

INFORMATION SOURCES

Data and information used in preparing this report were compiled primarily from Mexican journals and other publications on petroleum geology and general geology of the area. Of particular value were publications by Lopez-Ramos (1980), Charleston (1974, 1981), Humphrey (1956), Smith (1970, 1971, 1981), Gonzales Garcia (1979), Wilson and Pialli (1977), McBride and others (1974), articles from the *Oil and Gas Journal* and *World Oil*, and the information files of Petroconsultants, S.A. Additional references are
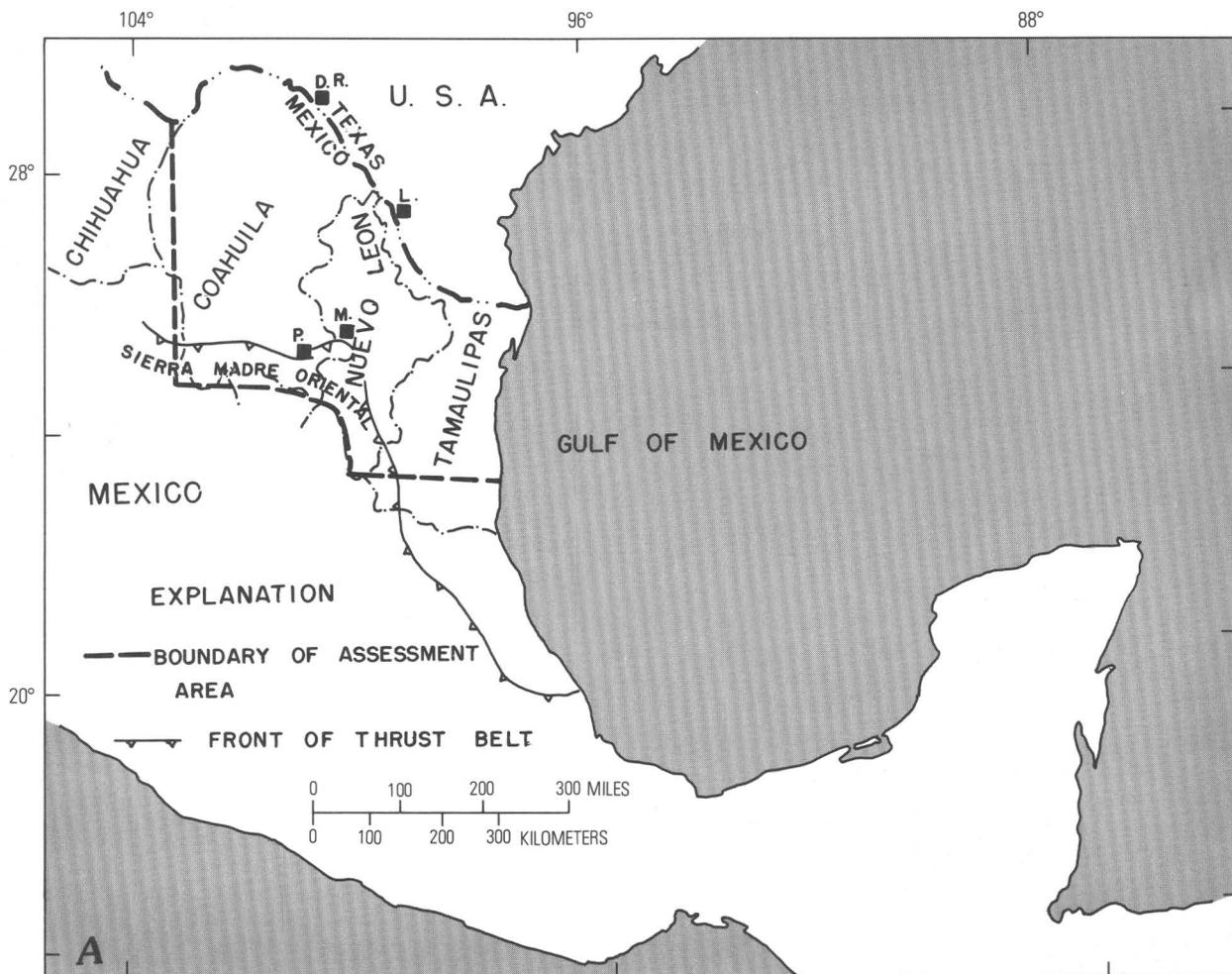
FIGURE 1.—Index maps of northeastern Mexico; cities shown are D.R., Del Rio, Texas; L, Laredo; M,

listed in the bibliography. Work on the report was completed in June 1981. Geological and other data made available after that date are not incorporated in the study.

The nomenclature used in the Texas area in this report was summarized from many reports; some has been adopted by the U.S. Geological Survey and some has not.

REGIONAL GEOLOGY

STRUCTURE

The main basin areas of northeastern Mexico are the Burgos basin, which is part of the Rio Grande embayment of the western Gulf of Mexico basin; the Sabinas basin (or "Gulf of Sabinas"); the Magiscatzin or Linares basin; and the Parras and La Popa basins (figs. 1–4). The Burgos basin occupies the eastern part of the assessment area and is filled with a thick sequence of Tertiary clastic rocks, which wedge-out rapidly updip to the west in the vicinity of Reynosa. West of the Tertiary wedge-out, the sedimentary cover comprises mainly Cretaceous marine carbonate rocks, which make up most of the surface exposures in Coahuila and Nuevo Leon, and a relatively unknown thickness of marine
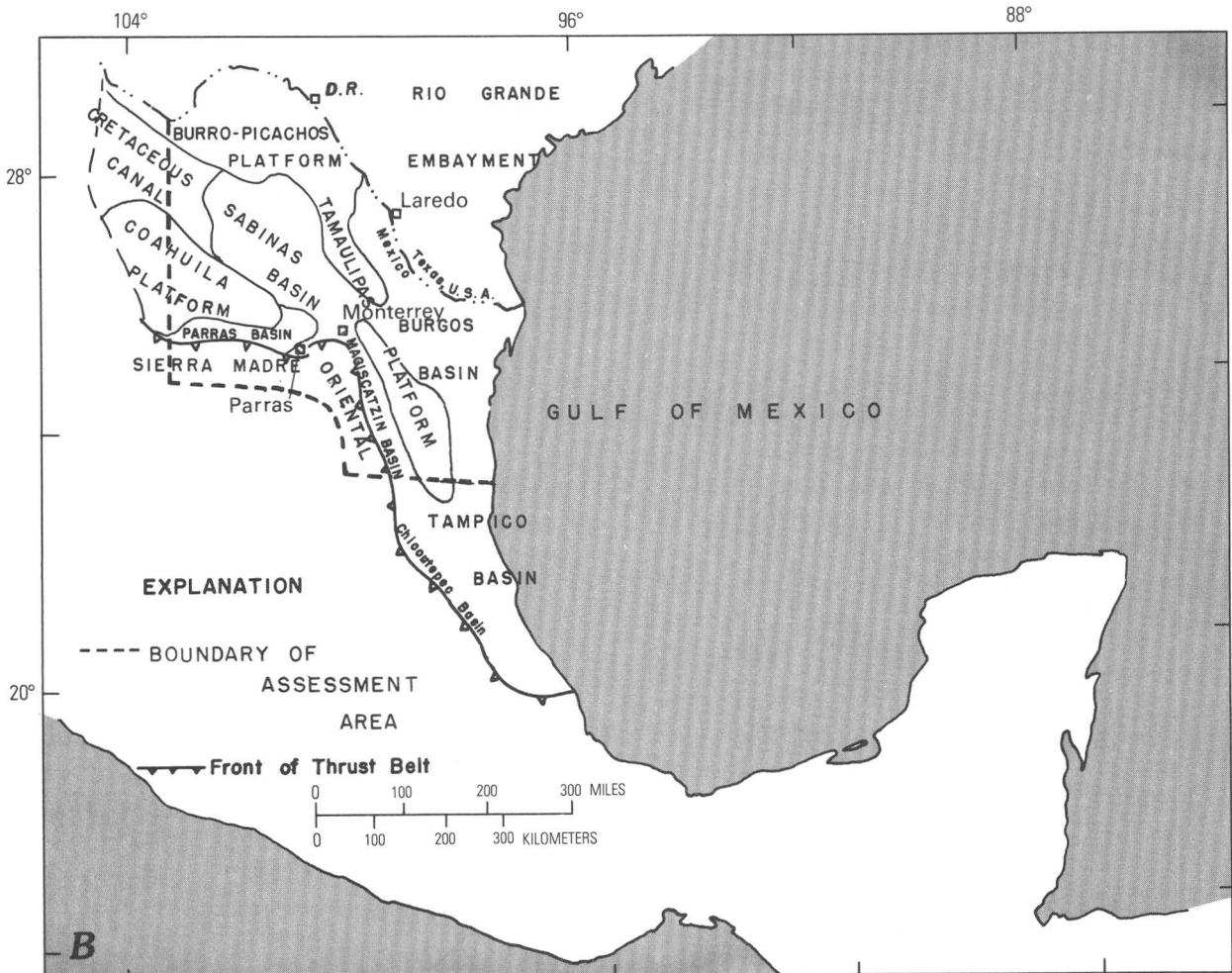
Monterrey, Mexico; P, Parras, Mexico.   *A,* Political boundaries and assessment area; *B,* Main basins and uplifts.

Jurassic carbonate, clastic, and evaporite rocks (fig. 2, cols. 1–3). The Burgos basin is bounded on the west by the Tamaulipas platform (arch) and the southeastern extension of the Burro-Picachos platform. The Sabinas basin or "Gulf of Sabinas" lies west of this platform belt and merges with the Parras and La Popa basins around the southeast extension of the Coahuila platform. The broad Coahuila platform or "peninsula" forms the southern and western boundaries of the Sabinas basin and the north boundary of the Parras basin. The Parras basin occupies a relatively narrow west-east-trending tightly folded outcrop belt north of the Sierra Madre thrust and fold belt and merges on the east with the Magiscatzin (Linares) basin southeast of Monterrey. Together, these two basins form a relatively narrow, Late Cretaceous-Tertiary foredeep trough adjacent to the Sierra Madre Oriental, which is

a broad belt of thick tightly folded and thrust-faulted Cretaceous and Jurassic platform carbonate deposits. To the south, the Magiscatzin basin joins the Tampico basin and the Chicontepec basin (fig. 1*B*).

Early growth of the Tamaulipas, Burro Picachos, and Coahuila platforms occurred in Triassic and Early Jurassic time as part of the regional tensional stresses associated with initial development of the ancestral Gulf of Mexico province. At this time, redbed clastics and evaporites were deposited in the Sabinas Gulf (ancestral Sabinas basin) and parts of the ancestral Gulf of Mexico basin (figs. 5–7). Intense growth of these paleostructures diminished after Triassic time, but moderate growth continued through most of the remainder of Mesozoic time and influenced depositional processes and distribution of both clastic and carbonate sedimentary facies. Growth of salt structures probably began

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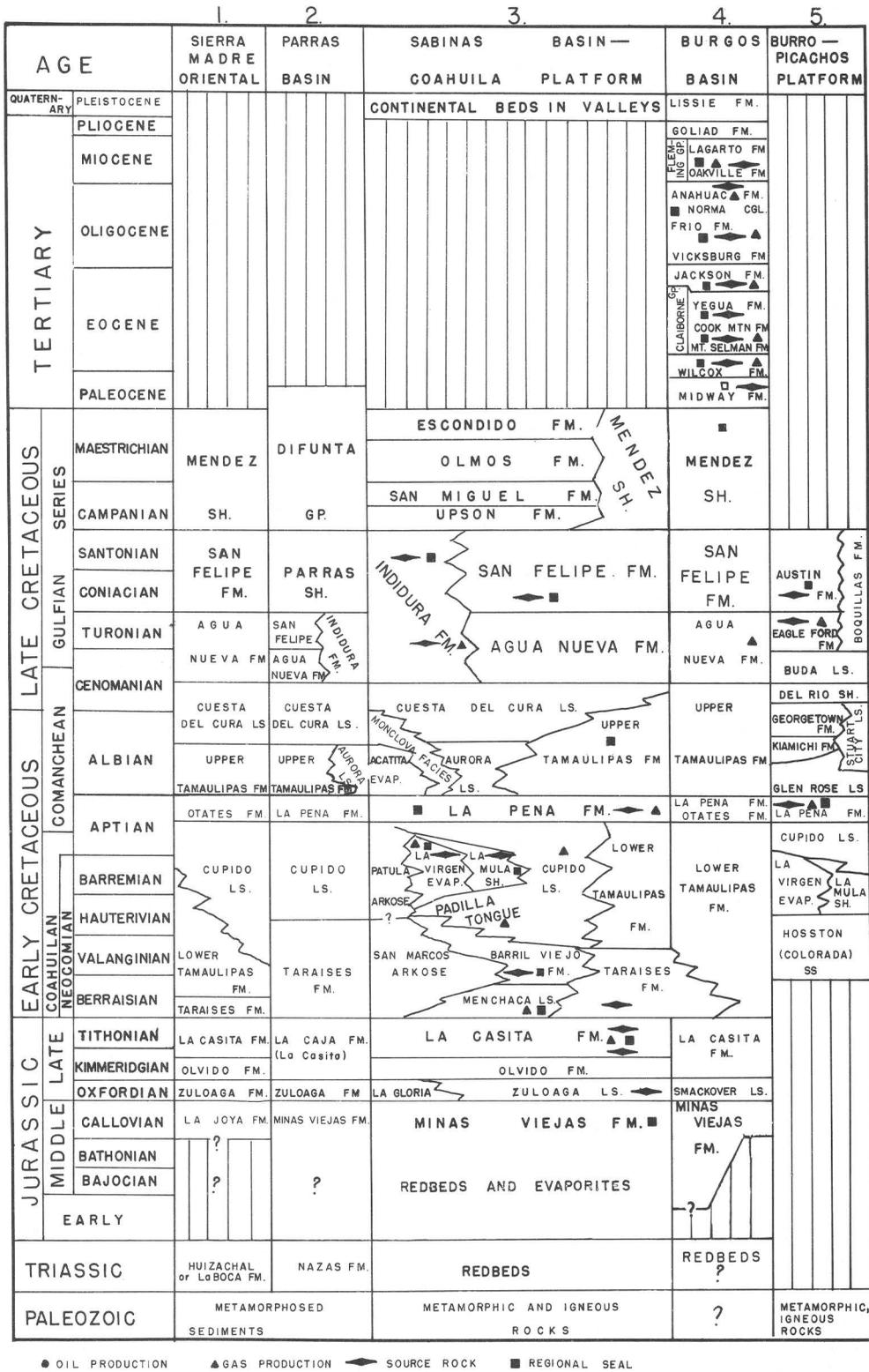
FIGURE 2.—Correlation chart, northeastern Mexico and adjacent area. 1., after Lopez-Ramos, 1980, Wilson and Pialli, 1977; 2., after Lopez-Ramos, 1980, McBride and others, 1974; 3., after Smith, C. I., 1981, Lopez-Ramos, 1980, Wilson and Pialli, 1977, Charleston, 1974; 4., after Lopez-Ramos, 1980; 5., after Smith, C. I., 1981, Lopez-Ramos, 1980, Gonzalez Garcia, 1979.

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EXPLANATION

┤—├ Overturned anticline
┤—┤ Anticline
━━━ Major left-lateral fault
┬┬┬ Thrust fault
┌┬┐ Normal fault
◯ Outcrop, Lower Cretaceous rocks
◇ Outcrop, Tertiary rocks
◇ Igneous, mainly Tertiary

◯ Gas field
● Oil field
◕ Oil and gas field
· Dry hole

0   50   100   150 mi
0   50   100   200   250 km.

— — ASSESSMENT AREA
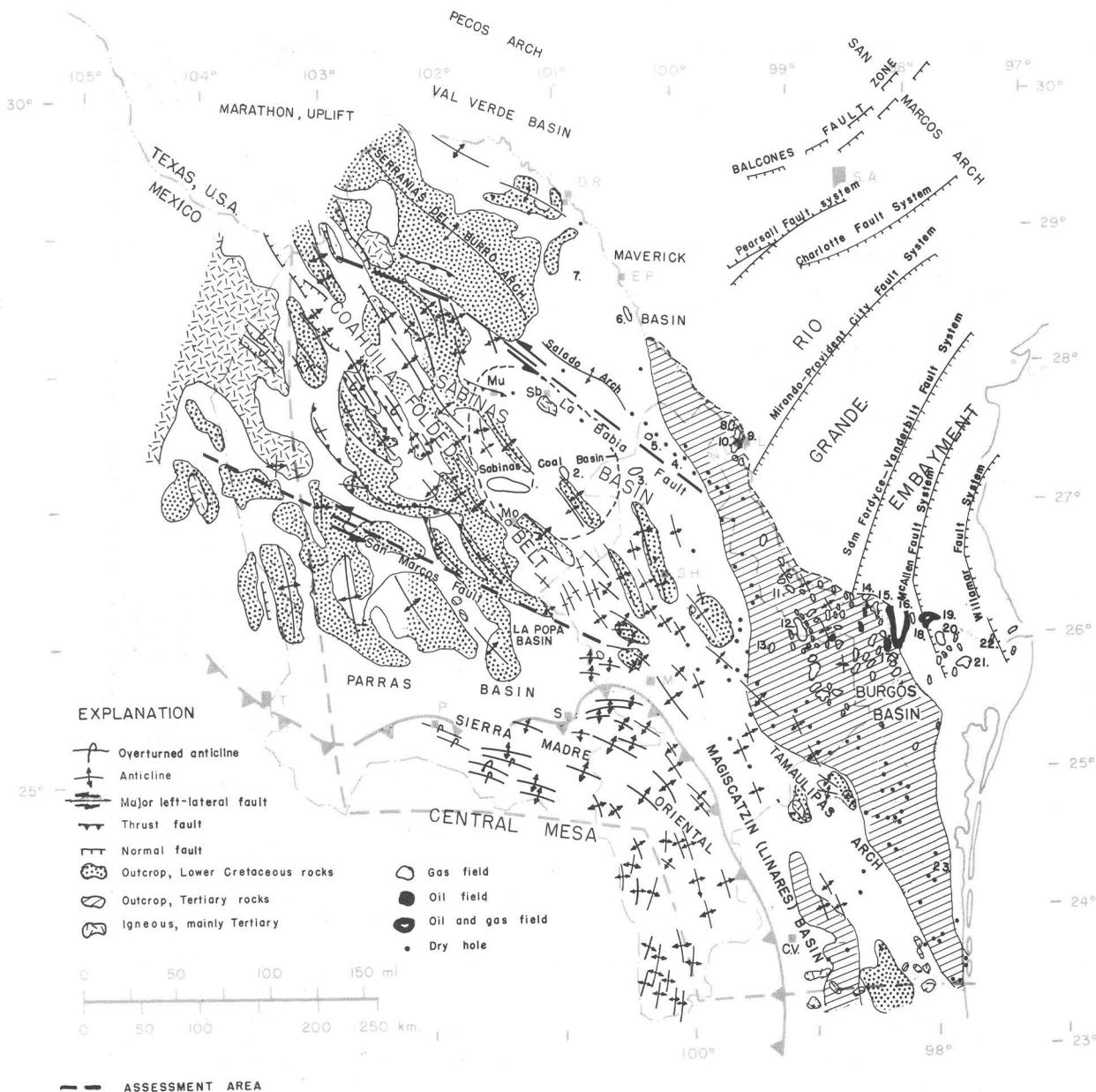
LIST OF NUMBERED FIELDS AND WELLS

1. Buena Suerte—Monclova	9. Laredo	17. Monterrey
2. Ulua	10. Oasis	18. Francisco Cano
3. Lampazos	11. La Presa	19. Trevino
4. Anahuac	12. Culebra	20. Brasil
5. Garza	13. Panalva	21. 18 de Marzo
6. Polvorin	14. Mision	22. Matamoras
7. Tribolites	15. Comitas	23. Lerna
8. Totonaca	16. Reynosa	

FIGURE 3.—Map of northeastern Mexico showing main structural features, oil and gas fields, important dry holes, and outcrop areas of Lower Cretaceous and Tertiary sedimentary rocks and Tertiary igneous rocks. Outcropping rocks are not shown in Sierra Madre Oriental in which mainly Cretaceous and some Jurassic rocks are exposed in fold and thrust structures. Lines of cross sections of figures 5, 6, and 7 are shown. Data are primarily from Charleston (1974, 1981), Lopez-Ramos (1980), and Corpus Christi Geological Society (1978, 1979). Significant fields or discoveries are numbered. Cities shown in Mexico: C, Chihuahua; C.V., Ciudad Victoria; Mo, Monclova; Mu, Muzquiz; N.L., Nuevo Laredo; P, Parras; S, Saltillo; Sb, Sabinas; S.H., Sabinas Hidalgo; T, Torreon; cities shown in Texas: C.C., Corpus Christi; D.R., Del Rio; E.P., Eagle Pass; L, Laredo; S.A., San Antonio.
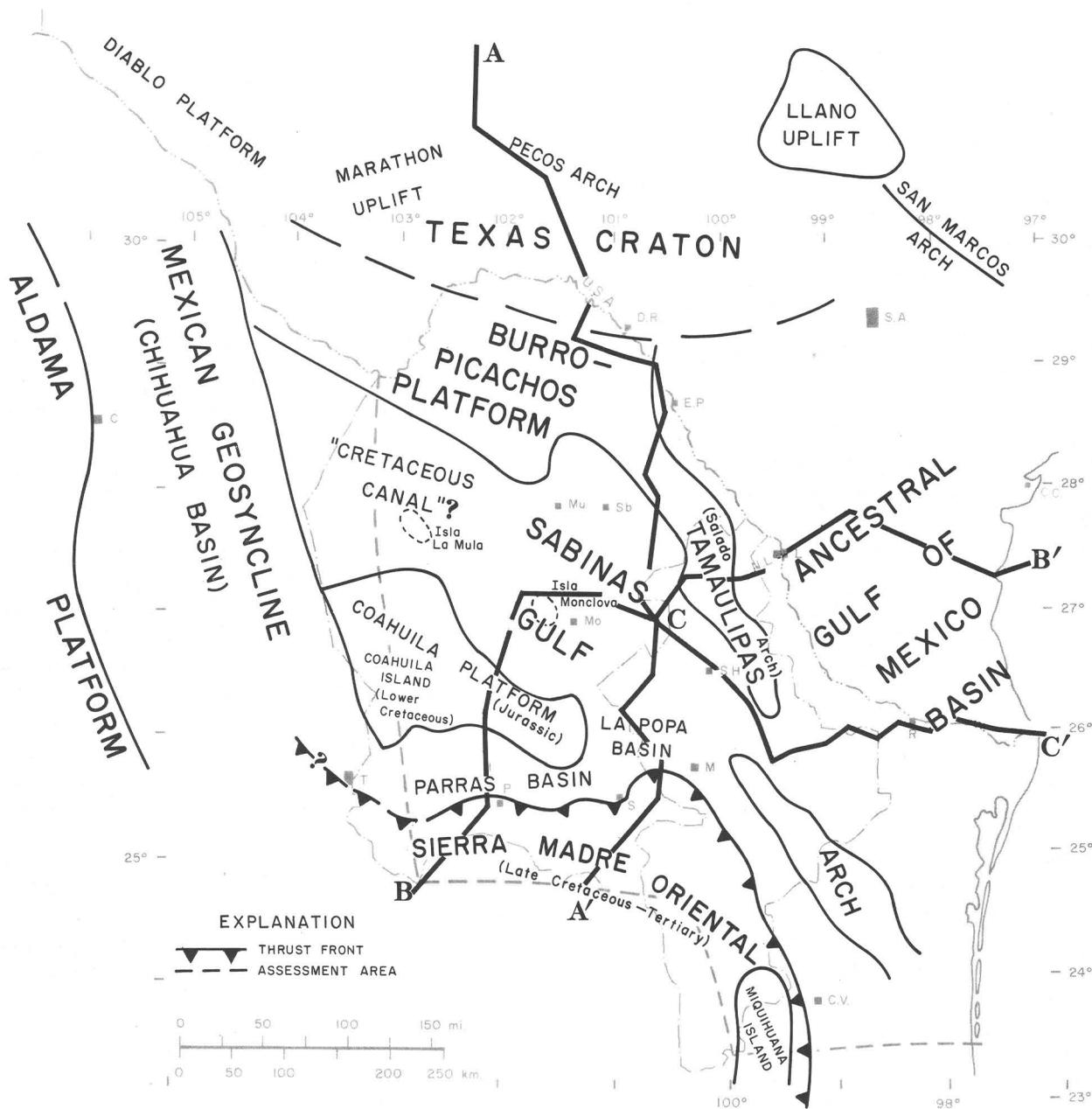
FIGURE 4.—Mesozoic paleostructure map showing regional basin and uplift features active during Jurassic and Cretaceous deposition. Lines of cross sections of figures 5, 6, and 7 are shown. Cities shown in Mexico: C, Chihuahua; C.C., Cuatro Cienegas; C.V., Ciudad Victoria; M, Monterrey; Mo, Monclova; Mu, Musquiz; N.L., Nuevo Laredo; P, Parras; R, Reynosa; S, Saltillo; Sb, Sabinas; S.H., Sabinas Hidalgo; T, Torreon; cities shown in Texas: D.R., Del Rio; E.P., Eagle Pass; L, Laredo; S.A., San Antonio. Sources of data: Humphrey (1956), McBride and others (1974), Gonzalez Garcia (1979), Lopez-Ramos (1980), Charleston (1974, 1981), and Smith, C. I. (1971, 1981).

by Late Cretaceous time and continued into early Tertiary time. Regional uplift during middle and late Tertiary time resulted in widespread erosion and exposure of Mesozoic rocks throughout most of northeastern Mexico, except for the Burgos basin, which underwent rapid subsidence throughout Tertiary time.

The Burgos structural basin is a part of the Rio Grande embayment, which forms the western part of the Gulf of Mexico basin. The basin area contains a thick sequence of Tertiary and upper Mesozoic deposits, which are cut by a series of normal fault zones displaced downward on the Gulf Coast side and roughly parallel to the coastline (fig. 3). Most of these are growth faults active during Tertiary deposition. Numerous faulted anticlinal or domal folds are present, some of which may be related to deep-seated salt structures.
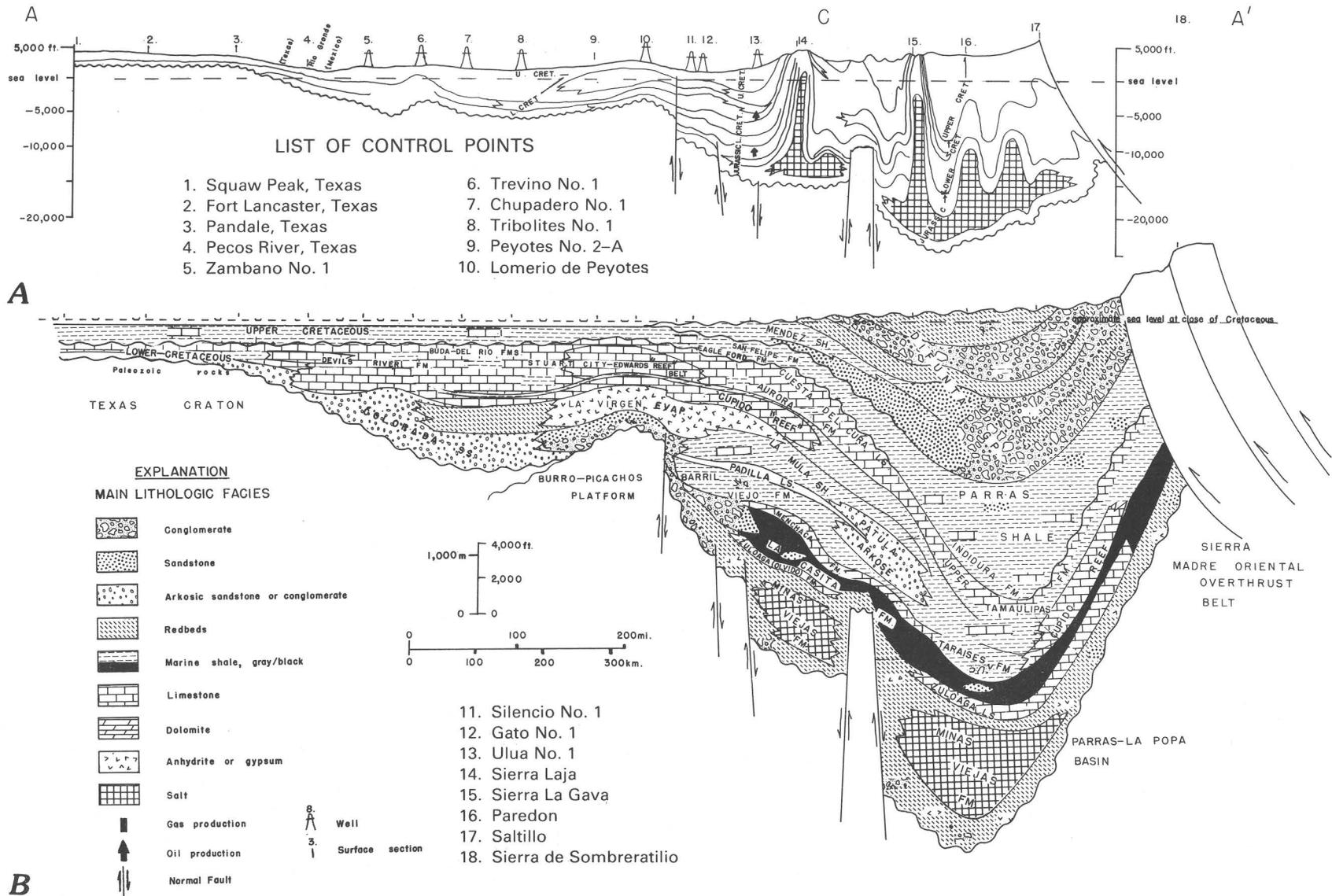
FIGURE 5.—North-south structural-stratigraphic cross section A–A′, southwestern Texas to Sierra Madre Oriental south of Monterrey, Mexico, showing Cretaceous and Jurassic sedimentary facies, structural features, and productive intervals. Top of La Casita Formation is the top of the Jurassic. Datum for lower cross section B is estimated sea level at close of Cretaceous time; datum for upper cross section A is present-day sea level. Cross section is based on available published data and is partly schematic, particularly in older and deeper parts of section. Data are mainly from Humphrey (1956), Charleston (1974, 1981), Smith, C. I. (1970, 1971, 1981), Lopez-Ramos (1980), and Gonzalez Garcia (1979). Line of cross section A–A′ is shown on figures 8–11.

A

LIST OF CONTROL POINTS

19. Sierras de Simon and Ramirez
20. Sierra de Parras
21. Sierra de Los Alamitos
22. Sierra de San Marcos

23. Sierra de Barril Viejo
24. Potrero de Menchaca
25. Buena Surete No. 1
26. Monclova No. 1

27. Lampazas No. 1
28. Reforma No. 1
29. Anahuac Field
30. Ambrosia No. 1

31. Laredo Field
32. Humble No. 1 Benavides, Texas
33. Philips, Nueches No. 1, Texas
34. Continental, No. 16 Driscoll, Texas

35. Sun, No. 117 Canales, Texas
36. Humble, No. J–7 Kenedy, Texas
37. Mobil, No. 1 St. Tr 1006–5, Texas

B

FIGURE 6.—Southwest-northeast structural-stratigraphic cross section B–B', Sierra Madre Oriental south of Parras, Mexico, to Gulf Coast south of Corpus Christi, Tex., showing Cretaceous and Jurassic sedimentary facies, structural features, and productive intervals. Datum for lower cross section B is estimated sea level at close of Cretaceous time; datum for upper cross section A is present-day sea level. Cross section is based on available published data and is partly schematic, particularly in older and deeper parts of section. Sources of data are same as for figure 5. Lithologic explanation is on figure 5. Line of cross section B–B' is shown on figures 8–12.
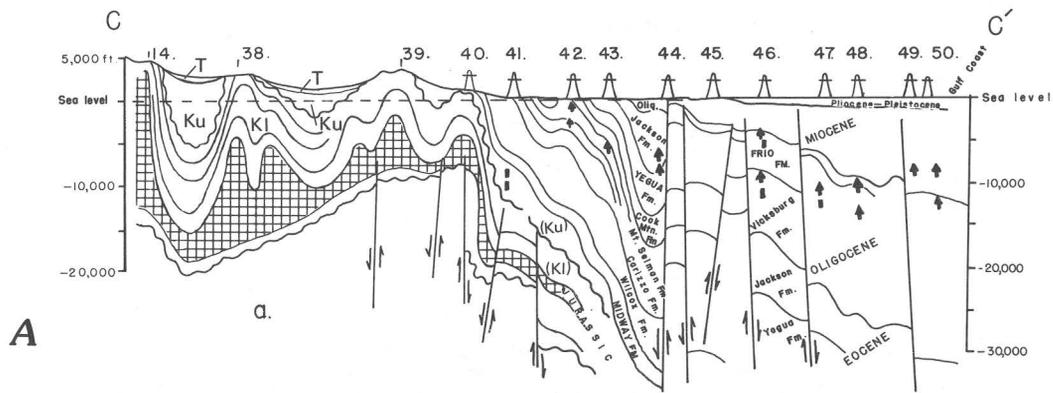
LIST OF CONTROL POINTS

14. Sierra Laja
38. Sierra Sabinas
39. Sierra de Picachos
40. Los Ramones No. 1
41. Los Herreras No. 1
42. Santa Monica No. 1
43. El Pato No. 1
44. Zacate No. 101
45. El Charro No. 1
46. Reynosa No. 1
47. Trevino No. 1
48. Cardenas No. 1
49. Texas No. C–1
50. Santa Fe No. 1
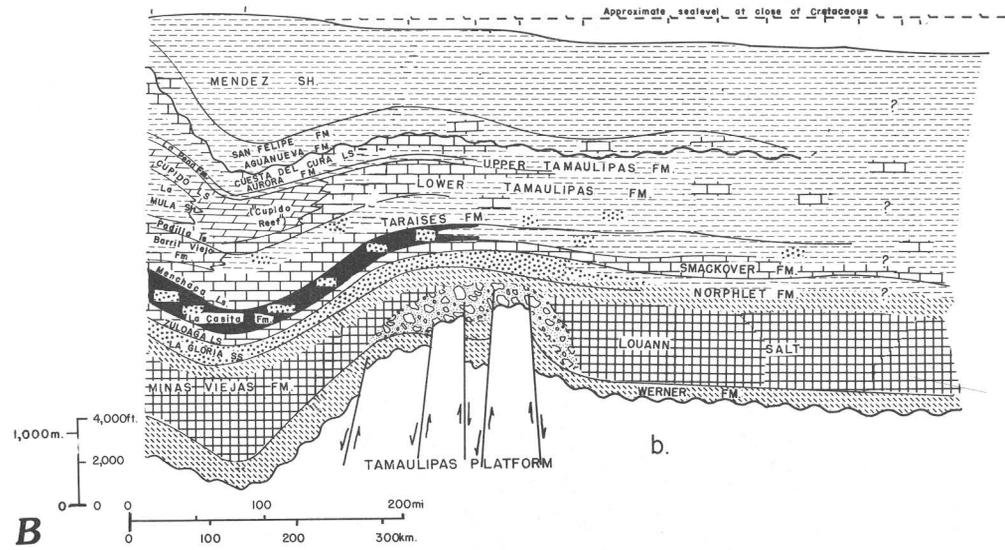
FIGURE 7.—West-east structural-stratigraphic cross section C–C', Sabinas basin to Gulf Coast at mouth of Rio Grande, showing Cretaceous and Jurassic sedimentary facies, structural features, and productive intervals. Datum for lower cross section B is estimated sea level at close of Cretaceous time; datum for upper cross section A is present-day sea level. Cross section is based on available published data and is partly schematic, particularly in older and deeper parts of section. Sources of data are same as for figure 5. Lithologic explanation is shown on figure 5. Line of cross section C–C' is shown on figures 8–12.

The Tamaulipas and Burro-Picachos platforms are broad and relatively gentle uplifts with superimposed north- or northwest-trending anticlines (fig. 3) that may have formed as a result of northeast-directed compressive Laramide stresses during the development of the Sierra Madre thrust and fold belt (Humphrey, 1956; Charleston, 1974).

The Sabinas basin is an elongate northwest-oriented basin with numerous northwest-trending local uplifts or sierras of exposed Cretaceous rocks (fig. 3), some of which have a narrow elongate belt of exposed Jurassic rocks in their centers (figs. 5-7). In the northern part of the basin, local uplifts are primarily elongated, relatively narrow, asymmetric anticlines, some of which are overturned and faulted (fig. 3). In the central and southern part of the basin, the folds are similar but tend to be broader to domal in shape with sharply plunging axes. These structures may be related in part to movement of underlying Jurassic salt and(or) gypsum (Weidie and Martinez, 1972; Gonzalez Garcia, 1979). Lower Cretaceous rocks are exposed in the centers of several larger structures, and in a few cases Upper Jurassic rocks are exposed (figs. 3, 5, 6, 7).

The Parras and La Popa basins (figs. 1, 3, 4) are characterized by surface exposures of thick Upper Cretaceous clastic sedimentary rocks and east-west oriented elongate anticlines that become more tightly folded and thrust faulted to the south toward the Sierra Madre Oriental thrust belt (Weidie and Murray, 1967; McBride and others, 1974). The small La Popa basin lies between the Sabinas basin on the north and the Parras basin on the south, but in many respects it is simply an extension of the Sabinas basin. Structures in the La Popa basin are similar to those of the Sabinas and are elongated northwest-southeast. The Parras is a narrow east-west basin lying between the Coahuila platform on the north and the Sierra Madre fold and thrust belt on the south, although thrusts related to the Sierra Madre belt extend into the younger rocks of the Parras basin. Structures in the northeastern part of the Parras basin are broad, domal folds or open, elongate folds, with minor thrust faults displaced toward the north. In the main part of the basin nearer the Sierra Madre front, folds are highly elongated east-west, tight, overturned, and thrusted toward the south, dipping away from the main Sierra Madre mass (Krutak, 1965; McBride and others, 1974).

STRATIGRAPHY

INTRODUCTION

The sedimentary cover of northeastern Mexico consists primarily of Mesozoic rocks in the States of Coa-

huila and western Nuevo Leon (Sabinas basin and adjacent area) (fig. 2). Mesozoic sedimentary rocks are 1,550 to 6,000 m (5,000-20,000 ft) thick in the Sabinas basin (fig. 6) and up to more than 9,000 m (30,000 ft) thick in the Parras and La Popa basins (figs. 5, 6, 8, 9, 10, 11). On the Burro-Picachos and Coahuila platforms and in the Sierra Madre thrust belt, Mesozoic rocks are about 1,550 to 4,650 m (5,000-15,000 ft) thick, except where partly removed by erosion in the main uplift areas. Except for a thin Paleocene section in the Parras and Magiscatzin basins, Tertiary rocks are present only in the Burgos basin, where they range in thickness from about 1,550 to 3,000 m (5,000-10,000 ft) in the outcrop belt on the west side of the basin to more than 15,500 m (50,000 ft) near the Gulf Coast (fig. 12). Total thickness of the sedimentary cover in the deeper part of the Burgos basin is not known but probably ranges to more than 21,000 m (70,000 ft) of Tertiary and Mesozoic rocks.

BASEMENT

The oldest rocks exposed in the area are scattered exposures of upper Paleozoic metamorphosed sedimentary rocks in the Burro-Picachos and Coahuila platform areas. Little is known of the basement rocks in the basins. According to Gonzalez Garcia (1979), the basement is probably composed of Permian-Triassic metasedimentary and intrusive rocks, but some areas of unmetamorphosed upper Paleozoic sedimentary rocks may be present in downfaulted blocks of the basement.

TRIASSIC

Unmetamorphosed rocks of Triassic age are known to overlie the basement in a few places around the borders of the assessment area, but little is known of their character except that they are primarily redbeds where observed, and they may underlie much of the area. South of Monterrey in the Linares trough, 2,000 m or more of Triassic redbeds (La Boca Formation) are present in exposures on the flanks of the Tamaulipas platform.

JURASSIC

The Jurassic Sabinas basin or Gulf of Sabinas was bordered by the ancestral Burro-Picachos and Tamaulipas platforms on the north and east and the Coahuila platform on the west. The ancestral basin opened on the southeast into the Tampico basin and on the east, through an opening between the Tamaulipas and Burro-Picachos platforms, into the ancestral Gulf of Mexico basin (figs. 1B, 3, 4). The Jurassic sequence in
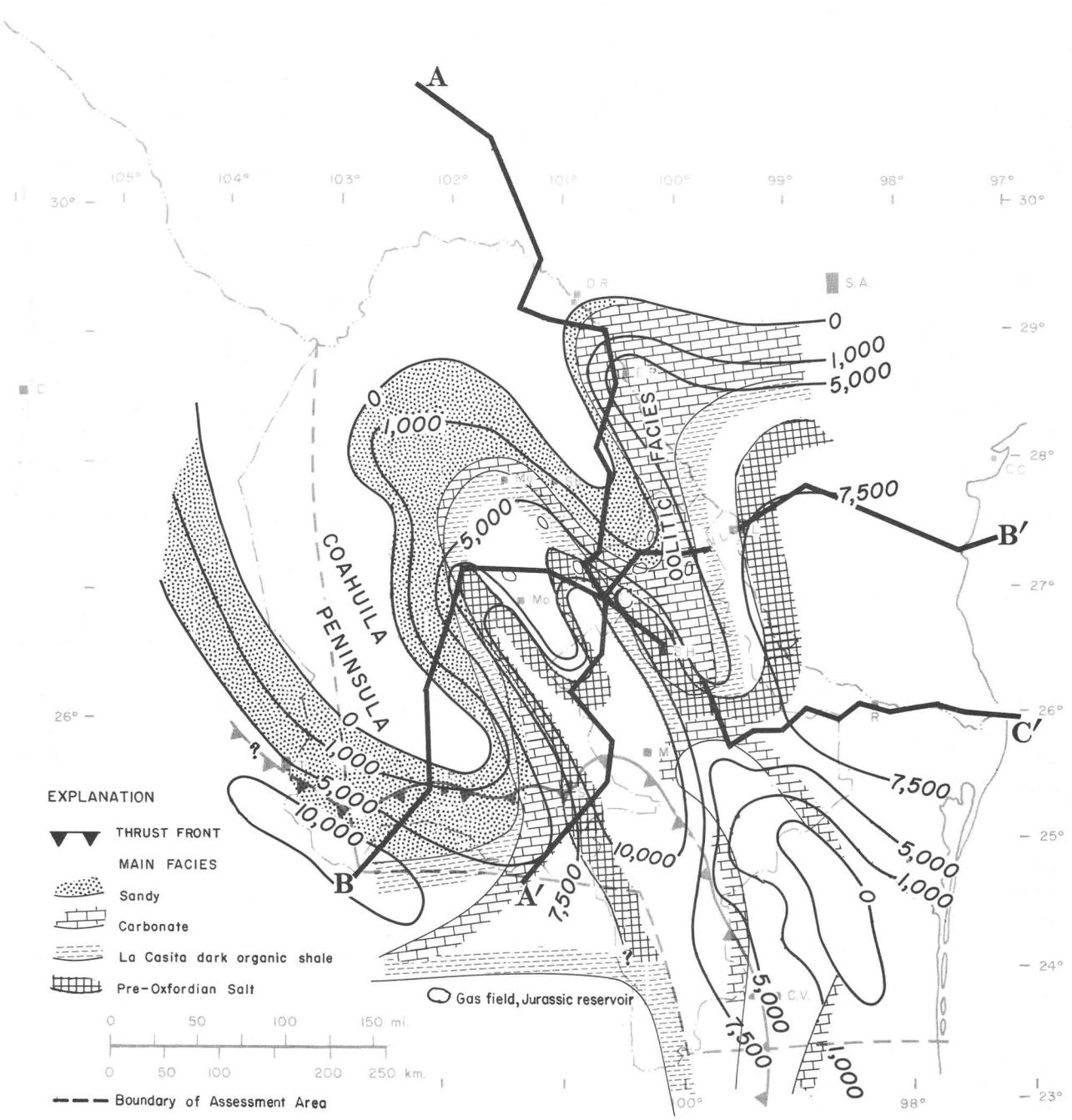
FIGURE 8.—Approximate thickness in feet, partly restored, Jurassic System, showing approximate distribution of pre-Oxfordian salt, postsalt Upper Jurassic main sedimentary facies, and gas fields producing from Upper Jurassic reservoirs. Lines of cross sections of figures 5, 6, and 7 are shown. Sources of data: Humphrey (1956), Erben (1957), Weidie and Wolleben (1969), Gonzalez Garcia (1979), Lopez-Ramos (1980), and Newkirk (1971).

northeastern Mexico consists of, in ascending order, the Minas Viejas (and its equivalent, the La Joya), the Zuloaga (and its equivalent, the La Gloria), and the Olvido and La Casita Formations (fig. 2). The Minas Viejas is a thick unit of redbeds, gypsum or anhydrite, and salt with minor interbeds of shale, carbonate, and sandstone. These beds are exposed in the centers of

several diapiric anticlines in the southeastern part of the Sabinas basin and have been penetrated in several wells. The formation may be approximately equivalent in age to the Louann Salt and the Werner Formation of the western Gulf of Mexico basin. Exact distribution and thickness of the salt section is not known, but original depositional thickness may have been as much
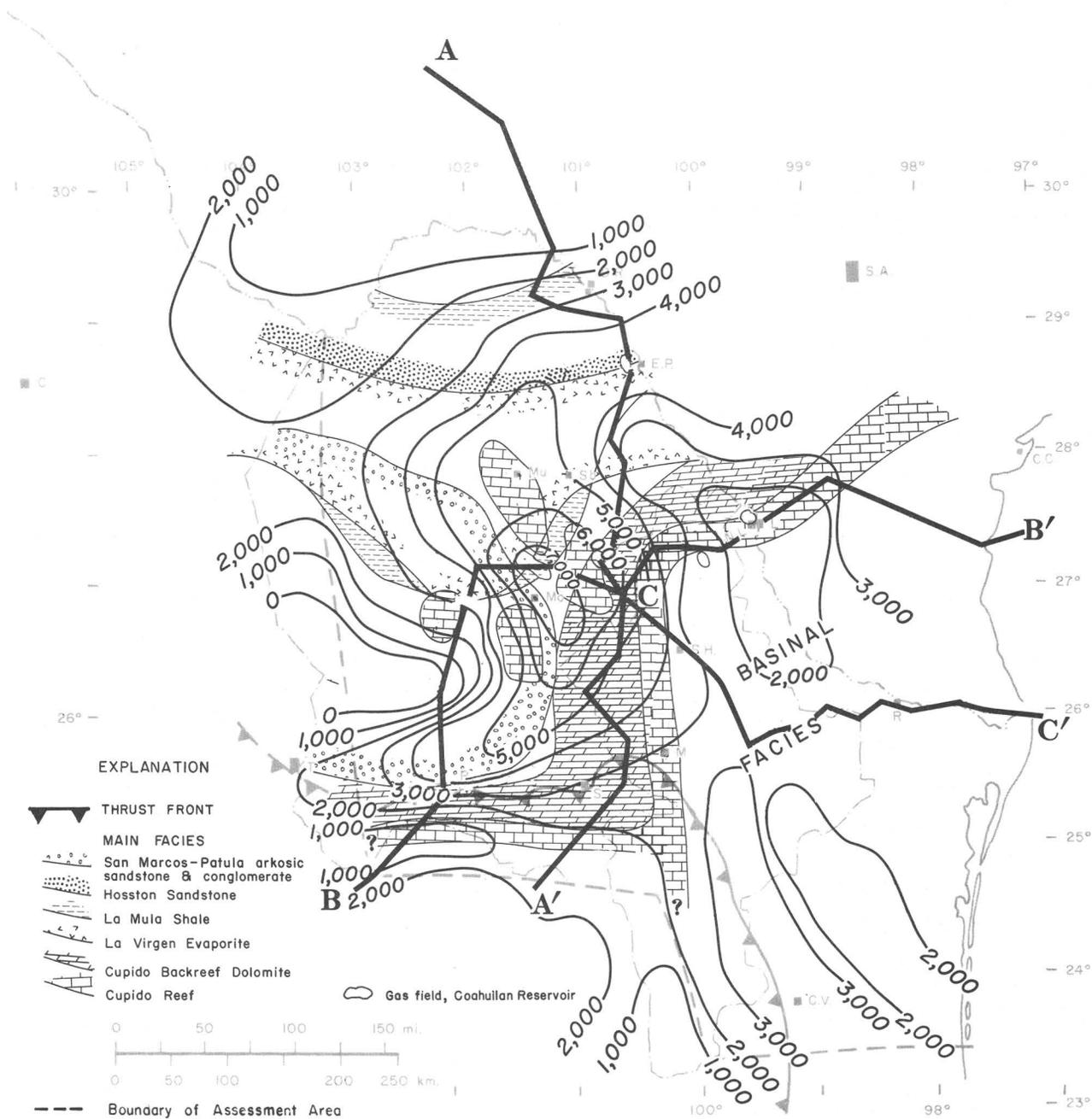
FIGURE 9.—Approximate thickness in feet, partly restored, Coahuilan Series, Lower Cretaceous, showing main sedimentary facies and gas fields producing from rocks of Coahuilan Series. Lines of cross sections of figures 5, 6, and 7 are shown. Sources of data: Humphrey (1956), Krutak (1965), Smith, C. I. (1971, 1981), Charleston (1974, 1981), Gonzalez Garcia (1979), Wilson and Pialli (1979), Lopez-Ramos (1980), Bebout (1977), Scott and Kidson (1977), and Rainwater (1971).

as 1,550 m (5,000 ft) or more in the southeastern part of the Sabinas basin. The Minas Viejas probably grades to redbeds of the La Joya Formation around the periphery of the salt basin; it is absent on the Coahuila platform (figs. 5–6).

The Zuloaga Limestone is a fossiliferous and oolitic limestone unit of middle to late Oxfordian age (fig. 2).

It is equivalent to the Smackover and Norphlet Formations of the U.S. Gulf Coast area (Imlay, 1980) and is widely distributed in northeastern Mexico (figs. 5–7). The Zuloaga has been identified in surface exposures in several breached anticlines in the Sabinas basin and in outcrops in the Sierra Madre Oriental fold and fault belt south of Monterrey. The Zuloaga grades westward

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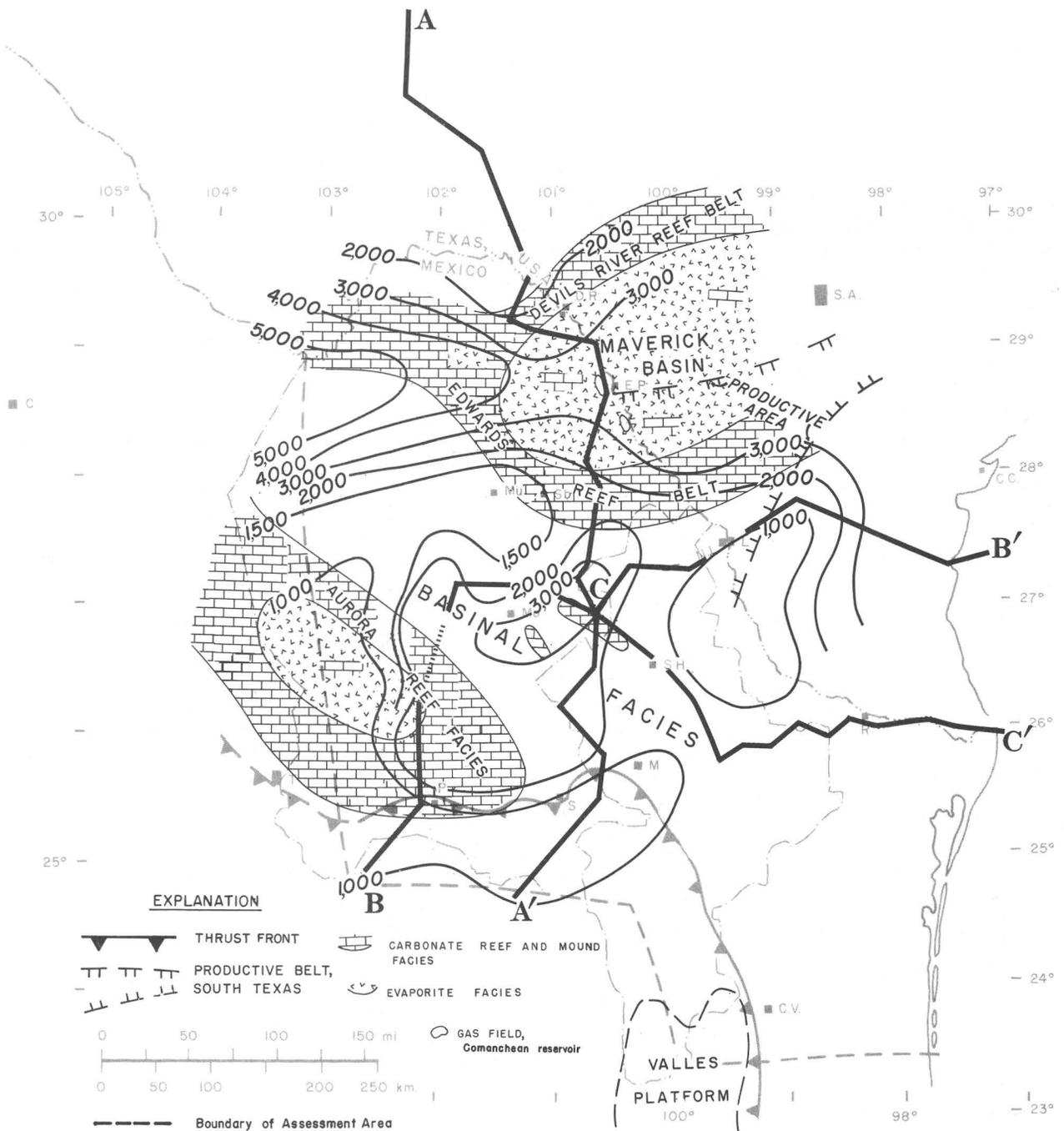
FIGURE 10.—Approximate thickness in feet, partly restored, Comanchean Series, showing main sedimentary facies and gas fields producing from rocks of Comanchean Series. Lines of cross sections of figures 5, 6, and 7 are shown. Sources of data: Humphrey (1956), Gonzalez Garcia (1979), Lopez-Ramos (1980), Rainwater (1971), and Fisher and Rodda (1969).

into sandstone and conglomerate of the La Gloria Sandstone, which is composed of lithologies reworked from underlying beds during the transgressive advance of the Upper Jurassic seaway. A limy transitional facies assigned to the Olvido Formation may be present between the Zuloaga or La Gloria and the overlying La Casita Formation.

The La Casita Formation is Kimmeridgian and Tithonian in age, equivalent to the Cotton Valley Group (Schuler and Bossier Formations) and to the Buckner Formation of the U.S. Gulf Coast (Imlay, 1980). The unit is about 300 to 1,000 m (975–3,250 ft) thick and is mostly black carbonaceous shale, marl, siltstone, and minor limestone in the lower part grading up to sand-
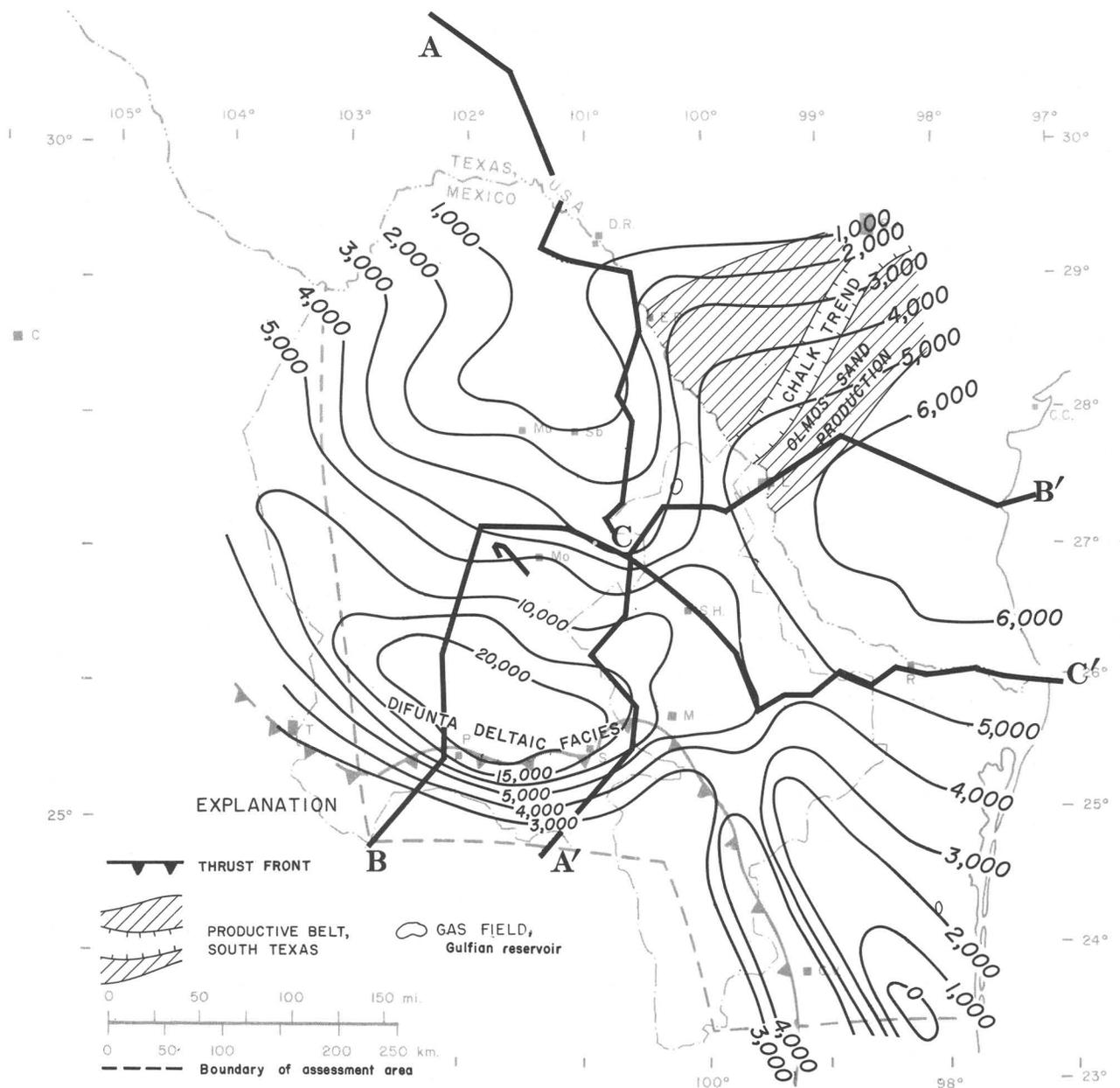
FIGURE 11.—Approximate thickness in feet, partly restored, Gulfian Series, showing main sedimentary facies and gas and oil fields producing from rocks of Gulfian Series. Lines of cross sections of figures 5, 6, and 7 are shown. Sources of data: Humphrey (1956), McBride and others (1974), Gonzalez Garcia (1979), Lopez-Ramos (1980), Holcomb (1971).

stone with some conglomerate and limestone in the upper part. The La Casita Formation occupies the main part of the Sabinas and Parras basins and extends southward into the Sierra Madre Oriental and Tampico basin areas where it becomes a more limy facies than in the Burgos basin (figs. 1, 8). In the vicinity of the Coahuila platform, the unit becomes much more sandy and in places is conglomeratic (fig. 6). In the Sabinas basin, the contact between the La Casita and the overlying Lower Cretaceous beds is transitional.

LOWER CRETACEOUS

Lower Cretaceous deposition in northeastern Mexico and adjacent Texas is dominated by two main marine transgressive cycles of reef-bearing carbonate facies deposition, the Cupido and Sligo Formations of Coahuilan age and the Glen Rose and Edwards or the Aurora and Cuesta del Cura Limestones of Comanchean age (figs. 2, 9, 10). The overlying Upper Cretaceous sequence is dominated by marine and continental clastic
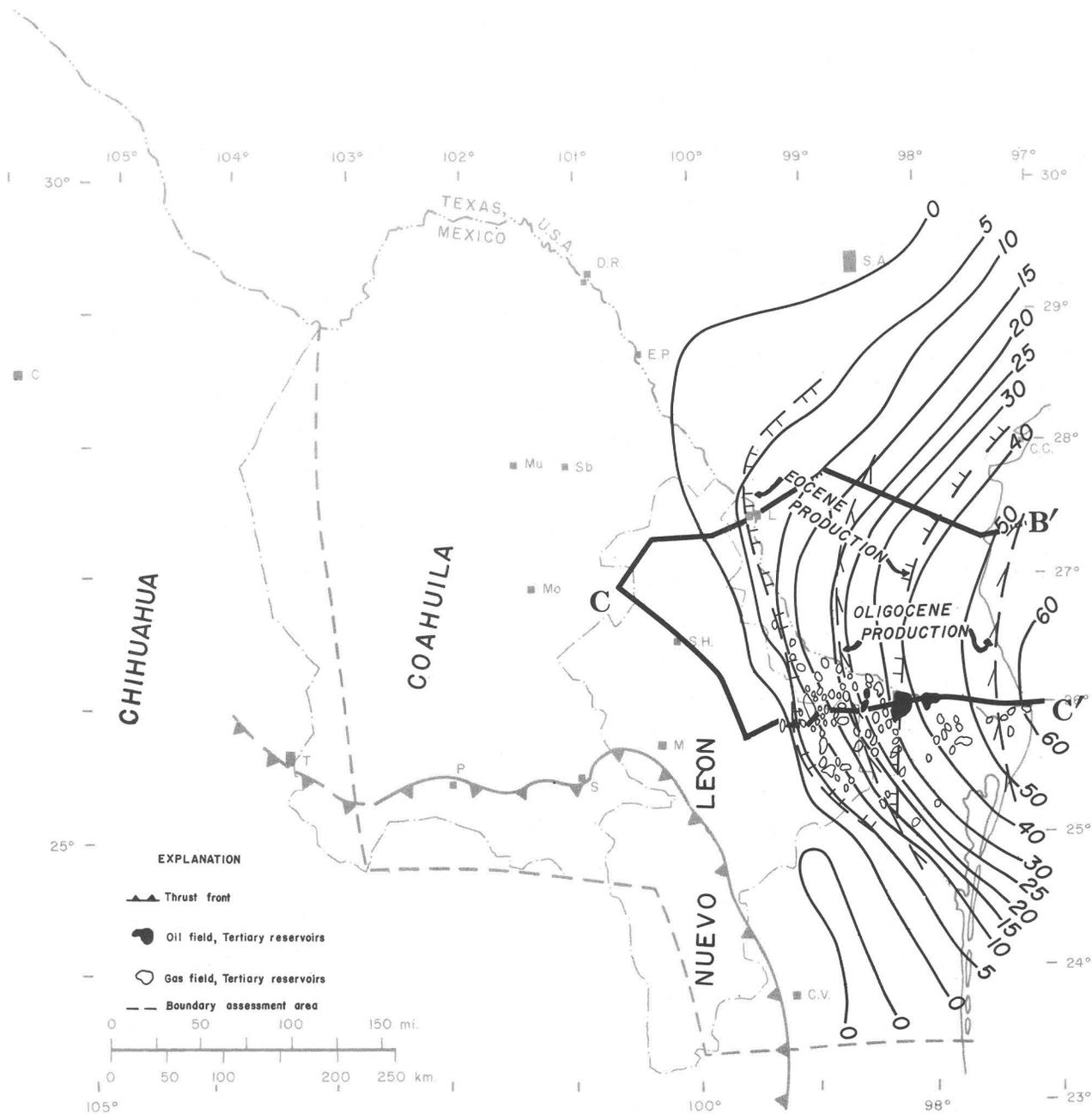
FIGURE 12.—Approximate thickness in thousands of feet, Tertiary System, showing gas and oil fields producing from Tertiary rocks in Mexico and from productive trends in south Texas. Sources of data: Guzman and others (1955), Beebe (1968), Fisher and McGowen (1967), Lofton and Adams (1971), Shinn (1971), Tipsword and others (1971), and Lopez-Ramos (1980).

deposits of Gulfian age that include substantial thicknesses of deltaic deposits and some coal beds in the upper half (figs. 2, 11).

Lower Coahuilan (lower Neocomian) lowermost Cretaceous deposits are dark shale and shaly limestones of the Taraises and Menchaca Formations, which are conformable with the underlying La Casita Formation. The Taraises and Menchaca were deposited in the main area of the Sabinas basin and part of the Parras basin.

These formations grade laterally into the lower part of the San Marcos Arkose near the Coahuila platform and into the Colorado Sandstone (equivalent to the Hosston Formation of Texas) near the Burro-Picachos platform (figs. 2, 5, 6, 9). In the vicinity of Monterrey in the southeastern part of the Sabinas basin, the upper part of the Taraises grades into the lower part of the Cupido Limestone, which may represent the initial depositional stages of the Cupido-Sligo platform margin reef belt.

To the south and east, equivalents of the Taraises are in the lower part of the Tamaulipas Formation, which is a deeper water offshore or basinal shaly carbonate and shale.

Middle Coahuilan beds in the central and southeastern part of the Sabinas basin are represented by the marine shales and marls of the Barril Viejo Formation, which grade upward into the fossiliferous rudist-bearing limestone and dolomite beds of the Padilla Tongue (Sacramento Limestone of Charleston, 1974), a westward-extending tongue of the Cupido platform limestone facies. The upper part of the Padilla contains oolitic and bioclastic beds in places. Along the southwestern flank of the basin, adjacent to the Coahuila platform, these beds grade into the green and red shales of the lower La Mula Shale, which grades farther southwest into part of the San Marcos and Patula Arkoses. To the east, Barril Viejo and Padilla grade into the main facies belt of the lower Cupido Limestone, which extends in a broad north-south belt along the east side of the Sabinas basin (figs. 5, 6, 9).

Upper Coahuilan beds in the main Sabinas basin area are represented by the limy and shaly shell-fragment beds of the upper La Mula Shale and the gypsum or anhydrite and limy or dolomitic beds of the La Virgen Evaporite. These beds grade southwestward into the Patula Arkose and eastward into the middle part of the Cupido Limestone. The La Mula and La Virgen Formations apparently represent a back-bank facies of the Cupido platform margin carbonate buildup. In Barremian time, organic bank and reef beds of the middle Cupido were deposited along a southwest-northeast belt between Saltillo in Coahuila State, and Laredo, Tex., across western Nuevo Leon State (fig. 9). This facies continues eastward into Texas as the Sligo Formation. In Nuevo Leon State, Cupido bank margin beds grade eastward to lime mudstone and shale of the lower Tamaulipas basinal facies. Lower Aptian (upper part of the Coahuilan Series) beds represent progradation and maximum development of the Cupido platform carbonate facies, which at this time covered most of the western part of Nuevo Leon and central to eastern Coahuila. The main platform margin Cupido-Sligo reef facies developed at this time and extended across Nuevo Leon between Laredo, Tex., and Monterrey. From here, the trend of the bank margin facies is uncertain, but it apparently continues southward for a short distance and then may continue westward into the Sierra Madre Oriental fold and thrust belt south of Saltillo (Gonzalez Garcia, 1979; Smith, 1981; Conklin and Moore, 1977; Wilson and Pialli, 1977).

Lower Comanchean shale and siltstone beds of the widespread upper Aptian La Pena Formation overlie the Cupido Limestone throughout the Sabinas basin

and adjacent area (figs. 5-7). These beds, which are about 25 to 100 m (80–325 ft) thick, represent deepening and transgression of the Cretaceous seas and termination of Cupido carbonate platform deposition and related organic bank and reef growth. At this time, widespread deposition of dark open-shelf shale, marl, and nodular limestone occurred across the submerged platform. To the east and southeast, the La Pena grades to open marine basinal thin-bedded argillaceous and cherty limestone and shale of the Otates Formation. The La Pena beds apparently represent the early stages of major transgression and foundering of the Cupido platform by basinal deposits of lime mudstone (upper Tamaulipas Formation) as the Cretaceous seas deepened and platform carbonate deposition shifted toward shallow-water areas to the west in the vicinity of the partly submerged Coahuila platform and to the north in the general area of the submerged Burro-Picachos platform (figs. 4, 10). The Sabinas basin formed an embayment (Ocampo embayment) where the shaly facies of the upper Tamaulipas and the lime mudstone facies of the Aurora were deposited farther to the west at this time. These beds grade laterally into rudist banks and reefs of the Aurora Limestone deposited in shallow-water environments in the vicinity of the Burro-Picachos platform (equivalent to the Glen Rose Limestone, a shelf deposit) (Smith, 1981).

Late Comanchean time was marked by submergence and transgression of the Cupido platform during early Albian time and the beginning of the second main Cretaceous carbonate cycle or reef belts, which included the Glen Rose, Edwards, Stuart City, and Devils River Limestones (figs. 5, 6, 10). Reef and organic bank facies growth continued in the vicinity of the submerged Coahuila platform and along the south border of the Texas craton from where the bank margin expanded and prograded basinward, with the total complex forming the successively deposited Glen Rose and lower Aurora Limestone, followed by the Stuart City, Devils River, and middle Aurora organic carbonate units, and finally in late Albian time, by the upper Aurora and upper Devils River bank carbonate units (figs. 6, 10). Farther south, in the Tampico basin area, the El Abra Limestone and equivalent reef and bank margin facies, and in southeastern Mexico, the main reef and bank margin facies of the Sierra Madre Limestone, were deposited in late Albian time.

UPPER CRETACEOUS

Following deposition of the Aurora Limestone and upper part of the Tamaulipas Formations and equivalent beds, marly beds of late Albian age were deposited across much of the Sabinas basin or Cupido platform

area (Georgetown Limestone of the Washita Group and Kiamichi Formation of the Fredericksburg Group and Sue Peaks or Sombreratillo Marl of Smith, 1981). Along a broad belt between Laredo and Monterrey, these beds grade upward into the Cuesta del Cura Limestone, a sequence of thin-bedded, cherty limestones, which were deposited approximately along the trend of the previously deposited Cupido bank margin facies. The Cuesta de Cura beds are partly equivalent to the Del Rio Clay and Buda Limestone of southwestern Texas and northern Coahuila.

Deposition of the Cuesta del Cura and equivalents was followed by an influx of fine calcareous clastics and argillaceous carbonates of the Cenomanian or basal Upper Cretaceous Agua Nueva or Indidura Formations, which probably represent the initial clastic influx related to Larmide orogenic activity (Smith, 1981). Organic carbonate production was greatly diminished at this time as terrigenous clay and silt covered the entire platform province.

The Parras Shale is a thick (1,000–2,000 m; 3,250–6,500 ft) sequence of dark-gray marine shale and siltstone overlying the limy Indidura beds. The Parras becomes more sandy in the upper part and is present throughout much of the Sabinas, Parras, and La Popa basins (figs. 5–6). Eastward, toward the Gulf basin, these beds grade into the lower part of the Mendez Shale (fig. 6), which is deeply buried beneath the Gulf Coastal Plain.

The Difunta Group conformably overlies the Parras or Mendez Shale and occupies most of the Parras, La Popa, and southern part of the Sabinas basins, except where removed by late Cenozoic erosion in the main uplift areas. The Difunta is a group of seven formations, which are thickest in the Parras and La Popa basins where they are 3,000 to 5,000 m (9,750–16,000 ft) or more thick, and is also present in the southern part of the Sabinas basin (figs. 5–6). This sedimentary complex represents the accumulation of a series of prograding and retrograding deltas into the Upper Cretaceous and Paleocene Gulf seaway by terrigenous detritus from highland areas in the vicinity of and southwest of the Sierra Madre Oriental and the Coahuila platform. Deltaic, nearshore, and marine-shelf environments are recognized in this complex intertonguing of sandstone, siltstone, redbeds, marine gray shale, and minor limestones deposited in the strongly subsided Parras and La Popa basins. The main part of the Difunta Group is of latest Cretaceous (Campanian-Maestrichtian) age, but the upper part is probably Paleocene (McBride and others, 1974). Eastward, these beds grade to the upper part of the Mendez Shale in the Gulf Coastal Plain region. The Difunta is partly removed by late Cenozoic erosion in the main uplift areas

of the Sabinas basin and is absent within and south of the Sierra Madre Oriental, which was rising at this time.

Except for probable Paleocene rocks in the uppermost beds of the Difunta Group, Tertiary rocks in northeastern Mexico are present only in the Burgos basin, which lies east of the trend of the Mesozoic Tamaulipas platform (fig. 12). West of here, Tertiary rocks are absent by erosion or nondeposition. The Burgos basin contains an eastward-thickening and offlapping wedge of Cenozoic open marine and nearshore marine, deltaic, and continental deposits 1,550 to 15,000 m (5,000–50,000 ft) or more thick. These beds are of Paleocene through Holocene age and are continuous with similar sequences of the western Gulf basin in Texas. However, some of the Tertiary formation names whose type localities are in Texas are no longer used in Texas even though they are valid in Mexico.

Paleocene rocks (lower part of Midway Formation of Mexico, lower part of Midway Group of Texas) crop out in a narrow belt along the western border of the Burgos basin, and a thin section of Paleocene beds also crops out in the Linares or Magiscatzin basin southeast of Monterrey. In the Burgos basin subsurface, these beds comprise a lower sequence of marine sandstone and glauconitic sandstone and shale grading upward to primarily marine shale in the upper part. The beds thicken eastward and are probably about 600 to 1,550 m (2,000–5,000 ft) thick near the Gulf coastline, where they are at depths greater than 12,000 m (40,000 ft).

Eocene rocks crop out along the western border of the Burgos basin but are in part overlapped by Pleistocene and younger beds. Eocene rocks are primarily a marine sandstone and shale sequence of six main formations, thickening eastward to more than 6,150 m (20,000 ft) near the Gulf Coast. The lithologic framework of subsurface Eocene rocks was worked out by industry geologists and others from the extensive drilling activity in the U.S. Gulf Coast area. Most of these lithologic divisions are also recognized in the Burgos basin of Mexico (fig. 2). All of the units thicken rapidly eastward from the outcrop belts along the west side of the basin.

The Wilcox Group is the basal Eocene unit and consists of alternating beds of marine shale and sandstone with some lignitic beds near the center. The Wilcox is about 770 to 1,230 m (2,500–4,000 ft) thick and is overlain by the Claiborne Group, which in ascending order consists in the Burgos basin of the Mount Selman, Cook Mountain, and Yegua Formations, all of which thicken eastward in the subsurface.

The Carrizo Formation, which conformably overlies the Wilcox, is a unit of fine- to medium-grained nearshore marine sandstone and shale, which thins and disappears southward in the Burgos basin.

The Mount Selman Formation (a term no longer used in Texas) is primarily marine and nearshore sandstone and shale 310 to 1,230 m (1,000–4,000 ft) thick. A deltaic unit (Queen City Sand) north of the embayment is an important reservoir section in south Texas.

The Cook Mountain Formation (a term used in the Burgos basin and in Texas north of the Rio Grande embayment) is a marine glauconitic sandstone and gray shale unit, which is probably several thousand feet thick in the deep subsurface to the east.

The Yegua Formation is a marine and nearshore marine or continental carbonaceous sandstone and shale unit 110 to 1,100 m (350–3,500 ft) thick.

The Eocene Jackson Group in Texas or Jackson Formation in the Burgos basin conformably overlies the Yegua Formation of the Claiborne Group and is a sequence of marine sandstone and sandy shale about 310 to 2,000 m (1,000–6,500 ft) thick.

Oligocene rocks thicken from about 310 m (1,000 ft) in the outcrop area on the west to more than 6,100 m (20,000 ft) in the eastern Burgos basin subsurface and represent continental beds on the west grading to nearshore marine and basin deposits to the east. A narrow band of outcropping Oligocene rocks extends from just west of Reynosa southeastward to near the Gulf Coast east of Ciudad Victoria (figs. 3, 11).

The Vicksburg Formation of earliest Oligocene age is mainly marine shale in the Burgos basin subsurface with beds of volcanic ash and some nearshore sandstone units in the western area. Vicksburg beds are about 3,000 m (9,750 ft) thick in the Reynosa Oriente No. 1 well and are thicker eastward toward the Gulf basin.

The Oligocene Frio Formation, which overlies the Vicksburg, is primarily a relatively thin continental facies in outcrop sections in southwestern Texas and northeastern Mexico, but it thickens and changes rapidly to a thick sequence of nearshore marine sandstone and shale in the subsurface. The marine sandstone and shale facies of the Frio reaches maximum thickness, as much as 2,000 m (6,500 ft) in the subsurface, along a northwest-southeast belt passing east to Reynosa. East of there, the formation grades to a basinal shale sequence more than 3,000 m (9,750 ft) thick.

The Norma Conglomerate, which unconformably overlies the Frio in the Burgos basin to the west, is a 75 to 300 m (250–975 ft) or more unit of lenticular conglomerate and sandstone deposited as a large alluvial fan. The unit grades basinward to marine sandstone and shale representing a regressive unit at the top of the Frio. The Norma represents coarse continental beds deposited during development of the regional mid-Oligocene unconformity.

The Anahuac Formation is an upper Oligocene subsurface unit of variable thickness (50–150 m; 160–485 ft) overlying the Norma in southwestern Texas. It is a marine unit of foraminiferal shale and poorly consolidated sandstone that probably extends to the southwest into the Burgos basin subsurface.

Miocene rocks crop out in a relatively broad band lying east of the Oligocene outcrop belt. They are in part overlapped by Quaternary beds in the eastern part of the Burgos basin.

The Fleming Group of Mexico includes the Oakville and Lagarto Formations, and it unconformably overlies the Anahuac and equivalent beds, thickens rapidly eastward from less than 100 m (325 ft) in the outcrop area to 3,000 m (9,750 ft) or more in the subsurface near the Gulf Coast. In south Texas the Oakville and Lagarto are not assigned to a group, and the Fleming Formation is not used. These beds are primarily a continental and nearshore marine sandstone, conglomerate, and shale facies on the west and grade eastward to marine shale and sandstone toward the Gulf of Mexico.

Pliocene rocks comprise a sequence of about 10 to 35 m (33–110 ft) of outcropping continental sandstone, gravel, and clay beds assigned to the Goliad Sand along the eastern border of the Miocene outcrop belt. These beds thicken in the subsurface to as much as 200 m (650 ft) or more near the Gulf Coast.

QUATERNARY

Continental gravels and clay overlie the Pliocene beds and onlap older Tertiary beds in a broad area extending from the Gulf Coast as far west as Reynosa. These beds thicken to more than 300 m (975 ft) near the mouth of the Rio Grande. Relatively thin deposits of Quaternary gravels are also present in topographically low areas throughout northeastern Mexico, particularly in the Sabinas basin, where they usually overlie Upper Cretaceous beds.

PETROLEUM GEOLOGY

INTRODUCTION

Exploration for petroleum in northeastern Mexico was stimulated during the 1920's and 1930's by the possibility of extending the producing zones of the Texas Gulf Coast southward into Mexico. Geophysical work, following surface geological studies in the upper Tertiary outcrop belt west and south of Reynosa, identified several subsurface structures, which resulted in

early drilling activity and the discovery of a small accumulation of gas in Eocene lenticular sandstone at the La Presa field (fig. 3) west of Reynosa in 1931. During the period 1931 to 1937, three other relatively small gas fields were discovered, all productive from Eocene sandstone reservoirs, including the Laredo field near Nuevo Laredo about 122 km (75 mi) northwest of the La Presa field. These discoveries, which demonstrated a significant potential for hydrocarbons in northeastern Mexico, led to additional seismic work in the coastal plain area south of the Rio Grande. Between 1945 and 1955, 21 additional gas fields with some oil production were discovered, including the largest (Reynosa, about 2 TCF) and the six other most important fields. The main production from these fields was from sandstone reservoirs in the Oligocene Frio Formation, which extended the Frio productive belt of Texas southward some distance into the Burgos basin of Mexico. A total of about 90 gas and gas-condensate fields and a few small oil fields has been found in the Burgos basin with cumulative production (about 1970) of approximately 4 TCF gas and 100 MMB oil and condensate. Estimated total ultimate recoverable reserves from these fields is about 5 TCF gas and 400 MMB oil and condensate.

An early period of petroleum exploration in the Sabinas basin, based on field geology, resulted in the drilling of two unsuccessful wells in the northwestern part of the basin. Further field work was conducted by Imlay (1936, 1940, 1944, 1953), Kellum and others (1936), Humphrey (1949, 1956), and by PEMEX (Petroleos Mexicanos) geologists between 1940 and 1960. A geophysical and drilling program was then organized, which resulted in the drilling of two unsuccessful wildcats, Minas Viejas (1968) and Anhelo (1969), in the southeastern part of the basin. In 1976, gas was discovered in Jurassic and Cretaceous rocks in the northwestern part of the basin at the Buena Suerte No. 1 well (fig. 3). Since then, a total of at least 10 gas fields has been discovered producing from Cretaceous carbonate and Jurassic sandstone reservoirs, with many of the wells producing at high rates. A small discovery in Upper Cretaceous beds was made at Garza No. 1 well in 1957 on the eastern border of the basin about 75 km (45 mi) west of Nuevo Laredo (fig. 3).

TERTIARY, BURGOS BASIN

Gas and condensate production in the Burgos basin is from sandstone and siltstone reservoirs of the Frio, Anahuac, and Vicksburg Formations of Oligocene age and of the Mount Selman, Jackson, and Yegua Formations of Eocene age, and Wilcox Formation of Eocene and Paleocene age (fig. 2). Minor gas is also produced from Miocene sandstone reservoirs, and some oil is produced from Frio and Vicksburg reservoirs. Production occurs in relatively well defined belts extending into Mexico from productive trends in southwestern Texas, arranged generally from oldest (Eocene) on the west to youngest (Miocene or late Oligocene) on the east (fig. 12).

RESERVOIRS

Lower Miocene sandstone reservoirs are productive over a relatively wide area along the Gulf Coast in Louisiana and Texas. In southwestern Texas and northeastern Mexico, a few fields produce from these beds in the vicinity of the Rio Grande delta. The reservoir sands are mainly discontinuous deltaic and delta fringe sand bodies probably deposited by the ancestral Rio Grande delta.

The Oligocene reservoir section of the Vicksburg, Frio, and Anahuac Formations is thickest along a belt about 50 km (30 mi) wide between Reynosa and Matamoras extending southward into the Burgos basin. Approximately within this belt the main production occurs, with maximum production from the Frio sands. Reservoirs are discontinuous and lenticular deltaic fringe sandstone and siltstone bodies interbedded with marine and nonmarine shale beds. Some localized conglomeratic beds are present in the Frio, and overall the sandstone sequence tends to be more shaly and silty than equivalents in southwestern Texas. Reservoir quality in the Oligocene beds diminishes southward into the Burgos basin; permeability is generally reported as poor to medium; porosity is highly variable but ranges as high as 20–25 percent in some cases. Gross pay thickness ranges from less than 3 m (10 ft) to as much as 155 to 310 m (500–1,000 ft) in some cases. Production rates range from 1 MMCFD or less to as much as 5 MMCFD or more in a few cases from Frio reservoirs. Cumulative production from Oligocene reservoirs as of about 1970 was somewhat over 2 TCF and about 30 MMB oil and condensate, almost all from Frio sandstone and siltstone reservoirs.

Eocene reservoirs in the Burgos basin include sandstone and siltstone beds of the Wilcox, Mount Selman, Yegua, and Jackson Formations, which produce gas and some condensate in about 60 fields. Total production, however, is much less than that from the Oligocene reservoirs. Nearshore marine and nonmarine discontinuous sandstone beds are gas reservoirs in the upper Eocene Jackson Formation at a few fields in the northwestern part of the Burgos basin, but production is relatively minor. The bulk of Eocene production is from deltaic and nearshore marine sandstone reservoirs of the Claiborne Group (Yegua, Cook Mountain, and

Mount Selman Formations). These reservoirs are best developed within a belt between Laredo, Tex., and Reynosa, Mexico, extending across the Rio Grande southward into the Burgos basin. Basal Eocene reservoirs are deltaic, fringe, and barrier bar sandstones deposited during a major regressive cycle (Rainwater, 1967; Fisher and McGowen, 1967). The main belt of sandstone development passes southward into Mexico a short distance east of Nuevo Laredo. Distribution of sandstone beds and thickness of the Wilcox are influenced greatly by a growth fault system downdropped toward the Gulf of Mexico. General reservoir quality of Eocene reservoirs decreases southward into the Burgos basin. Reported permeability is generally poor to medium, and porosity values are highly variable. Gross pay thicknesses range from less than 3 m (10 ft) to 30 to 60 m (100–200 ft) in a few cases. Production rates range from 0.5 MMCFD or less to more than 10 MMCFD in one case. Almost all of the production is from Mount Selman sandstone and siltstone reservoirs. As of about 1970, cumulative production from the Mount Selman was about 300 BCF with about 50 BCF from Jackson, Yegua, and Wilcox reservoirs.

SOURCE ROCKS

Marine argillaceous rocks, interbedded with deltaic and nearshore marine sandstone reservoirs, are believed to be the main source rocks for oil and much of the gas accumulations in Tertiary reservoirs. Carbonaceous deltaic and nearshore lagoonal or swamp-deposited argillaceous beds are also probable source rocks for some of the gas.

REGIONAL CAP ROCKS

Thick and widespread marine, and in some cases nonmarine, shale facies of the Gulf basin Tertiary sequence, which intertongue with and overlie the sandy reservoir facies, form numerous regional seals for the petroleum accumulations.

TRAPS

Most traps in Burgos basin Tertiary fields are associated with combined structural-stratigraphic relationships incident to complex facies patterns of the deltaic and related nearshore environments of deposition, growth faults, and faulted domal or anticlinal folds, which in some cases may be related to deep-seated salt structures. Except in the updip beds near the outcrop belts, few of the structures are expressed at the surface.

ANALOGS

The stratigraphic and structural aspects of the Burgos basin productive province are essentially the same as those of the analogous western Gulf basin U.S. province.

UPPER CRETACEOUS

Only minor production (gas) has been found in Upper Cretaceous rocks, mainly in fractured limestone beds of the San Felipe Formation at the Lerna field in the southeastern part of the Burgos basin and in limy beds of the Eagle Ford (Boquillas) Formation at the Garza field on the northeastern flank of the Sabinas west of Nuevo Laredo (fig. 3). Gas production from fractured Eagle Ford (Boquillas) beds is also reported northwest of Nuevo Laredo on the Burro-Picachos platform (Zwanziger, 1978). These are small accumulations, and thus far prospects for significant petroleum deposits in Upper Cretaceous beds have not been promising in the Burgos and Sabinas basins. In the Burgos basin, Upper Cretaceous beds are of the open-basin shaly marine facies, probably without reservoir development, and in most cases are buried to depths greater than 7,200 m (25,000 ft). The potential of the Upper Cretaceous section in the Sabinas basin is limited by the severe erosion and the probability that these beds have not been buried to thermal maturity depths, although some possibility for biogenic gas may exist in the coaly parts of the section in the Sabinas coal basin (fig. 3). The thick Upper Cretaceous sequence in the Parras and La Popa basins has not yet been explored, and several parts of this section may be attractive for gas prospects. Much of this section is an intertonguing marine and nonmarine facies with thick reservoir and potential source-rock beds, many fold and fault structures with good trap possibilities, and regional cap-rock facies. The upper part of this section has not been buried to thermal maturity depths in parts of these basins, but some of the shallower beds could be prospects for biogenic gas accumulations in the deltaic and nearshore marine facies. In the deeper parts of these basins, the lower half of the sequence has been buried to depths beyond the thermal maturity range.

LOWER CRETACEOUS

Lower Cretaceous fractured limestone and dolomite beds are productive of gas at about 10 fields in the Sabinas basin and Tamaulipas platform area. Reservoir facies are present in the carbonate beds of the Aurora Limestone, Monclova facies (upper Aurora Limestone or Actita Evaporite), Cupido Limestone and its Padilla

Tongue, La Virgen Evaporite, and Menchaca Limestone, in sandstones of the Barril Viejo Formation, and in fractured argillaceous limestone facies of the La Pena Formation (fig. 2).

RESERVOIRS

The Aurora Limestone and Monclova facies are equivalent to the Stuart City Limestone of Texas, a platform and rudist bank facies of Albian Age generally present in western Coahuila in the vicinity of the Coahuila platform (fig. 10). Good porosity is observed in outcrops of these beds (Gonzalez Garcia, 1979), and the potential for matrix and fracture porosity and permeability is good where structures in the area are covered by Upper Cretaceous shaly beds.

The La Pena argillaceous limestone or shale is present throughout northeastern Mexico (fig. 2). These beds are fractured reservoirs in the Sabinas basin and Burro-Picachos platform areas.

The Cupido (and its stratigraphic equivalent in Texas, the Sligo) platform limestone facies covers much of the Sabinas basin, Tamaulipas platform, and thrust belt area and contains the major shelf margin rudist reef and mound belt of the Lower Cretaceous. Gas shows are reported from these beds (Gonzalez Garcia, 1979), and although good matrix porosity has not been observed in wells drilled so far, fractured reservoirs are a good possibility as is the local development of matrix porosity in reef or back-reef dolomitized beds.

The limestone, dolomite, and evaporite beds of the La Virgen Evaporite are a platform interior facies equivalent to the platform margin facies of the Cupido Limestone (figs. 2, 5, 6). These beds are productive in the Buena Suerte, Monclova, and Ulua gas fields (fig. 3) from porous, finely crystalline dolomite beds, which are interbedded with nonporous limestone and anhydrite beds. The La Virgen is in facies relationship with the La Mula Shale, which is a probable good source-rock facies. Fracturing is an important factor in reservoir quality because of the fine-grained and generally low matrix permeability of the dolomites.

The Padilla Tongue represents a relatively widespread platform limestone tongue of the lower Cupido, which underlies and intertongues with the La Virgen Evaporite and La Mula Shale (figs. 2, 5, 6). The Padilla contains a thick section (up to 80 m; 260 ft) of porous dolomitized reef and back-reef facies with good reservoir quality (Gonzalez Garcia, 1979); the section has been saltwater bearing in several wells.

The Barril Viejo Formation, Patula Tongue, and San Marcos Arkose are a continental to marine coarse clastic facies present in the central and southwestern part of the Sabinas basin and adjacent areas. The sandstone, carbonate, and shale beds of the Barril Viejo Formation underlie the Padilla Tongue of the Cupido in the central part of the Sabinas basin. These beds grade westward into parts of the San Marcos and Patula Arkoses. The sandstone units of the Barril Viejo are of interest as potentially good reservoirs, although lack of control prevents a complete assessment at this time. Good gas shows are reported in Barril Viejo sandstones in the Colmar No. 1 and Dolomita No. 1 wells (Gonzalez Garcia, 1979).

The Menchaca Limestone is the basal Cretaceous shelf limestone and marl unit in the central and northern parts of the Sabinas basin. These beds grade eastward into marly and sandy beds of the Taraises Formation and southward into the lower San Marcos Arkose. Fractured Menchaca Limestone flowed gas under high pressure for a short time at the Buena Suerte No. 1 well (fig. 4), but the test was considered inconclusive (Gonzalez Garcia, 1979).

SOURCE ROCKS

Potential Lower Cretaceous source rocks are present in the La Pena, La Virgen, La Mula, Barril Viejo, Menchaca, and Taraises Formations. All these formations are marine shale or shaly carbonate beds with varying amounts of organic content. In most cases, they are in stratigraphic association with potential reservoir beds. Geochemical data are not available on any of the Cretaceous units, and in places the Lower Cretaceous rocks may not have been buried to thermal maturity depths. However, in areas where the Upper Cretaceous beds are present, the Lower Cretaceous section should have been buried to sufficient depth, particularly in the southern part of the area north and east of the Sierra Madre Oriental fold and thrust belt and in most of the Sabinas basin.

REGIONAL CAP ROCKS

Impermeable regional facies that are suitable as seals for Lower Cretaceous reservoirs include the widespread Upper Cretaceous argillaceous beds and the Lower Cretaceous shale and shaly carbonate beds of the La Pena Shale, upper Tamaulipas Formation, La Virgen Evaporites, La Mula Shale, and the Barril Viejo Formation and Menchaca Limestone. These units vary in regional distribution, but in general several of them are present in most parts of the assessment area.

TRAPS

Thus far, gas discoveries in the Sabinas basin and adjacent area are on anticlinal structures, most of them

faulted and most with large closures. Many similar structures are as yet undrilled; some are intruded by salt or gypsum but many may not be. Many potential fault and fractured reservoir traps should be present on the flanks of large structures. Facies changes are common in the Lower Cretaceous section with good possibility of stratigraphic traps; many of the accumulations appear to be combination structure, fracture pattern, and stratigraphic traps. Probably the most favorable structures are those over which the Upper Cretaceous shaly section is preserved. Accumulations may depend on the specific combination of the above factors.

ANALOGS

Stratigraphic analogs for the Lower Cretaceous section are found in much of the carbonate and evaporite section of similar age in the U.S. Gulf basin, the Tampico basin, and the southeastern Mexico-Guatemala basins. Structural styles in these areas are in the main somewhat different from those of the Sabinas and associated basin and uplift areas, where the structural styles are more directly related to the effects of Laramide folding and thrusting of the Sierra Madre Oriental. However, similarities are found in the presence of evaporite intrusion structures in some cases and in the high degree of fracturing in tightly folded structures. An important difference between the northeastern Mexico Mesozoic provinces and those of other Mesozoic productive regions of the Gulf of Mexico is the absence or thinning by erosion or nondeposition of the Upper Cretaceous and Tertiary cover in the Sabinas basin and related basins and uplifts.

JURASSIC

RESERVOIRS

The La Casita Formation contains sandstone and siltstone units, which are interbedded with high-organic shale beds in much of the Sabinas basin area. The sandstone facies is best developed in the vicinity of the Coahuila platform and the Tamaulipas platform paleostructures. Sandstone beds in the La Casita are productive of gas in the Lampazos field (fig. 3) and have had good gas shows in several other wells. The sandstones are composed of calcite-cemented quartz and carbonate grains, and interstitial porosity thus far has been low. However, their reservoir quality may improve in other parts of the basin depending on facies changes and paleostructure position. Fracturing also is important on the tightly folded Sabinas basin structures.

The Upper Jurassic Zuloaga Limestone includes the oolitic carbonate beds and evaporites of the Upper Ju-

rassic Olvido Formation. The Zuloaga is present in the central part of the Sabinas basin and grades into the sandy facies of the La Gloria Sandstone around the basin borders. The oolitic beds of the Zuloaga so far have not been porous where drilled, but facies changes could improve porosity, and fracturing is important on structural prospects. The La Gloria Sandstone beds are also of potential reservoir quality, although they are suspected in most areas to have low matrix porosity.

The presalt redbed clastics are probably widespread in the area and may be very thick in downwarped graben areas of the basement. Good matrix porosity and adequate associated source rocks would not be expected in this facies, but in anomalous structural situations they could be of interest.

SOURCE ROCKS

The Upper Jurassic La Casita Formation contains a substantial thickness (as much as 310 m; 1,000 ft or more) of dark organic shaly beds which underlie the Cretaceous section throughout most of the Sabinas basin. The La Casita has been buried to depths of more than 4,600 m (15,000 ft) in parts of the basin area, and there is some indication that these beds may have undergone severe thermal alteration (Gonzalez Garcia, 1979). Igneous activity, as well as burial depths, may have also contributed to the thermal effects. Excessive thermal activity may explain the high methane and CO_2 content of most of the gases, as well as the lack of significant oil indications in the fields discovered so far. In addition, there seems to be evidence that the basin is primarily a dry-gas basin. Condensate and some oil shows, however, have been encountered in a few wells, and current drilling density precludes an accurate assessment of these factors.

The Zuloaga Limestone, which is reported as black and argillaceous in places, may also contain a less important Upper Jurassic source-rock facies.

TRAPS

Petroleum deposits in Jurassic reservoir beds should be associated with the same kinds of traps as those of the Lower Cretaceous reservoirs that occur in folded and faulted structures having an important fractured reservoir factor and some possibility of stratigraphic trapping, particularly on the flanks of large structures.

ANALOGS

The Jurassic stratigraphic section in northeastern Mexico is similar in most respects to that of the north-

ern regions of the U.S. Gulf basin, except that the carbonate beds in the Zuloaga Formation do not appear to contain porous reservoir facies as extensive as those of the Smackover Formation. The La Casita and La Gloria beds are similar in most respects to clastic facies of the Cotton Valley Group in the northern Gulf basin and contain a significant thickness of dark high-organic facies and sandstone beds similar to equivalent productive reservoirs in Texas and Louisiana.

RESOURCE ASSESSMENT

PROCEDURES

The resource assessment was conducted by the Resource Appraisal Group (RAG) of the U.S. Geological Survey, Branch of Oil and Gas Resources, following the standard procedures developed since 1974 for domestic petroleum resource analysis. The technique, briefly, requires study of a given area paying particular attention to the geologic factors controlling the occurrence, quality, and quantity of the petroleum resource. Standardization of critical elements of the investigations is achieved by the preparation of data forms for each basin; the forms call for specific volumetric, areal, and rock-quality measurements, as well as the determination of basin analogs for comparison purposes. In addition, finding-rate histories and projections are constructed when possible. From these data and analyses, various analytical techniques are used to calculate a set of resource numbers. Not considered in this assessment are resources of heavy oil deposits, tar deposits, and oil shales; gas in low-permeability reservoirs, in geopressured shales and brines, and in natural gas hydrates; and gas occluded in coal.

The assessment process itself is subjective; the results of the geological investigation and of the resource calculations are presented to a team of U.S. Geological Survey assessment specialists who make their personal estimates conditional upon recoverable resources being present. Initial assessments are made for each of the assessed provinces as follows:

(a) A low resource estimate corresponding to a 95-percent probability of *more than* that amount; this estimate is the 95th fractile (F_{95}).

(b) A high resource estimate corresponding to a 5-percent probability of *more than* that amount; this estimate is the 5th fractile (F_5).

(c) A modal ("most likely") estimate of the quantity of resource associated with the greatest likelihood of occurrence.

The individual estimates are then posted and averaged, and the results debated from the perspective of the personal experiences of the individual assessors; a second and third iteration of the procedure may follow depending on consensus. If no commercial oil has been heretofore discovered in the basin, then a *marginal probability* is subjectively assessed reflecting the probability that any commercial oil will ever be discovered.

The results of the final estimates are averaged, and those numbers are computer processed using probabilistic methodology (Crovelli, 1981) to show graphically the resource values associated with a full range of probabilities and to determine the 95th fractile, the 5th fractile, and the mean, as well as other statistical parameters.

ASSESSMENT

The locations of the northeastern Mexico basins are shown in figure 1. Unconditional estimates by the U.S. Geological Survey of oil and gas resources in these basins are given in table 1 and figures 13 and 14. Data and summary information supporting these estimates are supplied in tables 2–4.

TABLE 1.—*Estimates of conventionally recoverable petroleum resources of northeastern Mexico, including those of the Sabinas, Parras, and Burgos basins*

[Unconditional resource assessment by U.S. Geological Survey as of June 23, 1981; see also figures 13 and 14]

Crude oil in billions of barrels			Natural gas in trillions of cubic feet		
Probability of occurrence (percent)					
95	5	Mean	95	5	Mean
Sabinas and Parras basins[1]					
0	2.9	0.8	18	122	55
Burgos basin					
0.1	1.2	0.5	1.6	12.5	5.5
Combined Sabinas, Parras, and Burgos basins[2]					
0.2	3.5	1.3	23	126	61
			BBOE at 6,000 ft^3/barrel*		
			4	21	10

[1] A marginal probability of 0.85 is assigned to the occurrence of commercial oil in these basins.

[2] Totals are derived by statistical aggregation; only the mean total equals the sum of the component parts.

* In PEMEX reports, conversion to BBOE is made at 5,000 ft^3/barrel, but the 6,000 ft^3/barrel is used here for comparison with other U.S. and world numbers.

COMMENTS

- Exploration in the Sabinas basin is in its very initial stages. So far, we have reports on four successful wildcats, each of which is reported to be capable of production in excess of 10,000,000 ft³/d. Though no oil has yet been reported, the geologic investigation suggests that oil in some part of the basin is likely.
- Giant fields are likely in the Sabinas and Parras basins owing to structural development, including salt and probable favorable Jurassic source rock. Overall stratigraphic thickness of Mesozoic units may be 30,000 to 40,000 ft.

- The Sabinas and Parras basins reflect geologic conditions similar to those in the western United States from the overthrust belt east to the North American craton. Production from Jurassic and Cretaceous units will predominate.
- The Burgos basin is an extension of the U.S. Western Gulf basin. Substantial production has been established from lower Tertiary rocks on both sides of the U.S.-Mexico border. Production from Eocene and Oligocene rocks will predominate.
- Giant fields are not likely in the Burgos basin owing to the state of maturity for exploration and the deltaic environment. Overall stratigraphic thickness of Tertiary rocks may exceed 50,000 ft.

TABLE 2.—*Data and information summary*

Geologic province: Mesozoic and Tertiary continental basins.
Areas included in assessment:
 Burgos basin
 Sabinas basin and adjacent uplifts
 Parras, La Popa, and Magiscatzin basins
 Northern and eastern borders of Sierra Madre Oriental overthrust belt.
Total area of province: 330,000 m² (125,000 mi²)

Prospective intervals:
 Tertiary continental-marine clastic sequence, Burgos basin.
 Upper Cretaceous continental-marine clastic sequence, Parras, La Popa, and southern Sabinas basins.
 Lower Cretaceous marine platform carbonate sequence, Sabinas, Parras, La Popa, and Magiscatzin basins; Burro-Picachos, Tamaulipas, and Coahuila platforms and Sierra Madre Oriental overthrust belt.
 Upper Jurassic marine clastic and carbonate sequence
 Pre-Upper Jurassic continental-marine clastic and evaporite sequence.
Source beds:
 Tertiary marine, lagoonal, and deltaic carbonaceous shales and siltstones.
 Upper Cretaceous marine and deltaic carbonaceous shales and siltstones.

Lower Cretaceous marine organic shale and argillaceous limestone.
Upper Jurassic marine organic shale and argillaceous limestone.
Prospective trap types:
 Tertiary and Upper Cretaceous marine, deltaic, and continental sandstones.
 Cretaceous and Jurassic reef, back reef, and fracture pattern porosity-permeability variations.
 Asymmetric, thrust-faulted, and normal faulted anticlines and domes, some related in part to salt or gypsum movement.
 Combination structural and stratigraphic traps
Exploration stage of province: Mature in Tertiary Burgos basin; early in province.
Number of fields: About 90 small to intermediate gas and gas-condensate fields in Burgos basin; about 10 dry gas fields in Sabinas basin and adjacent Burro-Picachos platform, some of which may be large.
Cumulative production: About 4 TCF gas and 100 MMB condensate and oil.
Average depth of undiscovered resources: About 4,500–6,000 m (15,000–20,000 ft) in Burgos basin; about 3,300–4,500 m (10,000–15,000 ft) in Sabinas-Parras-La Popa basins.
Recoverable basin richness: At mean, undiscovered estimate assuming 330,000 mi³ of sediments=43,000 BOE/mi³.
Analogs: Gulf basin, United States; Tampico basin, Mexico

ESTIMATES		
MEAN	—	1.31
MEDIAN	—	0.93
95%	—	0.24
75%	—	0.55
50%	—	0.93
25%	—	1.55
5%	—	3.51
MODE	—	0.41
σ	—	1.34

FIGURE 13.—Aggregate recoverable oil in the Burgos and Sabinas-Parras basins, Mexico.

| ESTIMATES		
MEAN	—	60.55
MEDIAN	—	52.20
95%	—	22.77
75%	—	37.03
50%	—	52.20
25%	—	74.74
5%	—	126.37
MODE	—	40.21
σ	—	35.55
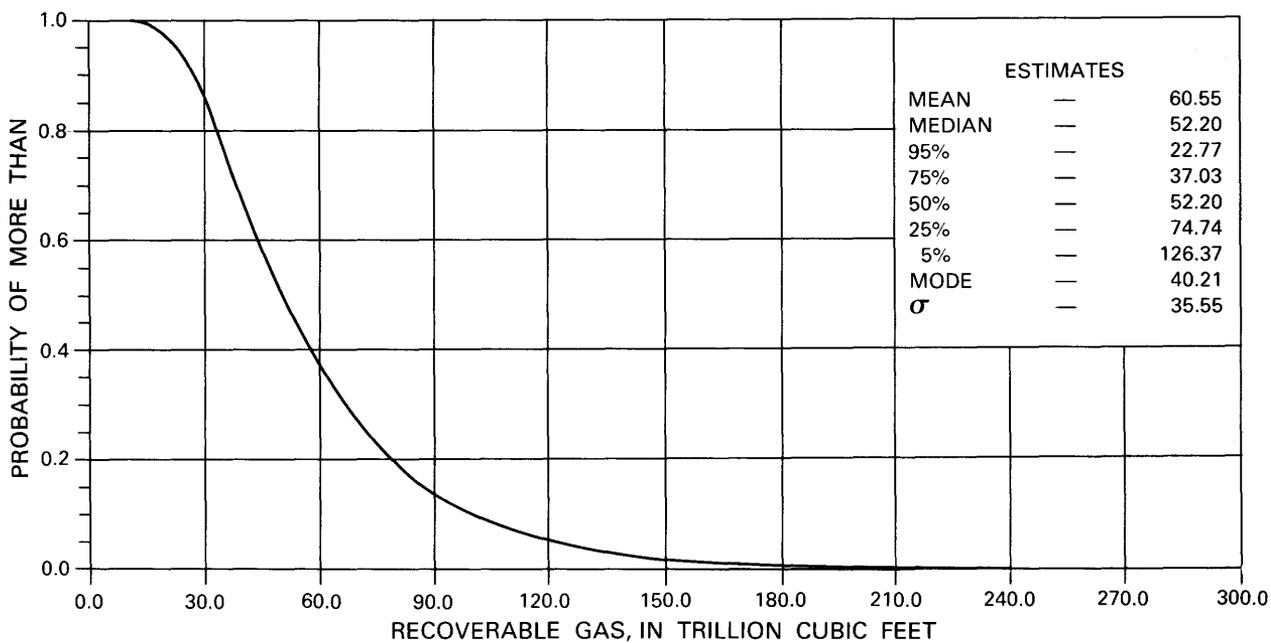
FIGURE 14.—Aggregate recoverable total gas in the Burgos and Sabinas-Parras basins, Mexico.

TABLE 3.—*Summary of assessment factors*

	Burgos basin	Sabinas basin area
Sedimentary section	85 percent marine; primarily Tertiary and Upper Cretaceous clastics; some Lower Cretaceous and Jurassic carbonates, evaporites, and clastics in lower part at great depths.	95 percent marine; primarily Lower and middle Cretaceous carbonates; Upper Jurassic carbonate and clastics; Upper Cretaceous clastics in south part; Jurassic and some Triassic clastics and evaporites in lower part.
Reservoirs	Mainly Tertiary deltaic and longshore marine sands, somewhat discontinuous; some possibility of Cretaceous and Upper Jurassic carbonate and Upper Jurassic clastic reservoirs at depth.	Mainly Cretaceous and Upper Jurassic carbonates, with reef, mound, or fractured carbonate reservoirs; clastic reservoirs in Upper Cretaceous and Upper Jurassic.
Source rocks	Tertiary marine shales, mainly gas; Cretaceous and Upper Jurassic marine black shales and shaly carbonates.	Upper Jurassic black shales; Lower and middle Cretaceous gray and black shales and shaly limestones; Upper Cretaceous marine gray shales.
Structure	Anticlines and domes, faulted, and vertical faults; possibly deep salt-structure influence.	Elongate anticlines and regional uplifts, many evaporite structures; common vertical faults; major thrust belt in south part.
Paleostructure	General continental border basin subsidence with down-to-gulf growth faults.	Regional Mesozoic paleostructures inherited from Paleozoic; major continental border evaporite basin subsidence in center; Laramide thrust belt growth in south part.
Time of migration and hydrocarbon generation	Good.	Good.
Depth of burial	Shallow in much of upper Tertiary with biogenic gas; moderate in remainder of Tertiary and Cretaceous but rapidly reaching excessive depths in coastal plain and offshore area.	Shallow in much of Upper Cretaceous with possibility of biogenic gas; moderate in remainder Cretaceous and Upper Jurassic in most of area, probably reaching postmaturation depths in central part of area.
Geothermal gradient	Normal.	Probably high in parts of area, particularly western part, because of Cenozoic igneous activity and overthrust activity.
Preservation history	Good.	Upper Cretaceous exposed over much of area; Lower and middle Cretaceous exposed in main structural areas; Upper Jurassic exposed in small areas of main salt anticlines and in parts of south thrust belt.
Size of area	Small—14,000 mi^3, 113,000 mi^3 of sediment; about 1/8 the size of western U.S. Gulf basin.	Intermediate—80,000 mi^2, 218,000 mi^3 of sediment; slightly smaller than Permian basin of Midcontinent areas, United States.
Exploration stage	Mature, except in deep part of basin where probability of good reservoir section is low.	Early; 65 or more important structures are as yet undrilled.

TABLE 4.—*Supplementary and comparative data supporting the resource estimates for northeastern Mexico*[1]

	Crude oil (billion barrels)	Natural gas (trillion cubic feet)
Cumulative production to Jan. 1, 1980		
Sabinas/Parras ------------ 0		+[2]
Burgos -------------------- .1		4.0
Measured reserves [3] to Jan. 1, 1980		
Sabinas/Parras ------------ 0		+[2]
Burgos -------------------- .3		5.0

Original recoverable resources (ultimate) of the two basins

	Oil	BBOE at 6,000 ft³/barrel
Cumulative production -----	0.1	4.0+
Identified reserves ---------	.3	5.0+
Undiscovered resources (mean) -----------------	1.3	61.0
Total ---------------	1.7	70.0+
		12+

Total 14+ BBOE

Recoverable basin richness: At mean, undiscovered estimate assuming 330,00 mi³ of sediments=43,000 BOE/mi³.

[1] *Cumulative production* and *reserves* are composited estimates from various sources.
[2] Quantity positive, but data unavailable.
[3] Follows terminology outlined in "Principles of a Resource/Reserve Classification for Minerals," 1980, U.S. Geological Survey Circular 831, by U.S. Bureau of Mines and U.S. Geological Survey, 5 p.

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