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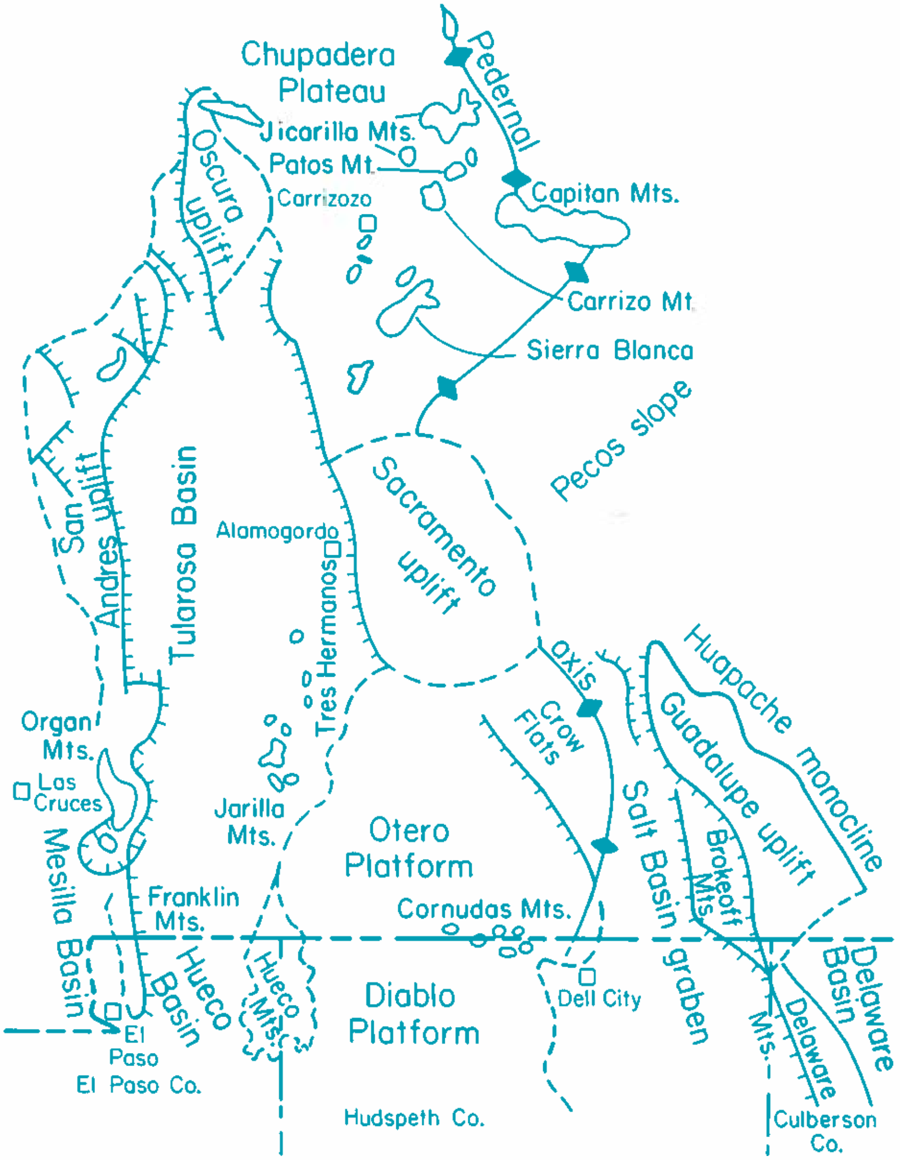

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COVER—See Fig. 1 on p. 5.

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Oil and gas potential of the Tularosa Basin-Otero platform-Salt Basin graben area, New Mexico and Texas

by William E. King[1] and Vicki M. Harder[2]

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Abstract

The Tularosa Basin—Otero platform—Salt Basin graben area has until now remained inadequately explored for hydrocarbons. Examination of numerous lithological logs, borehole geophysical logs, and gravity data together with the construction of four detailed cross sections reveal a complex fault-block structure of the Tularosa Basin. Noteworthy is the distribution of predominately Paleozoic source and reservoir beds. Analyses of drill-stem tests of the Houston Oil and Minerals No. 1 Lewelling and the Hodges No. 1 Houston test wells drilled near Three Rivers, New Mexico, indicate a potential for significant gas reservoirs in the Pennsylvanian and Permian portions of the strati-graphic section. A structural contour map on the top of the Precambrian and isopach—lithofacies maps of the Tularosa Basin show a thick and varied Paleozoic section to be explored with a high probability of success in the search for hydrocarbons.

The Otero platform is heavily influenced by the buried Pedernal uplift, as shown by isopach maps and two east—west cross sections. Although no oil and gas tests indicate a strong probability of production, possible hydrocarbon-bearing traps on the east and west flanks of the Pedernal uplift are postulated. There could be reef trends of Permian age. Problems that exist, however, are the uncertainty of the presence of adequate trap-sealing beds, the distance from major hydrocarbon source beds in the Delaware and Otero Basins, and the introduction of fresh water into reservoir beds due to Plio-Pleistocene faulting.

The Salt Basin graben area of New Mexico and Texas is illustrated by north—south and east—west cross sections showing both source and reservoir beds. However, wells drilled to date have been less than promising, in a large measure due to recent faulting which allowed fresh water to flush the reservoirs.

Introduction

Location of study area

The study area is located in Lincoln and Otero Counties of south-central New Mexico and northern Hudspeth and Culberson Counties of Texas (Figs. 1, 2).

The Tularosa Basin is one of the largest of the basins in the Rio Grande rift (Chapin, 1971). It covers an area of approximately 6,000 me and is over 100-mi long and up to 60-mi wide. It is bounded on the east by the Jicarilla, Sierra Blanca, and Sacramento Mountains, and on the west by the Chupadera Mesa and the Oscura, San Andres, Organ, and Franklin Mountains (Meinzer and Hare, 1915).

The Otero platform lies to the east and southeast of the Tularosa Basin, covers an area of approximately 2,916 mil, and is approximately 54 by 54 mi. It is bordered on the east by the nearly continuous escarpment of the Guadalupe Mountains and on the west by numerous small hills and flats which form the broad easterly dip slope of the northern Hueco Mountains as they merge northward into the southern Sacramento Mountains. The northern boundary of the area lies along and within the eastern slope of the Sacramento Mountains. The southern boundary approximates the Texas—New Mexico state line between the Tularosa Basin and the Salt Basin graben.

The Salt Basin graben is 130-mi long and 5-20-mi wide. This basin separates the Otero platform, Sierra Diablo, Carrizo, and Van Horn Mountains to the west from the Guadalupe, Delaware, Apache, and Davis Mountains to the east (Veldhuis and Keller, 1980). The portion of the Salt Basin graben considered in this report is only that of New Mexico and of the extreme northern Hudspeth and Culberson Counties in Texas (Fig. 1).

Acknowledgments

We are deeply indebted to the New Mexico Bureau of Mines and Mineral Resources for financial and technical assistance. In particular, thanks are due to Frank Kottlowski, director of the Bureau, who suggested the project and provided constant guidance. Further Bureau aid was received from Robert Bieberman, who provided logs, completion cards, samples, and constructive advice.

Ben Donegan of Leonard Minerals Company, Albuquerque, gave tireless encouragement and opened

FIGURE 1—General structure and physiography (modified from Kelley, 1983).

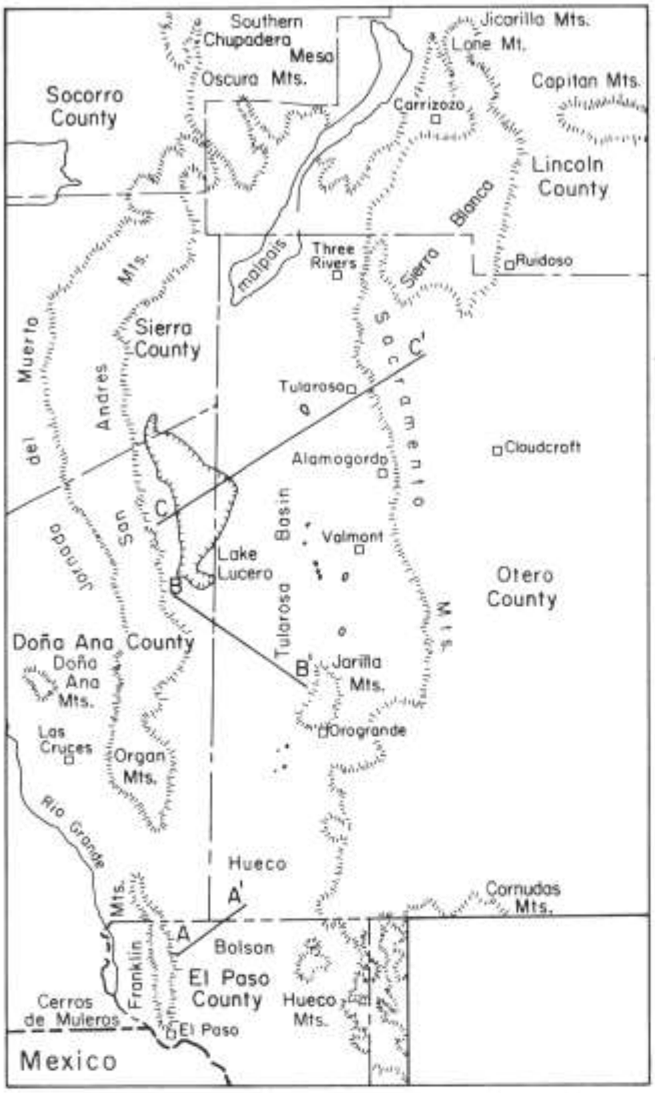

FIGURE 2—Physiographic map of Tularosa Basin showing location of gravity cross sections.

his vast files of information on the study area. The project could not have been done without Ben's cooperation and expertise gained through many years of exploration in the region.

Roy Foster, independent geologist at Socorro, provided valuable information about the Tularosa Basin portion of the study area and an extremely useful base map.

Bruce Black, consulting geologist at Farmington, who did his Ph.D. dissertation on the Otero platform and has written excellent papers about it, was very generous with logs, stratigraphic information, and carefully considered criticism.

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Jerry Mueller, Head of the Department of Earth Sciences at New Mexico State University, reviewed many of the maps and prepared some of them.

G. R. Keller, Chairman of the Department of Geosciences at the University of Texas at El Paso (UTEP), and James Lance of UTEP provided geophysical data. David LeMone, professor of geology at UTEP, reviewed several drafts of the manuscript and contributed many ideas.

Companies that allowed us to use information, much of which was released for the first time, are Texaco, Houston Oil and Minerals Company, Coastal Oil Company, Border Oil Company, Transocean Oil Company, Hunt Oil Company, and Hunt Petroleum Corporation. We are very grateful for their cooperation.

Pat Tamarin, Robin Ransom, and Nora Trentman drafted illustrations, and Marilynn Wilson helped with the typing.

Previous work

Regional studies of the area include an overview of the geology of Trans-Pecos Texas (Richardson, 1904) and a stratigraphic analysis of the Upper Carboniferous of west Texas and southwestern New Mexico (Richardson, 1910). P. B. King et al. (1948) focused on the pre-Permian rocks and expanded their studies into the Trans-Pecos area and southern New Mexico (King, 1949). Tectonic examinations of south-central New Mexico were published by Kelley (1955, 1973), lithofacies and isopach maps of the Pennsylvanian and Wolfcampian rocks of southeastern New Mexico by Meyer (1966), an examination of the sedimentary basins of south-central and southwestern New Mexico by Kottlowski (1965), stratigraphic analysis of the border region by Kottlowski and LeMone (1969), and an oil and gas evaluation of south-central New Mexico by Foster (1978). Black (1973, 1975) has written extensively on the geology of the Otero platform.

Studies of the Tularosa Basin region include the geology and water resources (Meinzer and Hare, 1915; Sandeen, 1954; Jicha, 1954), a study of the tectonics and general geology of the northern part of the basin (Kelley and Thompson, 1964), the geology of the Jarilla Mountains in the southern part of the basin (Schmidt and Craddock, 1964), the ground-water hydrology (Sloan and Garber, 1971), and a gravity survey (Healy et al., 1978).

Previous publications on, or pertaining to, the Salt Basin graben area include an integrated geological and geophysical study by Veldhuis and Keller (1980), and a paper on the Quaternary faulting by Goetz (1980).

A series of stratigraphic studies has been completed on the surrounding mountains. These include such classic studies as those of the Mississippian bioherms of the Sacramento Mountains (Laudon and Bowsher, 1941, 1949; Bolton, Lane, and LeMone, 1982), paleoecology of the Guadalupian reef complex (Newell et al., 1953), stratigraphy of the San Andres Mountains (Kottlowski et al.,1956), the Montoya Group and Fusselman Formation of the Franklin Mountains (Kottlowski, 1958), the structural features and stratigraphy of the Sacramento escarpment (Pray, 1959, 1961), and Permian sedimentary facies in the Guadalupe Mountains (Boyd, 1958). In-depth studies of the Upper Pennsylvanian and Lower Permian of the Sacramento

Mountains (Bachman and Hayes, 1958) and the Laborcita Formation of the northern Sacramento Mountains (Otte, 1959), the Guadalupe Mountains (Hayes, 1964), and mounds in the Sacramento Mountains (Toomey, 1977) are an important part of the literature.

General physiographic and structural location maps were derived from Ellsworth (1964) and Daggett (1982). Fig. 1 was modified from Kelley (1983).

Objectives of study

The principal objective of this study is to examine the potential for hydrocarbons in the area by utilizing lithologic and geophysical well logs, facies and isopach maps, cross sections, and well-test data that aid in delineating favorable areas in which to drill for oil and/or gas. The Tularosa Basin, Otero platform, and Salt Basin graben contain some promising oil and gas "shows," the best of which are in the Tularosa Basin. These factors justify a thorough research effort, the results of which might stimulate more drilling activity. In the event that the White Sands Missile Range should ever be opened to oil exploration, this study will aid in establishing a basic framework for detailed evaluation.

Geologic setting

The Rio Grande rift is a late Cenozoic continental rift which, in general, separates the Great Plains on the east from the Colorado Plateau and Basin and Range province on the west. Chapin (1971) defined the rift as a series of north—south-trending basins extending for over 600 mi from the northern end of the upper Arkansas Valley in Colorado to the Hueco bolson of west Texas and continuing on into northern Chihuahua, Mexico. North of Albuquerque, the rift is a series of in-line basins. To the south, however, the rift changes form and becomes a series of parallel basins separated by intra-rift horsts (Daggett, 1982). The Tularosa Basin is one of the southern basins (Fig. 3).

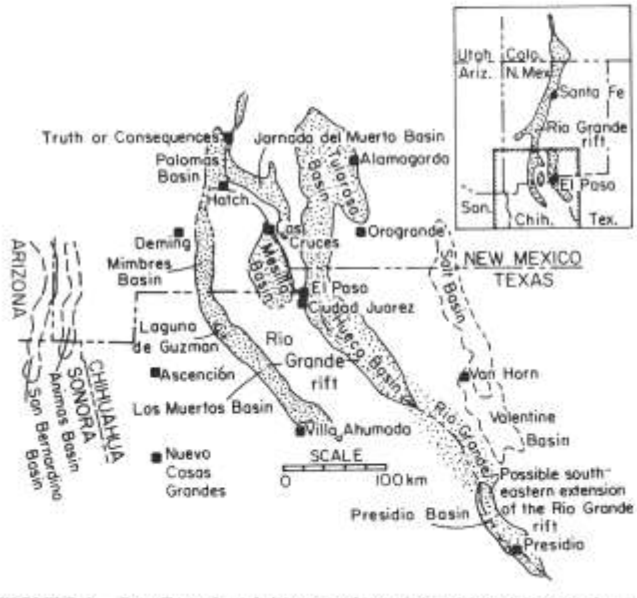


FIGURE 3—Rio Grande rift basins of southern New Mexico (from Daggett, 1982).

The Otero platform is probably part of the Basin and Range province, which encompasses a large part of the southwestern and western United States. Structurally, the Otero platform lies across the southern extension of the buried Paleozoic Pedernal uplift (Black, 1973).

Within the study area, late Cenozoic features so dominate the landscape that they tend to mask the earlier history of the region. However, it is apparent that the study area contains older tectonic provinces with widely variable histories.

Merging with the study area to the east and southeast is the High Plains province. This province masks much of the Permian Basin, which, in many respects, has a geologic history similar to that of the study area (Sandeen, 1954). Unlike the study area, the Permian Basin is a major hydrocarbon-producing province.

The Tularosa Basin and Otero platform are separate physiographic units and will be discussed separately. Main physiographic features and general structure of the area are presented in Figs. 1 and 2.

Methods of investigation

The data accumulated to construct the maps presented here were compiled from sources such as well logs, scout tickets, and completion cards. Of the 74 wells in the New Mexico part of the study area, only 39 provided enough information to prepare isopach-lithofacies maps. These maps were not prepared for those units where data were considered insufficient. All maps were drawn on a modified standard base designed to be free of extraneous data and to demonstrate only significant features.

When three lithologic components are involved in a facies study, it is convenient to express the relations among them by use of a 100% triangle. The facies triangle (see Fig. 9) is used when the stratigraphic unit has only three components or when any three components in a stratigraphic unit of N components are selected for study.

The thickness ratio of one rock type to another (such as sand—shale ratio) provides an effective means for displaying the interrelations between two lithologic components with a single set of contours. If the range of ratio values is large, a geometric interval is most effective. The ratio name is determined by the components in the numerator. The interplay between sand and shale, expressed as a ratio, may shed light on interrelations among reservoir and source rocks.

Numerous facies maps can be designed for three-component systems by using the method of multiple contouring of ratio lines. In preparation of multiple-ratio facies maps of this study, the following three component parameters were established: (1) Component A, which includes carbonates (limestone and dolomite) and evaporites (anhydrite, gypsum, and salt); (2) component B, which represents sandstone and conglomerate; and (3) component C, which represents siltstone and shale. The ratio (B + C)/A thus expresses the relationship between detrital (clastic) sediments and the nondetrital (nonclastic) sediments. This is the clastic ratio. The ratio B/C contrasts coarse and fine clastics and is the sand—shale ratio.

The clastic-ratio and sand—shale-ratio maps are useful for interpretation of some features of stratigraphic units. However, to show interrelations among all three components, it is conventional to superimpose one map on the other. The triangle is divided into segments at sand—shale-ratio lines 8, 1, and 1/8 (0.13), and at clastic-ratio lines 8, 1, and 1/4 (0.25). This selection serves two purposes: First, the lines divide the map into selected "pattern areas" that show where the stratigraphic unit is mainly sandstone, shale, or nonclastics, or where a given lithologic component constitutes more than 50% of the unit. Further simplification is achieved by eliminating the sand—shale-ratio line of 1 where the clastic ratio falls below 1/4 (that is, where the strata are more than 80% carbonate or evaporites), and by using the sand—shale-ratio lines 8 and 1/8 only in those map areas where the clastic ratio exceeds 8 (that is, where approximately 90% or more of the section is sandstone or shale) (Krumbein and Sloss, 1963).

Cross sections of lithologic and geophysical borehole logs were drawn to illustrate the stratigraphy and structure of the three main areas. For example, the influence of the Pedernal uplift is clearly shown in the cross sections across the Otero platform, and the faulting in the Tularosa Basin is demonstrated by the east—west cross sections in that province. Cross sections along and across the Salt Basin graben indicate the complex stratigraphy and structure of that feature. Structural and stratigraphic relationships indicate the possibility of various types of hydrocarbon traps.

Geophysical data have been integrated into the study and can be used with the cross sections to better understand the geology. References are made to published geophysical studies. However, if a study is unpublished or open-filed, maps and sections selected from it are reproduced in this paper.

Brief descriptions of the general lithology and paleontology of stratigraphic units, along with references to the literature, have been incorporated in the paper to aid the reader. In many cases, fusulinids were used in order to subdivide the Pennsylvanian and Permian sequences.

A number of the wells on the cross sections provide data that have not been previously released to the log services or the petroleum industry. We have been very fortunate in being able to convince several companies to allow us to use information previously held confidential; our investigation has been greatly enhanced by those data.

Stratigraphy and geologic history

The Tularosa Basin—Otero platform—Salt Basin graben area contains sedimentary rocks ranging from Precambrian through Cenozoic (Fig. 4). Well-documented Precambrian and Cenozoic intrusive rocks are also present. The Precambrian and early Paleozoic history of the area is not as well known as that of the late Paleozoic because of less-comprehensive well control and limited outcrop exposure. Triassic rocks are present only in the extreme northern part of the study area in the Tularosa Basin. Cretaceous rocks are present mainly in the northern Tularosa Basin, but also along the margin of the laccolithic Cornudas Mountains on the Otero platform (Clabaugh, 1941). Paleocene through Pleistocene deposits are present in the Tularosa Basin, and Miocene surficial deposits form significant cover in many parts of the region.

Precambrian

In the Proterozoic, this region was on the southwestern edge of the North American craton (Hill, 1984). The oldest known Precambrian rocks recorded in the subsurface to the east and west of the area belong to the 1,350-m.y.-old Chaves granitic terrane (Black, 1973). A sequence of younger Precambrian sediments was deposited upon this terrane. These younger sediments were subsequently metamorphosed to form the 950-1,000-m.y.-old DeBaca metamorphic terrane. Although specific Precambrian events subsequent to this igneous activity are unknown, it is probable that these Precambrian rocks underwent additional episodes of burial and uplift. Eventually, the area was deeply eroded to a surface of maturity, which is assumed to have approached a peneplain (Black, 1973). Lower Paleozoic rocks were deposited upon this surface.

Precambrian rocks are exposed in the Sacramento Mountains; they have been described by Pray (1961) as slightly metamorphosed sedimentary rocks intruded by diorite and diorite-porphyry sills.

Numerous wells have penetrated the Precambrian in the study area, particularly on the Otero platform. The Precambrian in this area is in the shallow subsurface due to the uplift and erosion of the pre-Pennsylvanian Paleozoic units on the Pedernal landmass. The structural contour map of the Precambrian surface clearly reveals this feature (Fig. 5). Some of the well data used to make the map are shown in Table 1.

Paleozoic

Cambro-Ordovician

By the close of the Precambrian and the beginning of the Phanerozoic, the entire region was welded to the southwestern portion of the craton and gradually sank to form the shallow Tobosa Basin. The Cambro-Ordovician seas spread west—east across the area, advancing over a deeply weathered mature surface cut on granitic rocks and depositing the largely littoral to intertidal basal Bliss Sandstone, which is the oldest Paleozoic formation in the study area (LeMone, 1969). The Bliss Sandstone is a Cambro-Ordovician time-transgressive unit consisting primarily of a quartz sandstone with minor dolomite units. Typically cross-

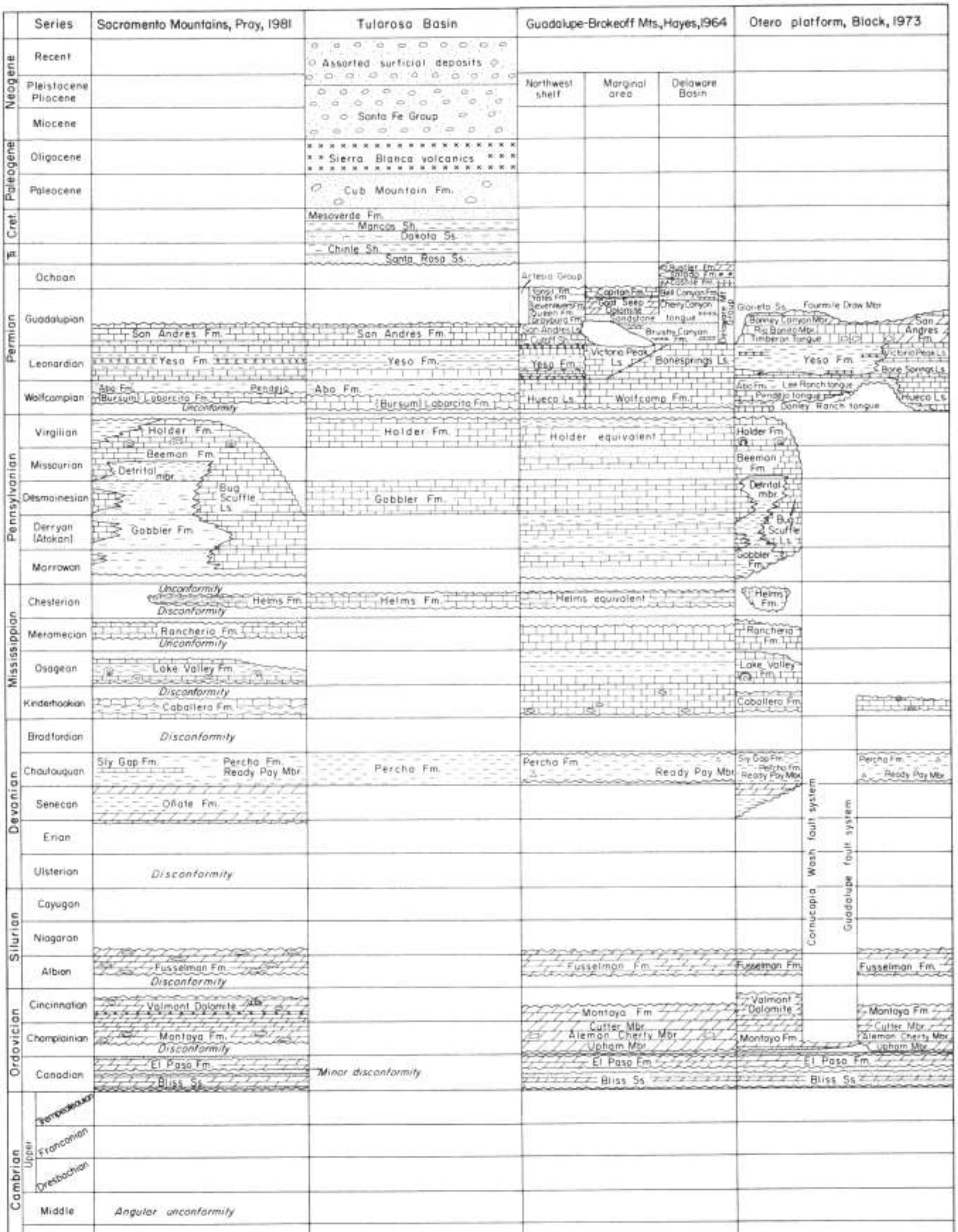


FIGURE 4—Columnar stratigraphic sections. Based on outcrops except the column of Black, which shows both surface and subsurface units.

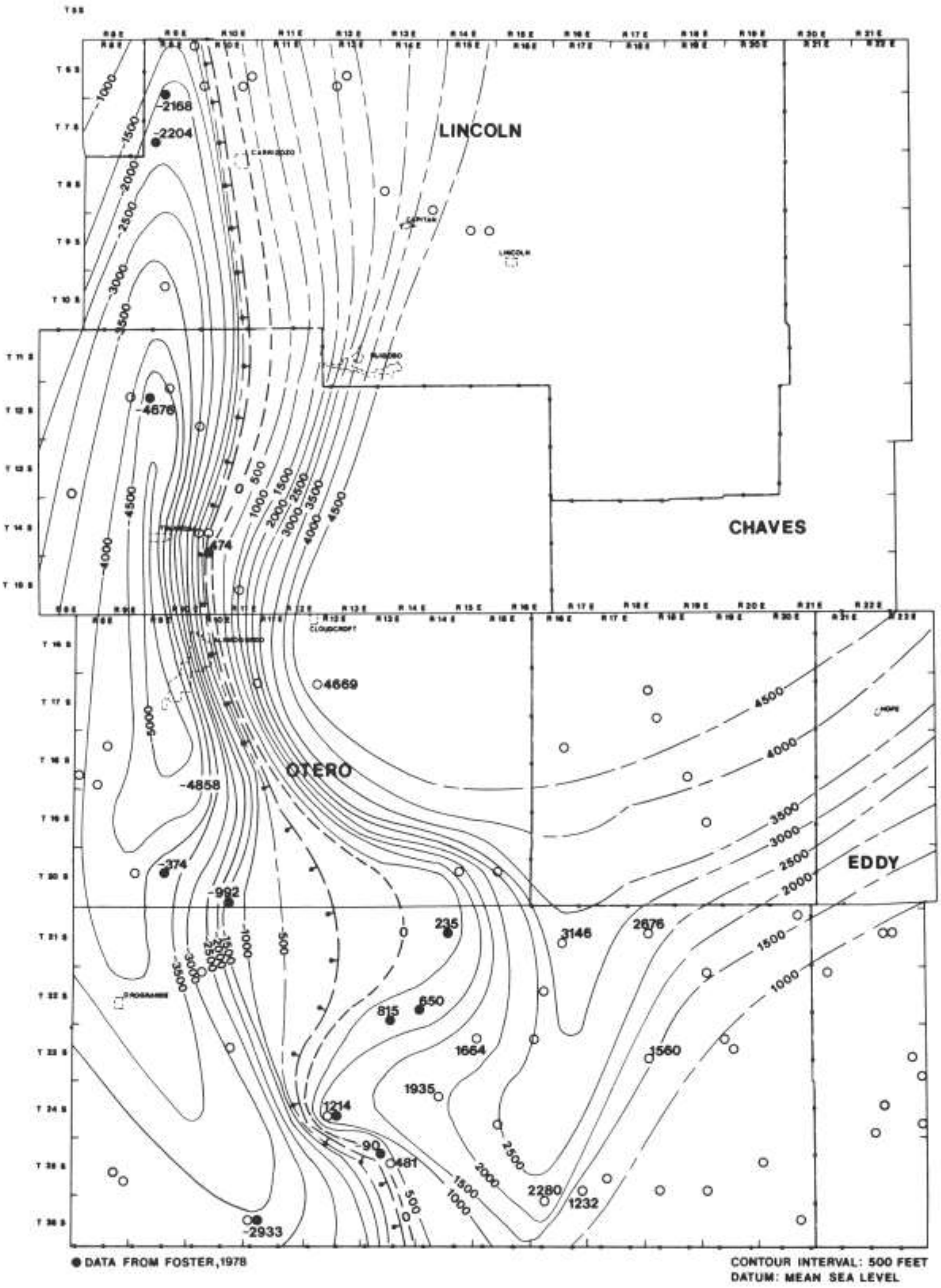


FIGURE 5—Structural contour map on top of Precambrian.

TABLE 1—Precambrian subsurface data. Data from Foster (1978) indicated by asterisks.

Well	Location	Elevation (ft)
Standard Texas 1 Heard	33–6S–9E	−2,169*
Houston 1 Lewelling	12–12S–9E	474*
Southern Production 1 Cloudcroft	5–17S–12E	4,669
Plymouth 1 Federal	15–20S–9E	−374*
Sun 1 Pearson	35–20S–10E	−992*
Stanolind 1 Thorn	15–21S–14E	235*
Lefors 1 Federal	22–21S–16E	3,146
Standard Texas Scarp Unit 1	18–21S–18E	2,676
Turner 1 Everett	34–22S–13E	815*
Campbell 1 Hurley	30–22S–14E	650*
Campbell 1 Lieberman	7–23S–15E	1,664
Coral 1 Warren	19–23S–18E	1,560
Coral 1 Spanel	9–24S–14E	1,935
Turner 1 Evans	22–24S–12E	1,214*
Transocean 1 Ablah	15–25S–13E	481
Turner 1 Federal State	36–25S–16E	1,232
Union 1 McMillan	9–25S–13E	−90
Seaboard 1 Trigg Federal	18–26S–11E	−2,933

TABLE 2—Ordovician subsurface data.

Well	Location	Thickness (ft)
Southern Tularosa Basin 1	34–13S–8E	320
Southern Production 1 Cloudcroft	5–17S–12E	807
Plymouth 1 Federal	15–20S–9E	615
Lefors 1 Federal	22–21S–16E	370
Standard Texas Scarp Unit 1	18–21S–18E	470
Turner 1 Everett	34–22S–13E	TD 845 in fm.
Continental 1 Bass	5–22S–21E	TD 990 in fm.
Weaver 1 Thompson	9–23S–19E	430
Union 1 McMillan	9–25S–13E	TD 1,095 in fm.
Turner 1 Federal State	36–25S–16E	1,090
Texaco Federal E	10–18S–8E	TD 260 in fm.
Tri-Service 1 Little Dog	6–22S–19E	580
Sun Oil 1 Pearson	35–20S–10E	TD 79 in fm.
Pasotero 1 Evans	22–24S–12E	425

laminated and crossbedded, the Bliss weathers a dark reddish-brown. The formation is about 110-ft thick in the Sacramento Mountains and approximately 200-ft thick in the Hueco Mountains.

Clastic deposition of the Bliss eventually gave way to primarily carbonate deposition of the El Paso (Canadian) and Montoya (Cincinnatian) Formations. Later, the Ordovician and overlying Silurian were bevelled locally to the north as a result of periodic uplift of the Peñasco dome.

Ordovician

The Ordovician sequence overlying the Bliss Sandstone consists of the El Paso Formation (Lower Ordovician), the Montoya Formation (Upper Ordovician), and Valmont Dolomite (Upper Ordovician). The Middle Ordovician is not present in the study area. The Tobosa Basin became much deeper during Ordovician time and extended far to the south (Hills, 1984).

The El Paso and Montoya Formations were originally grouped together in the El Paso Group (Richardson, 1904) and included all Ordovician carbonate rocks. Richardson (1910) divided the group into the El Paso and Montoya Formations. The El Paso Formation averages 439 ft in thickness in the Sacramento Mountains and 1,300 ft in the Hueco Mountains, and consists of light-gray to light-olive-gray, very fine- to medium-grained dolomite with minor chert.

The Montoya Formation is locally subdivided into the Cable Canyon, Upham, and Aleman Members (Pray, 1961). The Cable Canyon and Upham Members contain many poorly preserved fossils, especially corals and sponges, in a quartz sandstone and sandy dolomite. The thickness of these two members ranges from 0 to 100 ft. The Aleman Member is a light-olive-gray, finely crystalline, cherty dolomite. It ranges in thickness from 85 to 125 ft in the Sacramento Mountains.

The Valmont Dolomite (probably a Cutter Formation equivalent) is a light- to very light-gray sublithographic dolomite. Bedding planes are up to 2-ft thick and sharply defined. The formation is divided into two members on the basis of a thin argillaceous zone about one-third of the distance above the base. The thickness of the entire unit ranges from 150 to 225 ft (Pray, 1961). The Upper Ordovician in the Franklin Mountains is named the Montoya Group and is divided into the Upham, Aleman, and Cutter Formations. An isopach map of the total Ordovician is shown in Fig. 6 and well data in Table 2. In Late Ordovician, and continuing into the Silurian and Devonian, platform carbonate deposition was dominant (Hills, 1984).

Silurian

The Silurian Fusselman Formation was originally described by Richardson (1910) as the Fusselman Limestone. The Fusselman rests unconformably on the Upper Ordovician Valmont Dolomite. It is primarily a dark-weathering, cherty dolomite. The formation is resistant to erosion, forming dip slopes, ledges, and cliffs. The formation boundaries are regional disconformities. The Fusselman is Early to Middle Silurian in age, and was deposited in a normal marine environment on a stable shelf where terrigeneous detritus was virtually absent. Thickness of the formation in the subsurface ranges from 0 to 100 ft near the Sacramento Mountains to over 1,000 ft in the Salt Basin graben (Pray, 1961).

The wells penetrating the Silurian of the New Mexico study area are listed in Table 3. An isopach map of the Silurian is shown in Fig. 7. The Silurian strata

TABLE 3—Silurian subsurface data.

Well	Location	Thickness (ft)
Southern Production 1 Cloudcroft	5–17S–12E	210
Texaco Federal E	10–18S–8E	470
Texaco Federal G	33–18S–8E	100
Plymouth 1 Federal	15–20S–9E	290
Sun Oil 1 Pearson	35–20S–10E	130
Standard Texas Scarp Unit 1	18–21S–18E	788
Campbell 1 Hurley	30–22S–14E	TD 270 in fm.
Tri-Service 1 Little Dog	6–22S–19E	190
Campbell 1 Lois Spanel	7–23S–16E	TD 170 in fm.
Weaver 1 Thompson	9–23S–19E	360
Pasotero 1 Evans	22–24S–12E	TD 1,615 in fm.
Union 1 McMillan	9–25S–13E	575
Transocean 1 Ablah	15–25S–13E	1,774

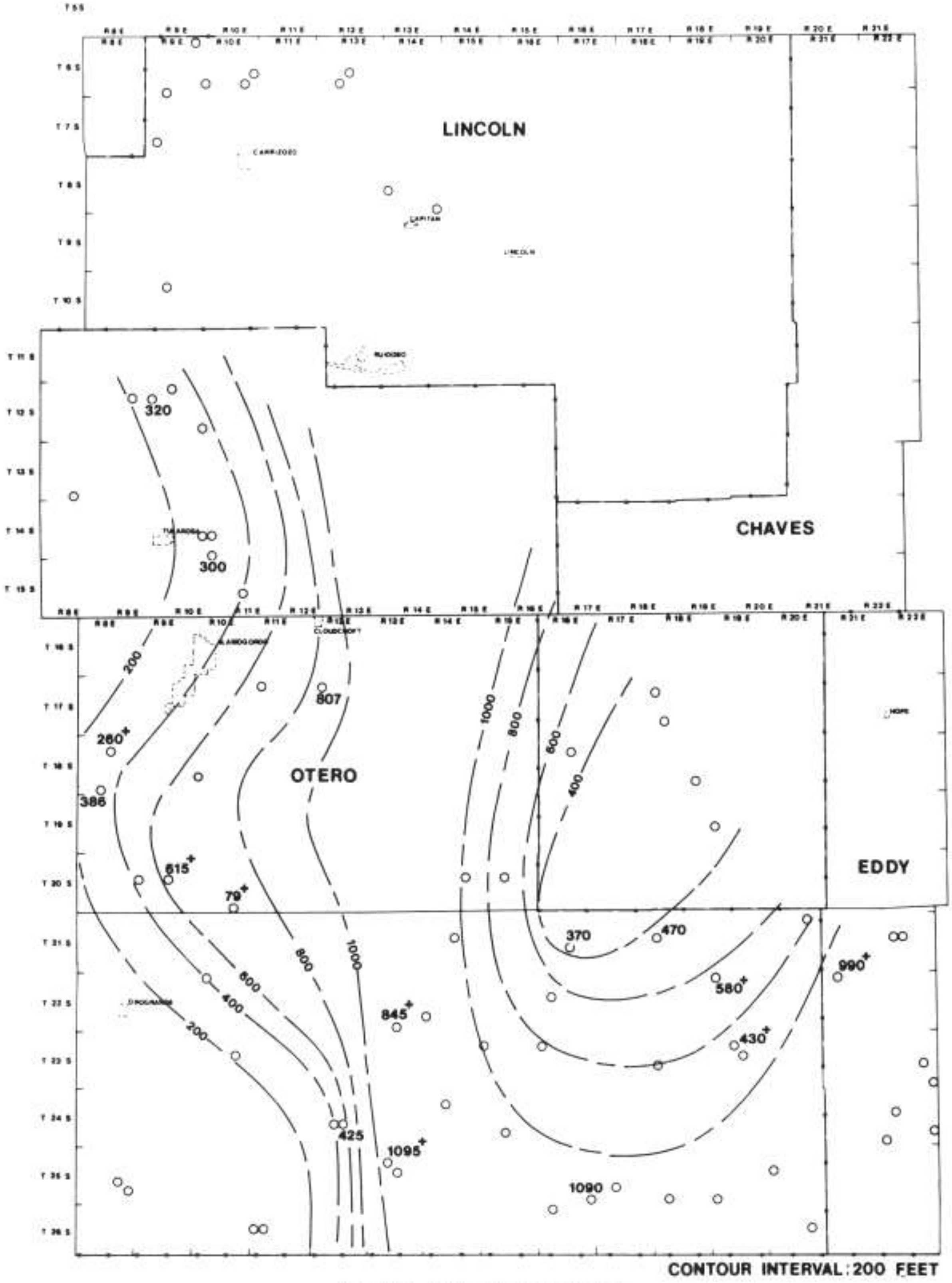


FIGURE 6—Ordovician isopach map.

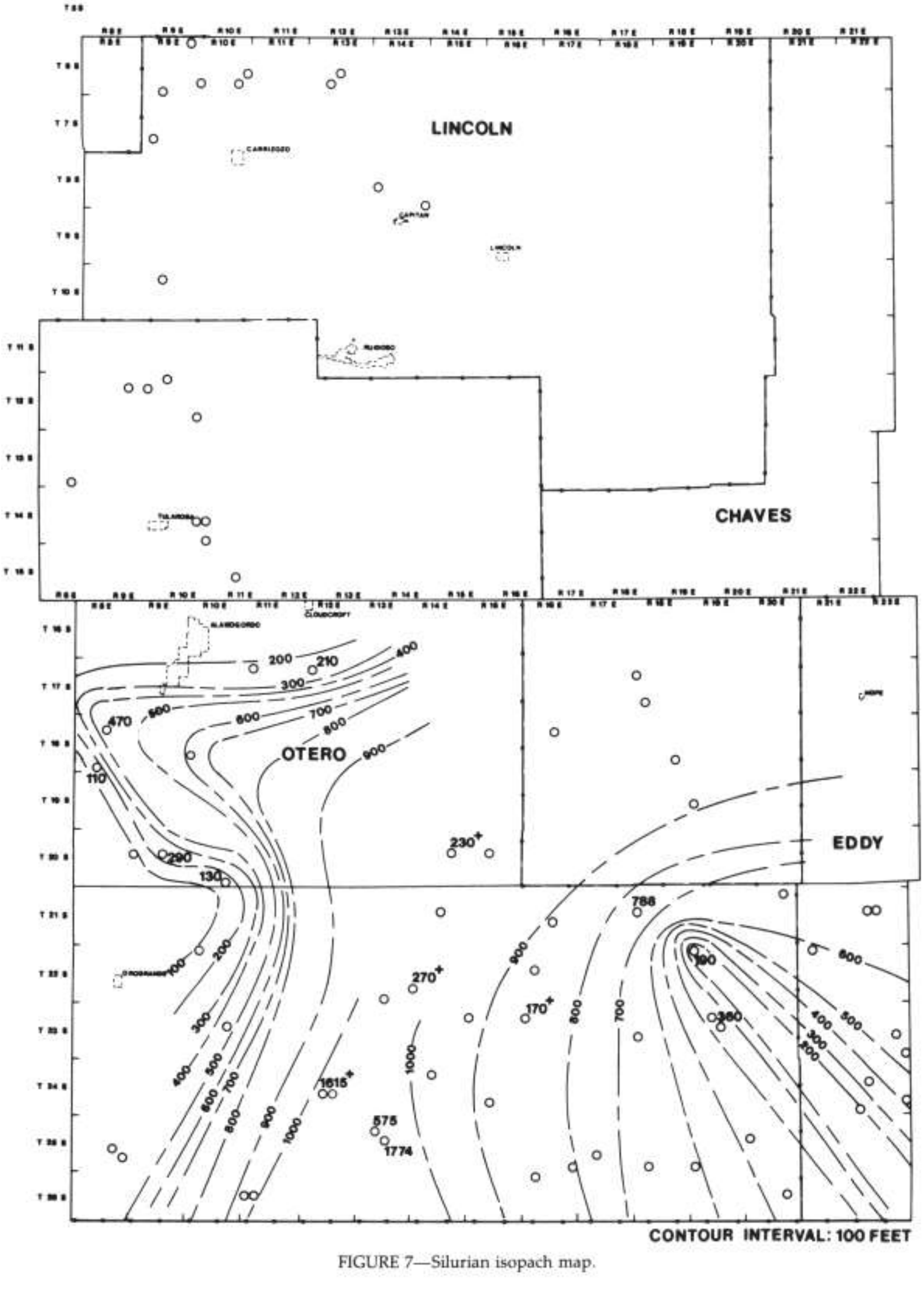


FIGURE 7—Silurian isopach map.

appear to be unaffected by the Pedernal uplift, being thickest over the area of the uplift and thinning towards the northwest and southeast. The dashed lines in Fig. 7 indicate areas where data are scarce.

Devonian

Devonian strata in the study area were deposited on a regional unconformity produced by the erosional interval that bevelled Silurian and Ordovician rocks (Kottlowski, 1965). The Otero platform in Middle and Late Devonian time was the site of a shallow sea with the low Peñasco dome probably emergent to the north. The highly organic black to gray mud and silt of the Percha Group were deposited over most of the study area. To the east of the area in the Delaware Basin, black organic muds of the Woodford Formation were accumulating.

Devonian lithostratigraphic units in the area are the Oñate Formation, the Sly Gap Formation, and the Percha Shale. The Oñate Formation varies from a silty dolomitic sandstone to a very fine-grained quartz sandstone which ranges from medium- to brownish-gray or olive-gray. "Ribbon" bryozoans and brachiopods are the most common fossils (Pray, 1961). The thickness of the formation in subsurface ranges from 0 to 60 ft near the Sacramento Mountains.

The Sly Gap Formation consists of interbedded sequences of gray calcareous shale; thin, somewhat nodular, gray limestone; and minor black shale. Its reported thickness in the subsurface ranges from 30 to 40 ft.

The Percha Shale is a fissile, noncalcareous shale ranging in thickness from 10 to 20 ft (Pray, 1961). The wells penetrating the Devonian of New Mexico are listed in Table 4. The Devonian strata (Fig. 8) are absent over much of the Pedernal uplift.

Mississippian

In Mississippian time seas extended up into present-day New Mexico from the south. A wide variety of Mississippian carbonates was deposited in the area, including crinoidal and normal shelf limestones, a variety of bioherms, and basinal limestones. The Mississippian sequence thickens to the southwest into the Pedregosa Basin and to the southeast into the Delaware Basin. Mississippian rocks on the Otero platform are thin due to erosion during Pennsylvanian time. Black (1973) stated that deposition during Mississippian time undoubtedly extended over the entire area. Devonian and Mississippian strata are thin or absent near the Jarilla Mountains, suggesting a small positive area exposed to erosion during Mississippian and the Early Pennsylvanian. The Orogrande Basin, in west-central Otero County, was then a poorly defined autogeosyncline (Kottlowski, 1965).

TABLE 4—Devonian subsurface data.

Well	Location	Thickness (ft)
Kewanee 1 F–M	26–18S–18E	TD 100 in fm.
Turner 1 Everett	34–22S–13E	686
Tri-Service 1 Little Dog	6–22S–19E	20
Continental 1 Bass	5–22S–21E	150
Campbell 1 Spanel	7–23S–16E	40
Campbell 1 McMillan	15–23S–19E	TD 5 in fm.
Union 1 McMillan	9–25S–13E	100
Dunigan 1 Alpha Federal	31–25S–19E	74

The Mississippian sequence in the Tularosa Basin—Otero platform area has been divided into the Caballero, Lake Valley, Rancheria, and Helms Formations. Laudon and Bowsher (1941, 1949) established the basic stratigraphic framework of the Mississippian in southern New Mexico. They recognized three formations, in ascending order the Caballero Formation (Kinderhookian), the Lake Valley Formation (Osagean), and the Rancheria Formation (Meramecian). Pray (1961) modified their work by recognizing the Helms Formation (Chesterian) in the southernmost Sacramentos. Excellent outcrops of Mississippian rocks are present along the Sacramento Mountains escarpment, with bioherms of the Lake Valley Formation prominently exposed. Bioherms of similar age produce oil and gas in central Texas, Tennessee, and Kentucky (Bolton, Lane, and LeMone, 1982).

The Caballero Formation consists of interbedded gray, very nodular, argillaceous limestone and gray calcareous shale. Some even-bedded crinoidal calcarenites and calcirudites occur in the upper few feet. An excellent marine invertebrate fauna is present. The basal contact with the underlying Devonian rocks is disconformable. The formation ranges in thickness from 15 to 60 ft.

The Lake Valley Formation was divided by Laudon and Bowsher (1949) into six members, in ascending order the Andrecito, Alamogordo, Nunn, Tierra Blanca, Arcente, and Doña Ana Members.

The Andrecito Member is the basal member of the Lake Valley Formation and consists largely of calcareous shale, marl, thin-bedded argillaceous limestone, some well-sorted crinoidal calcarenites, and minor quartzose siltstone (Pray, 1961).

The Alamogordo Member is typically a medium-grained, cherty calcilutite developed in massive beds ranging from a few inches to several feet in thickness. These beds are resistant to weathering and in most places form a ledge or scarp. The thickness in subsurface ranges from 15 to 40 ft. Many Lake Valley bioherms began their growth during the deposition of this member.

The Nunn Member consists of interbedded friable or poorly cemented crinoidal limestone with minor amounts of crinoidal marl. The thickness is very variable, particularly in the vicinity of the underlying bioherms.

Normally, the highest member of the biohermal sequence is the Tierra Blanca. It is typically composed of crinoidal calcarenites and calcirudite with large nodules of light-colored chert. This member characteristically forms resistant cliffs and ranges in thickness from 100 to 200 ft.

The Arcente Member consists largely of dark calcareous shale and thin-bedded, medium-grained, argillaceous limestone. The conditions that prevailed during deposition of this member probably were unfavorable for the growth of bioherms. Some of the topographic relief previously developed by biohermal

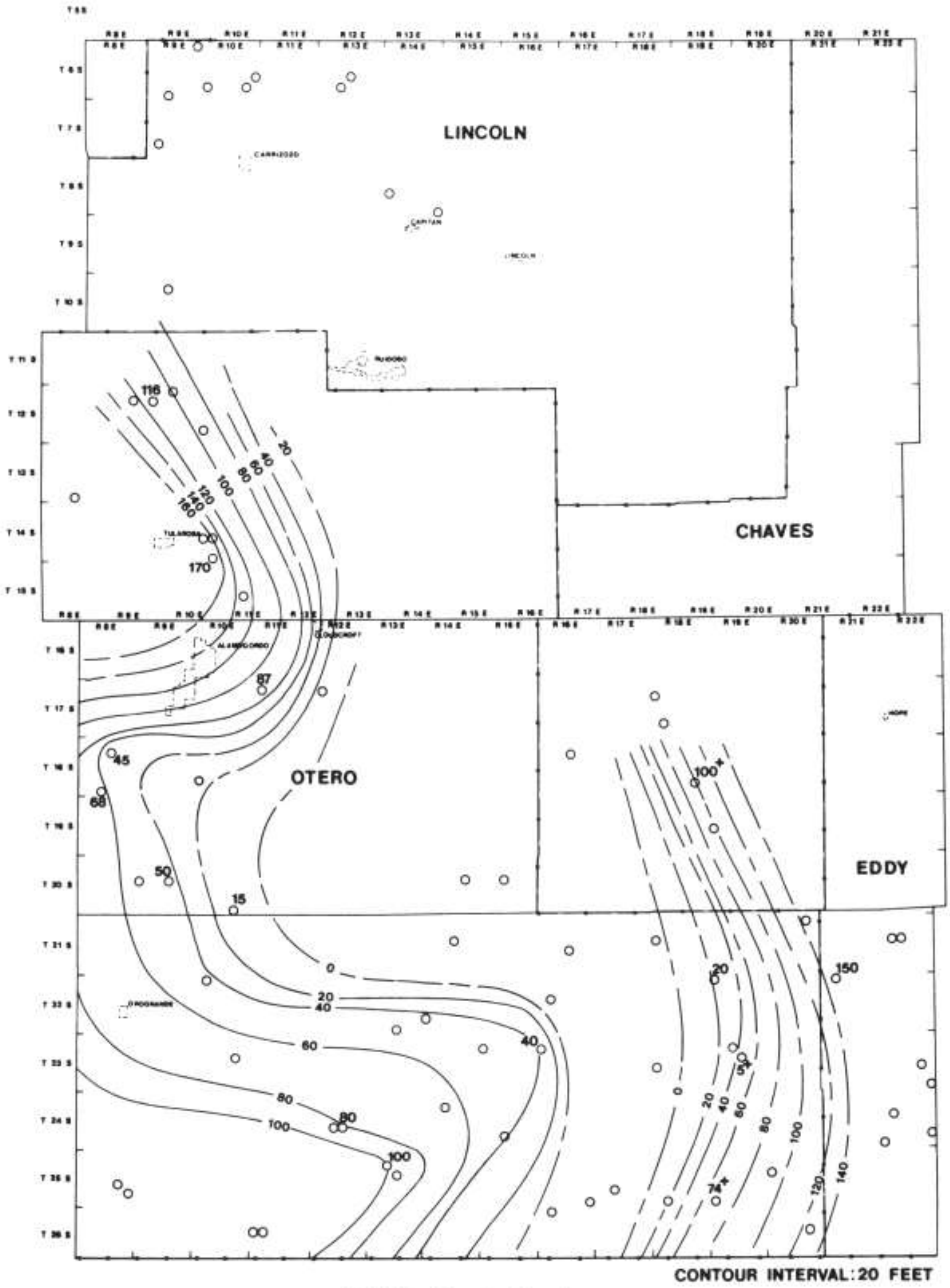


FIGURE 8—Devonian isopach map.

growth was leveled before deposition of the Arcente Member.

The uppermost Doña Ana Member has been interpreted as deposited in clear seas with profuse growth of crinoids. It is composed of a light-gray, cherty, irregularly bedded crinoidal limestone which reaches a maximum thickness of 150 ft. The Doña Ana Member thins abruptly or pinches out at the edges of major bioherms.

The basal contact of the Rancheria Formation is an unconformity with low-angle of discordance that cuts out the underlying Lake Valley and Caballero Formations toward the southeast. It consists of dark-gray, thin-bedded, argillaceous, and silty limestone or similar calcareous siltstone that contains abundant streaks and laminae of porous chert.

The maximum thickness of the Helms Formation is 960 ft. It consists of thin-bedded argillaceous limestone and yellow and gray interbedded shale. Several thin beds of oolitic limestone near the top of the formation have been reported by Pray (1961). The wells penetrating New Mexico Mississippian strata are listed in Table 5.

More than 100 ft of Mississippian is present in the Sacramento Mountains and about 500 ft in the Hueco Mountains. An isopach–lithofacies map (Fig. 9) shows that during the Mississippian sediments were accumulating toward the southwest into the Pedregosa Basin and to the southeast into the Delaware Basin. Mississippian rocks are relatively thin on the Otero platform due to erosion during Pennsylvanian time.

Pennsylvanian

The general pattern of a periodically uplifted low and distant Peñasco dome to the north of the area, acting as the major influence on sedimentation, had begun to change at the outset of the Pennsylvanian Period. By Middle Pennsylvanian time, the Pedernal uplift became the dominant structural feature in the area. The southern extension of this positive feature, which divides the Otero platform from north to south, played an important role in Pennsylvanian tectonics and the subsequent deposition of Middle to Late Pennsylvanian and Permian sediments. Even in the earliest Pennsylvanian, the Pedernal uplift began to rise slowly from the sea floor in areas to the north. The Delaware Basin to the east was synchronously developing into a negative feature which was beginning to receive significant amounts of clastic sediments.

TABLE 5—Mississippian subsurface data.

Well	Location	Thickness (ft)
Southern Production 1 Cloudcroft	5–17S–12E	280
Kewanee 1 F-M	26–18S–18E	310
Texaco Federal E	10–18S–8E	400
Texaco Federal G	33–18S–8E	TD 860 in fm.
Plymouth 1 Federal	15–20S–9E	300
Sun 1 Pearson	35–20S–10E	230
Zapata 1 Federal 14	14–20S–14E	190
Atlantic 1 AV	16–20S–15E	TD 270 in fm.
Standard Texas Scarp Unit 1	18–21S–18E	50
Hilland 1 Burro	2–21S–20E	TD 585 in fm.
Campbell 1 Hurley	30–22S–14E	66
Continental 1 Bass	5–22S–21E	280
Campbell 1 Spanel	7–23S–16E	120
Campbell 1 McMillan	15–23S–19E	114
Turner 1 Evans	22–24S–12E	280
Union 1 McMillan	9–25S–13E	320
Transocean 1 Ablah	15–25S–13E	356
Dunigan 1 Alpha Federal	31–25S–13E	416
Seaboard 1 Trigg Federal	18–26S–11E	804

In the Sacramento Mountains, the 3,200-ft-thick Pennsylvanian section is as thick or thicker than the entire underlying Paleozoic section. The lithologies of the Pennsylvanian are radically different from those of the underlying Paleozoic section. The Pennsylvanian section is typified by the influx of large quantities of terrigenous clastics which demonstrate rapid vertical and lateral facies changes. Lithologic changes over short distances and varying time spans record the tectonic unrest of this period (Black, 1973). The Pennsylvanian System of the Sacramento Mountains consists of three formations, in ascending order the Gobbler, Beeman, and Holder Formations.

The oldest Pennsylvanian strata are represented by the Gobbler Formation. This unit was probably deposited on a marine shelf which was receiving relatively coarse detrital tongues of material derived from the early pulses of the Pedernal uplift to the north. A north–south lineation between a positive shelf area to the east and a negative deeper-water area to the west (Orogrande Basin) developed by Missourian time along what may have been a large flexure or hinge line. The shelf became a very shallow to emergent platform. The tectonics of this time is illustrated by the lithofacies of the Gobbler Formation.

The Gobbler Formation is 1,200 to 1,600-ft thick and consists of a wide variety of lithologies which represent environments of deposition ranging from terrestrial to open marine (Pray, 1961). The basal beds are coarse sandstone and chert-cobble conglomerates with overlying dark, cherty limestones and quartz sandstones, and with some dark shales composing the next upper 200 to 500 ft of the formation. The Bug Scuffle Limestone Member lies above these dominantly clastic beds and reaches thicknesses of up to 1,000 ft. It consists primarily of limestone layers of calcarenites and calcilutites that are locally cherty. The uppermost part of the Gobbler Formation is a clastic facies which interfingers with the lower Bug Scuffle Limestone Member. It is composed mostly of shales and quartz sandstones with only minor amounts of limestone. This facies is called the detrital facies (Black, 1973).

By late Missourian time the Pedernal uplift probably became a gently east-tilted fault-block with a steep western side providing arkosic detritus directly into the Orogrande Basin. Silt and clays were washed eastward into the Delaware Basin. The Beeman Formation is interpreted by Pray (1961) as reflecting this tectonic activity. The Beeman Formation consists largely of thin-bedded, argillaceous limestone interbedded with calcareous shale. The formation ranges in thickness from 350 to 500 ft. Pennsylvanian sedimentary cyclicity ranges from marine to transitional to nonmarine

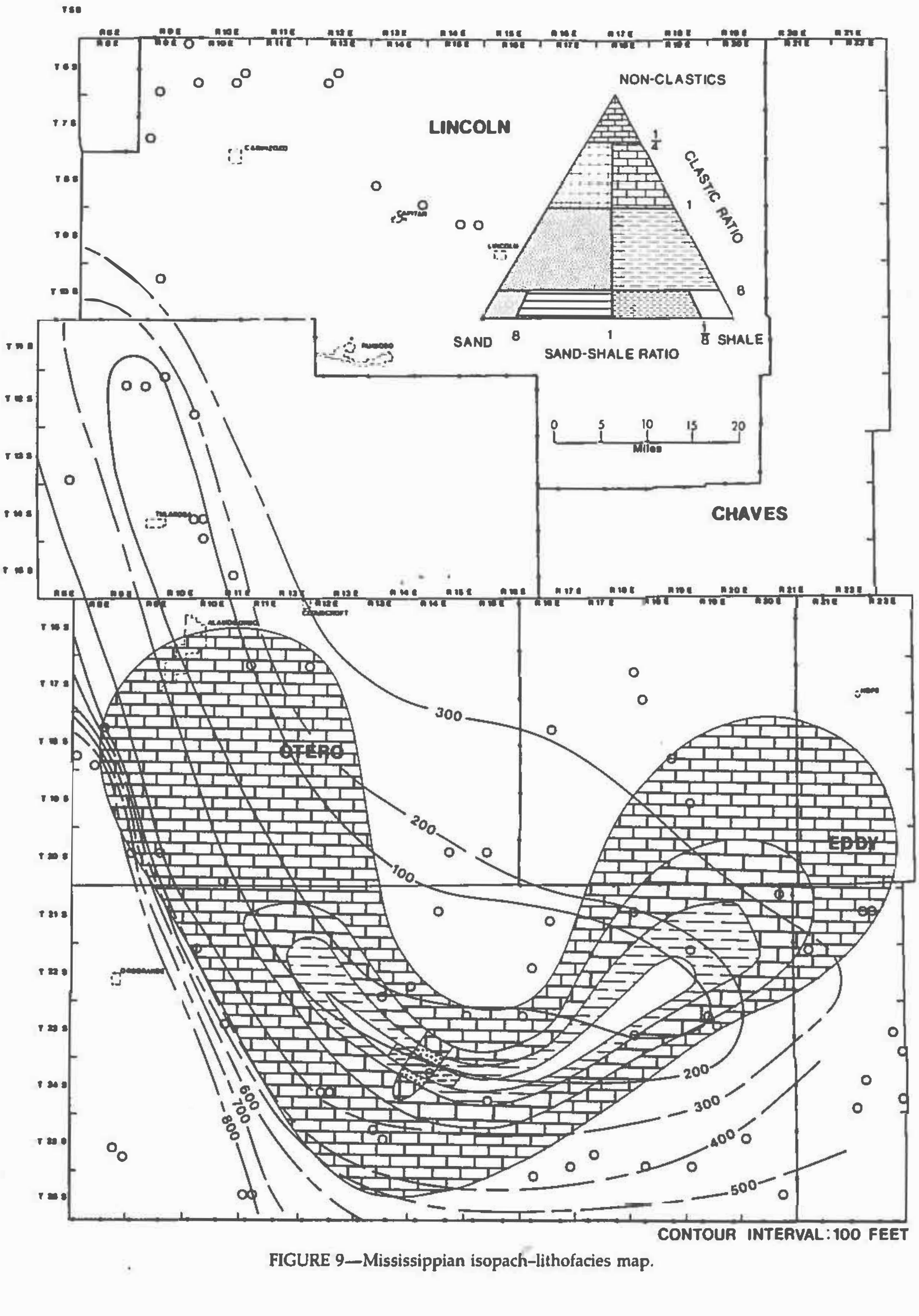


FIGURE 9—Mississippian isopach-lithofacies map.

strata. The first red beds of the local Pennsylvanian System are recorded in the Beeman Formation.

Continued major uplift of the Pedernal is evident into Virgilian time. Tectonic movement culminated in late Virgilian and early Wolfcampian with a vast accumulation of arkose, subgraywacke, and red silt in the Orogrande Basin (Black, 1973). The uppermost Pennsylvanian Holder Formation contains a wide variety of rock types which were deposited on the relatively shallow-marine-shelf area (Pray, 1961). Table 6 is a list of the wells penetrating the Pennsylvanian strata in the New Mexico study area.

Three Pennsylvanian maps are presented: a sand–shale-ratio map (Fig. 10), a clastic-ratio map (Fig. 11), and an isopach–lithofacies map (Fig. 12). They demonstrate the effect of tectonic activity during the Pennsylvanian because they help to define the boundaries of the Pedernal uplift. The structure and geographic configuration of the Pedernal uplift in the area are not well known, but available well control yields evidence which suggests that it was probably a 6 to 10-mi-wide fault-bounded feature over much of its length, splitting the area from north to south. To the north of the study area, the Pedernal uplift appears to have been a much broader feature. The rocks types, illustrating the varying environments of Pennsylvanian time in the study area, indicate the presence of potential source and reservoir rocks as well as stratigraphic traps.

Permian

Wolfcampian strata are the last of the extensive units in the Orogrande Basin which thicken markedly westward from the Pedernal uplift. The Permian paleotectonic setting in the study area was dominated by the same tectonic elements that were present in Middle and Late Pennsylvanian. These tectonic elements were active, at least sporadically, through Wolfcampian time. The Huapache fault, probably a high-angle upthrust, was active to the east beyond the study area. This feature defines the easternmost edge of tectonic activity in the area. The fault, at least in part, controlled the deposition of the Permian units throughout Wolfcampian time. The Permian rocks in the study area are, in ascending order, the Bursum, Abo, Yeso, and San Andres Formations in the Tularosa Basin and on the Otero platform. In the Guadalupe–Brokeoff Mountains and in the Salt Basin graben the formations present are (ascending) the Hueco Formation, the Yeso–Victorio Peak–Bone Springs Formations, the San Andres–Brushy Canyon Formations, the Goat Seep Limestone–Cherry Canyon Formation, and the Capitan–Bell Canyon Formations.

TABLE 6—Pennsylvanian subsurface data.

Well	Location	Thickness (ft)
Standard Texas 1 Heard	33–6S–9E	1,413
Texaco Federal D	29–7S–9E	TD 1,635 in fm.
Southern Tularosa Basin 1	34–13S–8E	TD 790 in fm.
Hodges 1 Houston	23–14S–10E	TD 1,982 in fm.
Southern Production 1 Cloudcroft	5–17S–12E	59
Texaco Federal E	10–18S–8E	2,660
Texaco Federal G	33–18S–8E	780
Texaco Federal F	30–18S–10E	TD 1,250 in fm.
Kewanee 1 F–M	26–18S–18E	1,182
Plymouth 1 Federal	15–20S–9E	4,135
Sun 1 Pearson	35–20S–10E	979
Zapata 1 Federal 14	14–20S–14E	818
Atlantic 1 AV	16–20S–15E	1,124
Hilland 1 Burro	2–21S–20E	895
Turner 1 Everett	34–22S–13E	200
Kinney 1 State	14–23S–10E	TD 1,168 in fm.
Flynn–Welch–Yates 1 Donahue	28–24S–15E	TD 253 in fm.
Union 1 White	17–24S–22E	TD 1,541 in fm.
Ernest 1 LL Well	20–25S–7E	TD 1,138 in fm.
Union 1 McMillan	9–25S–13E	970
Transocean 1 Ablah	15–25S–13E	490
Seaboard 1 Trigg Federal	18–26S–11E	868

The Bursum Formation has been described near Alamogordo as a shaly carbonate-rock facies which within a few miles to the northeast grades into red beds. The facies change is caused by the proximity to a landmass. The formation is almost exclusively red mudstones which are intermixed with less-abundant, but conspicuous, layers of limestone-pebble and limestone-cobble conglomerates. The formation ranges in thickness from less than 3 to 350 ft.

The northwestward transition from the typical Abo Formation carbonate marine facies (Hueco facies) in the south to the Abo Formation transitional and terrestrial facies (red-bed facies) in the north is not abrupt. It takes place within a belt 10 to 20 mi wide. Bioherms occur locally near the shoreline where marine facies intertongue with the red-bed facies (Kottlowski, 1965). The Abo Formation has been described by Pray (1959) as a sequence of dark, reddish-brown mudstone and arkose with a southward-thickening tongue of gray shale, limestone, and dolomite. Bachman and Hayes (1958) have divided the Abo Formation into three units. The basal red beds are informally named the Danley Ranch tongue. The middle calcareous unit thickens to the south and is informally named the Pendejo tongue. The carbonate Pendejo tongue is a nearshore equivalent of the Hueco Group. The Pendejo tongue generally thins from the west to the east and completely pinches out as the Abo facies laps onto the Pedernal uplift. The uppermost unit is a red-bed sequence of reddish-brown mudstone, fine-grained sandstone, and siltstone informally named the Lee Ranch tongue. By later Wolfcampian time nearly all of the Pedernal uplift was buried beneath the Abo red beds, with a few monadnocks rising above the mud flats in the areas to the north (Black, 1973). Most of the Abo Formation had been deposited by Leonardian time.

The Yeso Formation consists of a variety of lithologic types, including limestone and some dolomite; red, yellow, and gray shales and siltstones; evaporites, largely anhydrite and minor halite; and yellow, fine-grained sandstone. This sequence was deposited on the former mudflats of the Abo. Yeso deposition was dominated by a thick, gypsum-rich facies in the lagoonal Carrizozo salt basin near Carrizozo, New Mexico. The Yeso Formation in that area has been estimated to be more than 4,000-ft thick (Pray, 1959). The Yeso sediments north of the Otero platform may

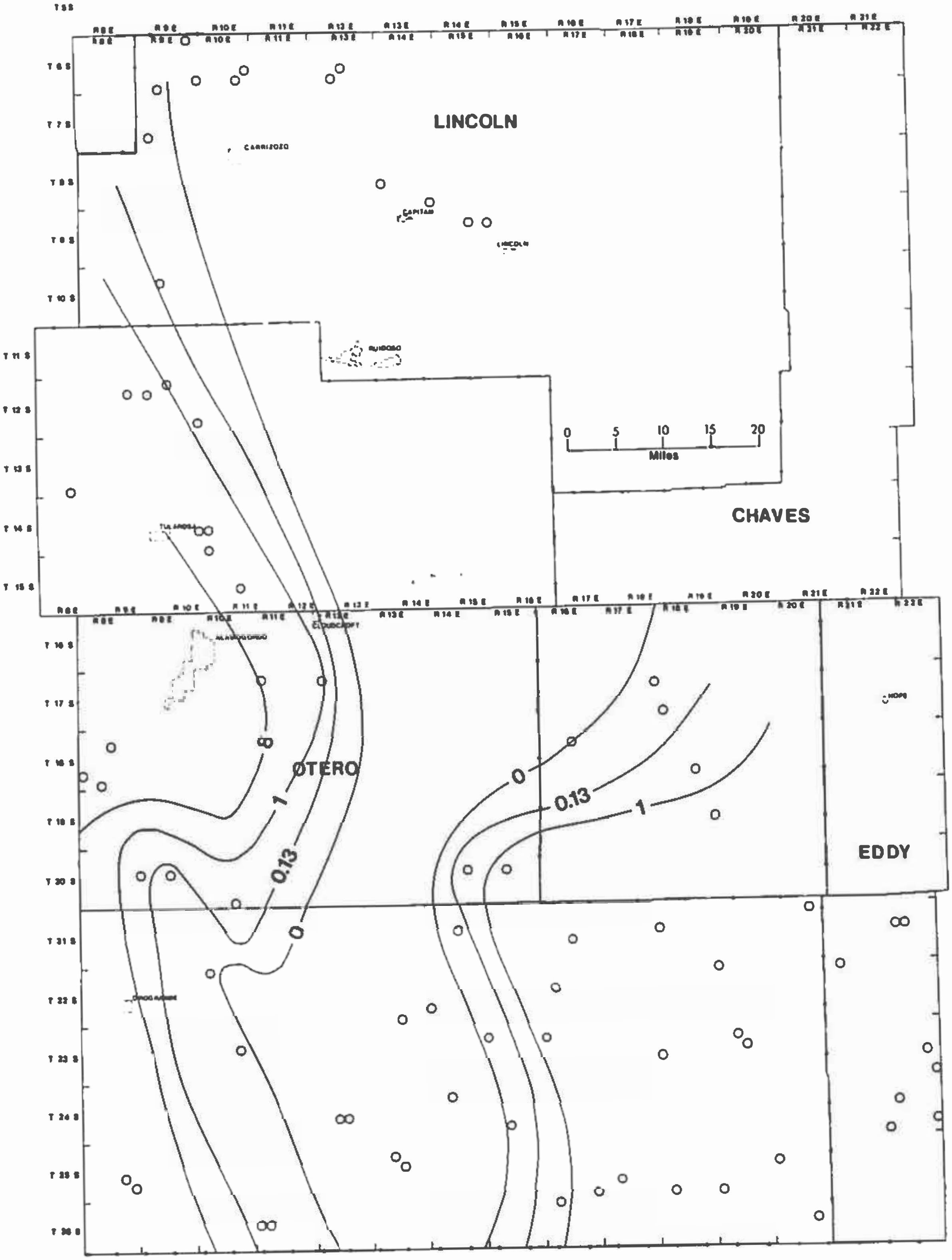


FIGURE 10—Pennsylvanian sand-shale-ratio map.

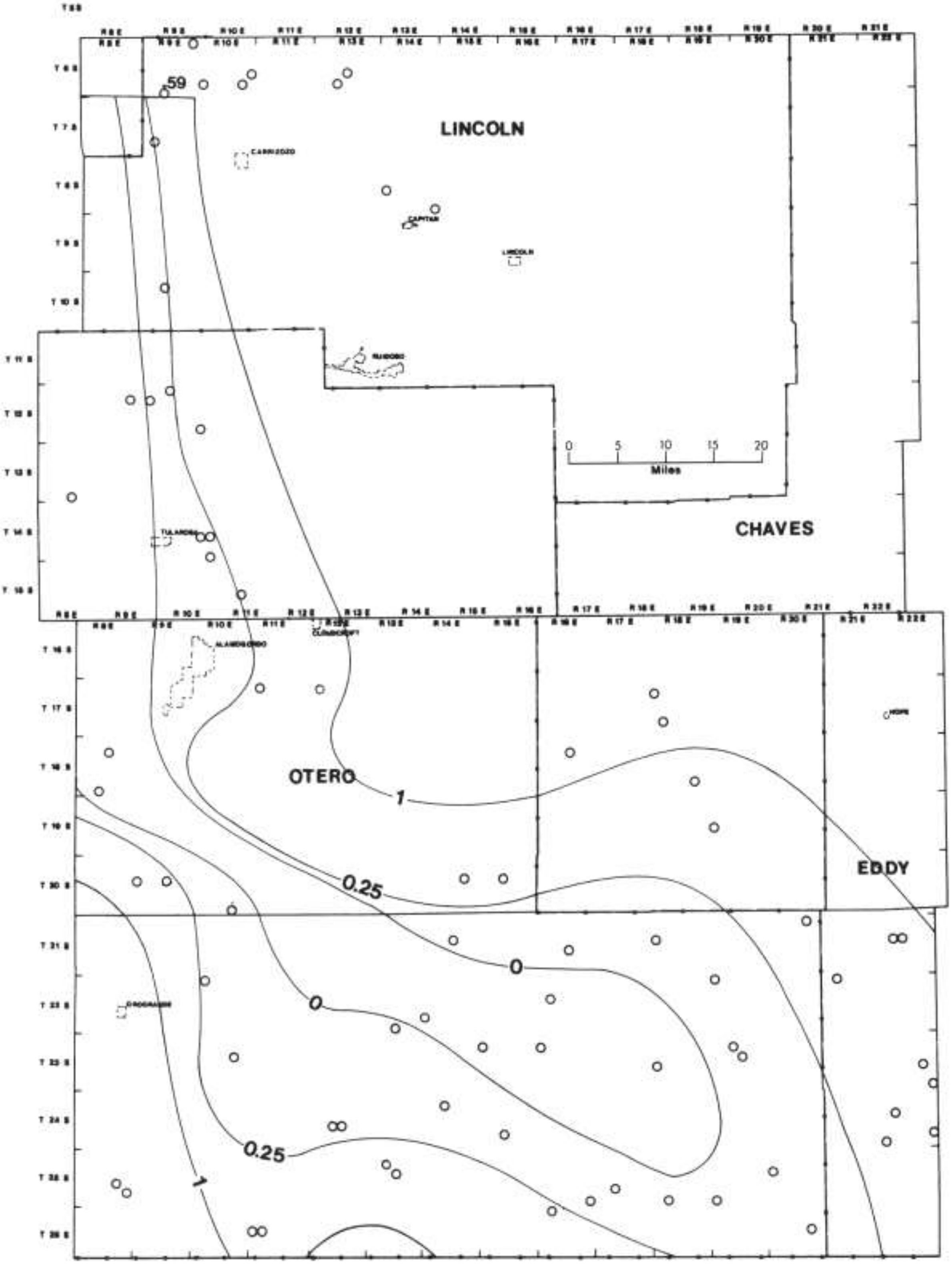
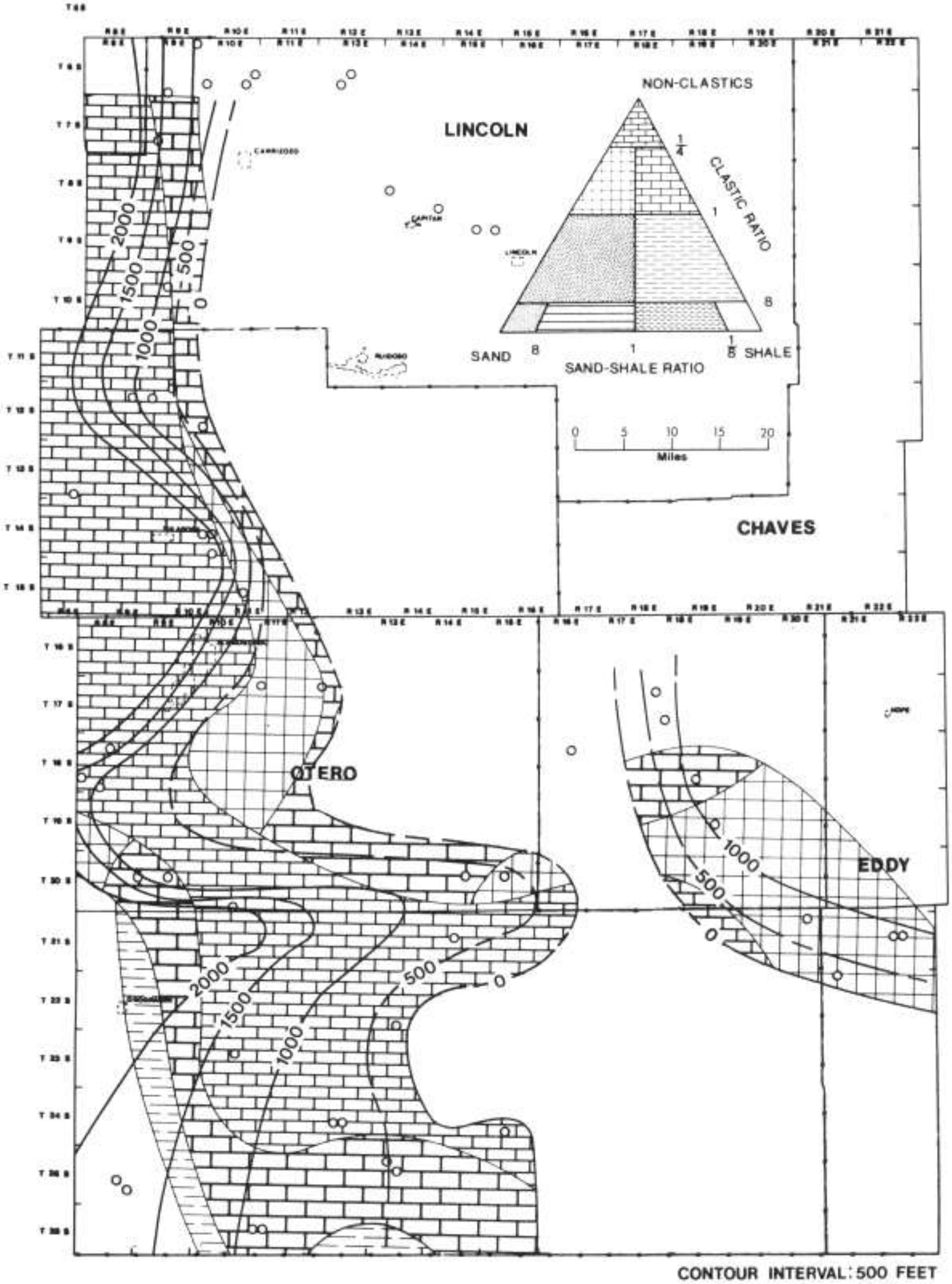


FIGURE 11—Pennsylvanian clastic-ratio map.



CONTOUR INTERVAL: 500 FEET

FIGURE 12—Pennsylvanian isopach–lithofacies map.

have been deposited directly on the Precambrian terrane. In the Otero platform area, the upper Yeso silts, muds, and evaporites grade abruptly southward into calcareous muds as the facies change across the shelf and onto the basin margins. Locally, the shelf-area Yeso sediments intertongue with the San Andres carbonates. The Leonardian—Guadalupian boundary is located within the transitional beds of the Yeso Formation, which pass upward into cherty limestone of the basal San Andres Formation.

The Victorio Peak Limestone consists of thin beds of grayish-orange, fine-grained sandstone alternating with thicker beds of dense, very light-gray dolomite. The rest of the section is composed of light-olive-gray to light-gray dolomite and limestone in beds two feet or less in thickness. The Bone Springs Limestone, the lateral equivalent of the Victorio Peak Limestone, consists of dark-gray limestone in layers mostly less than six inches thick. The limestone beds are separated by thin beds of black shale and one-inch-thick layers of black chert (Boyd, 1958).

Kelley (1971) designated three members for the San Andres Formation in the study area, in ascending order the Rio Bonito, Bonney Canyon, and Fourmile Draw Members.

The Rio Bonito Member is the basal and most widespread of the three members. It contains the thicker and more massive part of the San Andres Formation. Thin- to medium-bedded carbonates 2-5-ft thick are common, but massive beds in excess of 20 ft also occur. Fossils are common in the upper Rio Bonito, with brachiopods, ammonites, and trilobite pygidia being the most noteworthy.

The Bonney Canyon Member consists of thin- to medium-bedded limestone and dolomite which are light to medium gray to black. The carbonates typically weather to a light gray. The most distinctive feature of the Bonney Canyon Member is its "birdseye maple" banding. The banded "birdseye maple" outcrop pattern of this member is not so much due to different colors of the individual beds as due to a terrace and step-like weathering pattern. This weathering pattern encourages differential soil and vegetation development which results in the "birdseye maple" appearance observed in the abundant bare-rock outcrops.

The Fourmile Draw Member of the San Andres Formation is composed of a dark-gray and brown dolomite that weathers to steep, rounded slopes (Kelley, 1971).

Erosion has apparently removed all evidence of subsequent Paleozoic deposition. However, part of the late Guadalupian Artesia Group of southeastern New Mexico, as observed in the Guadalupe Mountains to the east, was deposited over the Otero platform in the study area. It is reasonable to assume that the area became emergent and was stripped of sediments during late Guadalupian and Ochoan time, with sediment of these series being preserved only in the Salt Basin graben in the study area. In the mountainous areas to the east and in the Salt Basin graben we see the Delaware Mountain Group or its lateral-equivalent beds of the reef. The group is made up of three formations, from oldest to youngest the Brushy Canyon, Cherry Canyon, and Bell Canyon. The Brushy Canyon Formation consists of sandstone which pinches out by overlap in the Guadalupe Mountains. The Cherry Canyon Formation is also composed mainly of sandstone and grades into carbonates at the margin of the basin. In the lower portion of the formation is the Cherry Canyon sandstone tongue which is composed predominantly of yellowish-gray to dark-greenish-gray arkosic sandstone. The Bell Canyon Formation is also composed mainly of sandstone which grades into carbonates at the margin of the basin.

The Goat Seep Limestone is the basin-margin equivalent of the Cherry Canyon. The Goat Seep reef is medium- to very light-gray dolomite containing clusters of calcite crystals. Poorly preserved sponges, corals, and brachiopods are randomly distributed through the rock. The overlying Capitan Formation of the marginal area includes nonbedded reef rock and bedded, reef-derived talus. It is composed of very light-gray fossiliferous limestone which has been somewhat recrystallized (Boyd, 1958).

The Delaware Basin to the east of the study area is an area of salt and gypsum deposition that developed from marine waters essentially cut off from the late Paleozoic seas to the south. Widespread erosion of the surface rocks probably took place in latest Permian and Early Triassic time, and by Late Triassic the area may have been eroded essentially to a near-peneplain upon which the Dockum Group was deposited (Black, 1973).

Well data are shown in Table 7. Three Permian maps of the New Mexico area have been constructed: sand-shale-ratio map (Fig. 13), clastic-ratio map (Fig. 14), and isopach—lithofacies map (Fig. 15). These maps show that during the Permian time the Pedernal uplift was still extant, because the strata thin over the Otero platform area. The Permian lithofacies represent a shelf-edge environment.

Mesozoic

Triassic and Cretaceous sedimentary rocks occur mainly in the northern part of the Tularosa Basin (Fig. 4). Jurassic rocks are not present in the area. They are absent due to nondeposition and/or erosion.

Triassic

The Dockum Group, of Triassic age, has been divided into the Chinle Formation and Santa Rosa Sandstone. The Chinle Formation consists of a clastic sequence of red beds, shales, and siltstones. The finer muds and silts represent fluviatile and lacustrine conditions, showing considerably reduced elevations in the sedimentary provenance.

The Santa Rosa Sandstone is composed primarily of sandstones. The study area had positive relief from the end of the Triassic until the Late Cretaceous. Crustal movements were epirogenic, as they had been throughout the Paleozoic (Smith, 1964).

TABLE 7—Permian subsurface data.

Well	Location	Thickness (ft)
Standard Texas 1 Heard	33–6S–9E	5,318
Texaco Federal D	29–7S–9E	1,247
Southern Tularosa 1 Basin	34–13S–8E	2,100
Hodges 1 Houston	23–14S–10E	872
Houston 1 Federal A	24–14S–10E	937
Southern Production 1 Cloudcroft	5–17S–12E	1,350
Texaco Federal E	10–18S–8E	2,390
Texaco Federal G	33–18S–8E	4,530
Texaco Federal F	30–18S–10E	3,015
Gulf 1 Chaves–State U	10–18S–16E	TD 1,768 in fm.
Kewanee 1 F–M	26–18S–18E	4,612
Sun 1 Pearson	35–20S–10E	2,938
Zapata 1 Federal 14	14–20S–14E	3,276
Atlantic 1 AV	16–20S–15E	2,359
Stanolind 1 Thorn Unit	15–21S–14E	TD 3,483 in fm.
Lefors 1 Federal	22–21S–16E	1,354
Standard Texas Scarp Unit 1	18–21S–18E	2,078
Hilland 1 Burro	2–21S–20E	985
Otero 1 MacGregor	5–22S–10E	TD 1,220 in fm.
Turner 1 Everett	34–22S–13E	906
Campbell 1 Hurley	30–22S–14E	1,917
Tri-Service 1 Little Dog	6–22S–19E	2,960
Continental 1 Bass	5–22S–21E	2,078
Kinney 1 State	14–23S–10E	970
Campbell 1 Lieberman	7–23S–15E	1,959
Campbell 1 Spanel	7–23S–16E	1,714
Coral 1 Warren	19–23S–18E	1,796
Weaver 1 Thompson	19–23S–19E	1,984
Campbell 1 McMillan	15–23S–19E	2,191
Eisner 1 Federal	21–24S–12E	TD 1,353 in fm.
Turner 1 Evans	22–24S–12E	1,465
Coral 1 Spanel	9–24S–14E	1,720
Flynn–Welch–Yates 1 Donahue	28–24S–15E	135
Union 1 Federal White	17–24S–22E	2,960
British American 1 Huapache	25–24S–22E	TD 2,769 in fm.
Ernest 1 LL Well	20–25S–7E	160
Union 1 McMillan	9–25S–13E	1,700
Turner 1 Federal State	36–25S–16E	664
Dunigan 1 Alpha Federal	31–25S–19E	4,157
Seaboard 1 Trigg Federal	18–26S–11E	2,760
Hunt 1 McMillan–Turner	5–26S–16E	1,604
Campbell 1 Spiegel	14–26S–20E	1,841

Cretaceous

The Late Cretaceous sequence is divided (in ascending order) into the Dakota Sandstone, Mancos Shale, and Mesaverde Group.

The Dakota Sandstone consists of a basal conglomerate and sandstone with shale, siltstone, and an upper sandstone.

The overlying Mancos Shale is a black, soft shale with thin bentonite seams at the base and thin limestone beds in the lower part.

The overlying Mesaverde Group has not been subdivided in this area. It is composed of yellowish-brown sandstone with interbedded dark-gray shales and lignitic to sub-bituminous coals (Sloan and Garber, 1971).

Erosional pinch-outs of the Cretaceous generally occur to the southwest, where they appear to parallel the Burro uplift in southwestern New Mexico (Black, 1973). The area was for the most part near, or slightly below, sea level during the Early Cretaceous. Cretaceous strata that rest upon the Permian rocks in the Cornudas Mountains, Hueco Mountains, and Diablo Plateau would seem to substantiate this fact. Cretaceous rocks cropping out around the fringes of the Cornudas Mountains on the Otero platform area are composed of buff, sandy limestone and sandy shale (Pray, 1961).

Post-Cretaceous erosion began with broad Laramide upwarping. This event probably took place during the interval between the Late Cretaceous and early Tertiary (Black, 1973).

Cenozoic

Tertiary

Tertiary sedimentary-rock units of the northern part of the Tularosa Basin include the Cub Mountain Formation. This formation is a sandstone that contains interbedded purple and red shale (Sloan and Garber, 1971).

The Tertiary marks the advent of extensive igneous activity with the eruption of the Sierra Blanca volcanics and intrusives of the Jarilla, Cornudas, Sierra Blanca, Lone, and Tres Hermanos Mountains.

Eruption of the Sierra Blanca volcanics started during the early Oligocene and extended into earliest Miocene time. These volcanics lie essentially unfolded above the Sierra Blanca Basin (Kelley, 1973). Intrusion of the basin dikes and sills in the area followed the extrusive activity and was concentrated on the eastern side of the Sierra Blanca Basin (Haynes, 1968).

The intrusive rocks of the Jarilla Mountains were probably emplaced in early or middle Paleogene time, as indicated by analogy with rocks of similar composition and origin that occur to the northeast in the Sierra Blanca and Capitan Mountains. The Jarilla intrusives were injected in three main pulses: syenodiorite first, then monzonite—adamellite, and finally orthoclase adamellite. The abundance of biotite in some of the Jarilla plutonic rocks indicates moderate- to high-water pressures, which would indicate that the intrusives were probably emplaced at a considerable depth (Schmidt and Craddock, 1964).

The Cornudas Mountains are a cluster of intrusive peaks that stand as isolated high areas above the surrounding region. They are exposed laccoliths and sills which are predominantly syenitic in composition.

Crudely aligned along a trend from the Jarilla Mountains to Tularosa Peak along the east side of the Tularosa Basin are several hills of Permian strata and Tertiary intrusives known as the Tres Hermanos Mountains. The bolson fill is relatively thin, suggesting that some of these hills are peaks of a fault-block ridge partly buried by alluvium (Kottlowski, 1965).

The intrusion of Lone Mountain and associated stocks into the upper crust domed and warped the overlying thin sedimentary cover and apparently created fractures which were later filled with igneous rock as dikes and sills. Following the intrusion of the stocks, volcanic activity began on a broad scale. Volcanic debris was spread over a wide area and subsequently intruded by dikes and sills. During the last stages of intrusive activity, basaltic dikes were intruded; these

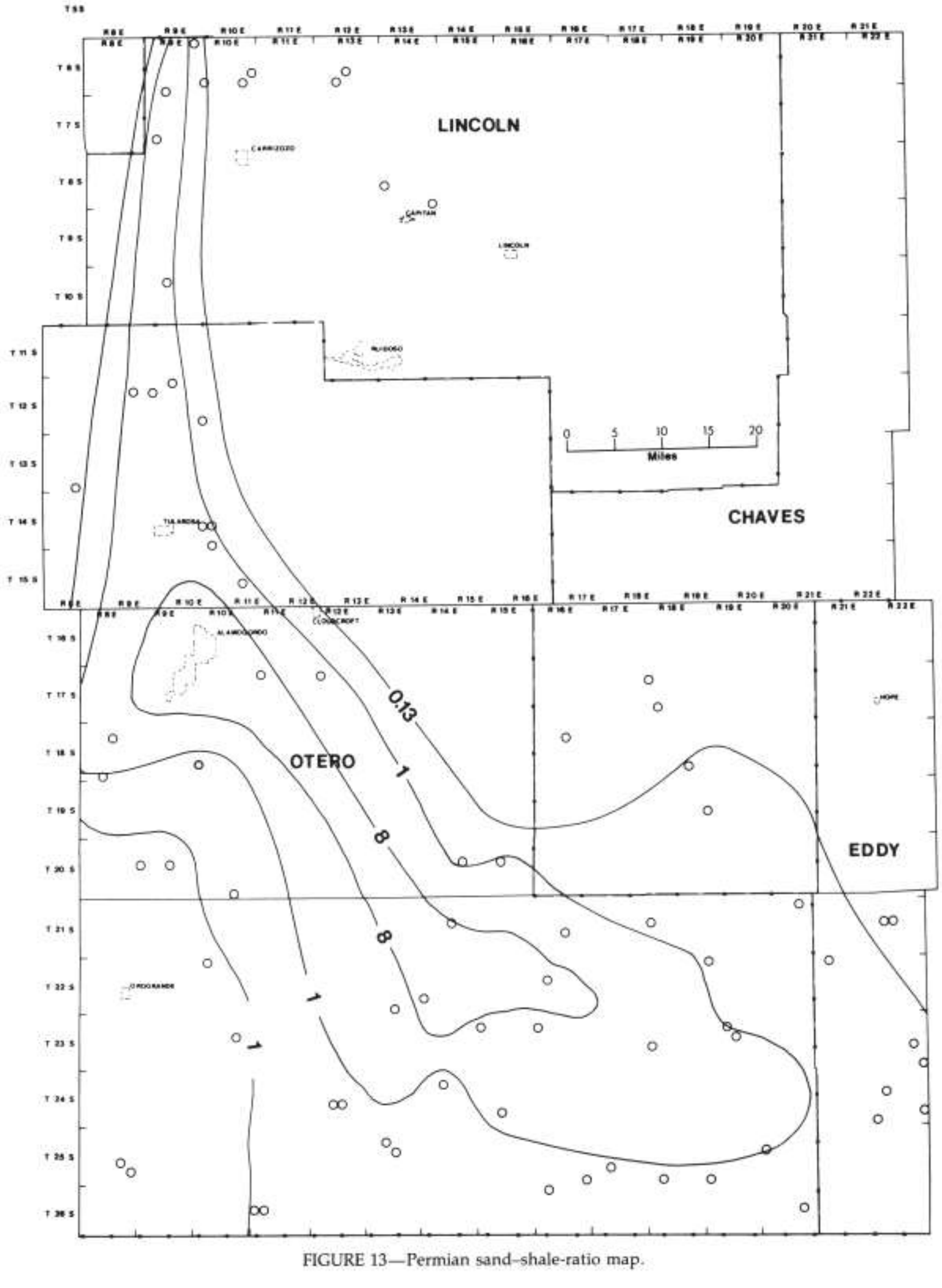


FIGURE 13—Permian sand–shale-ratio map.

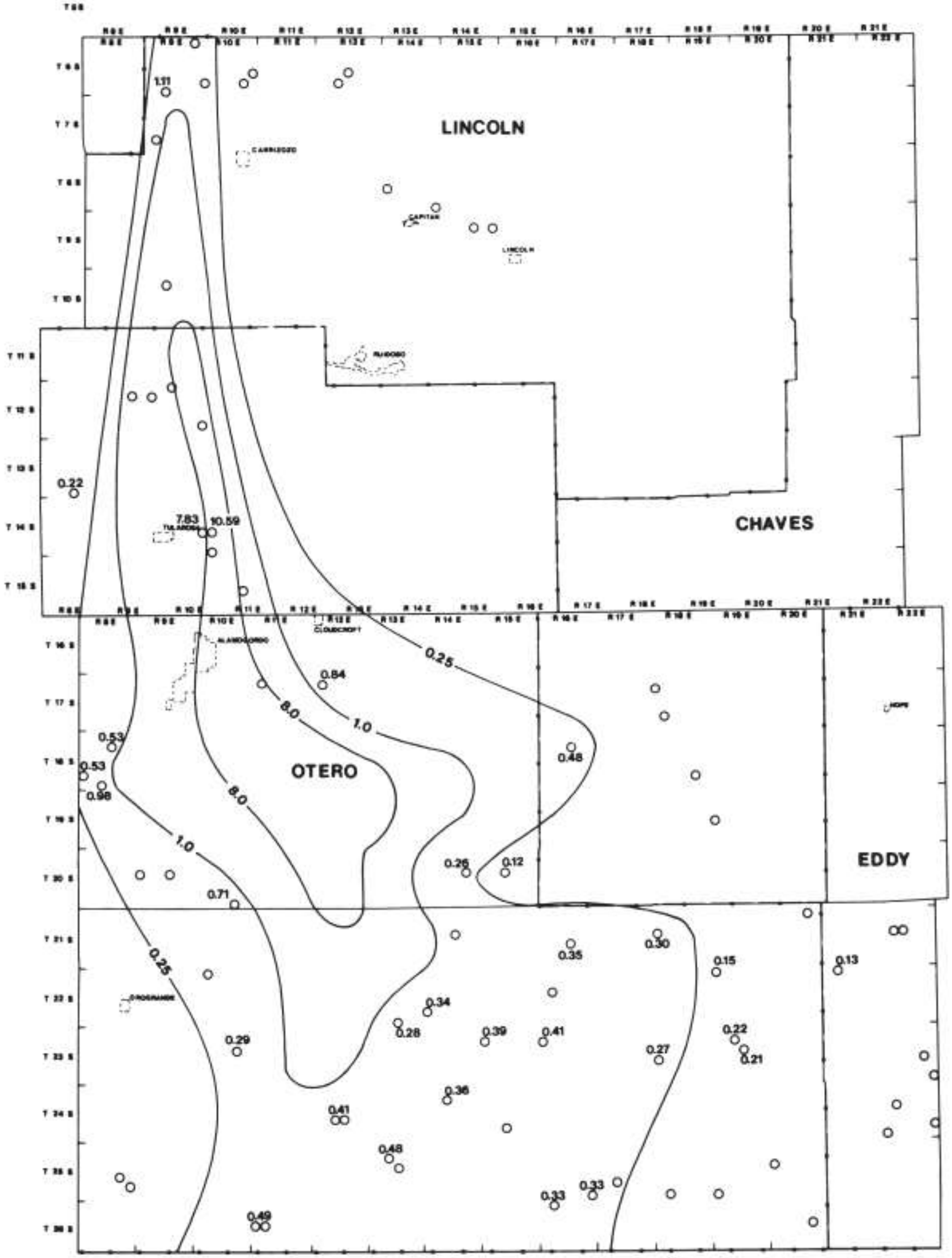


FIGURE 14—Permian clastic-ratio map.

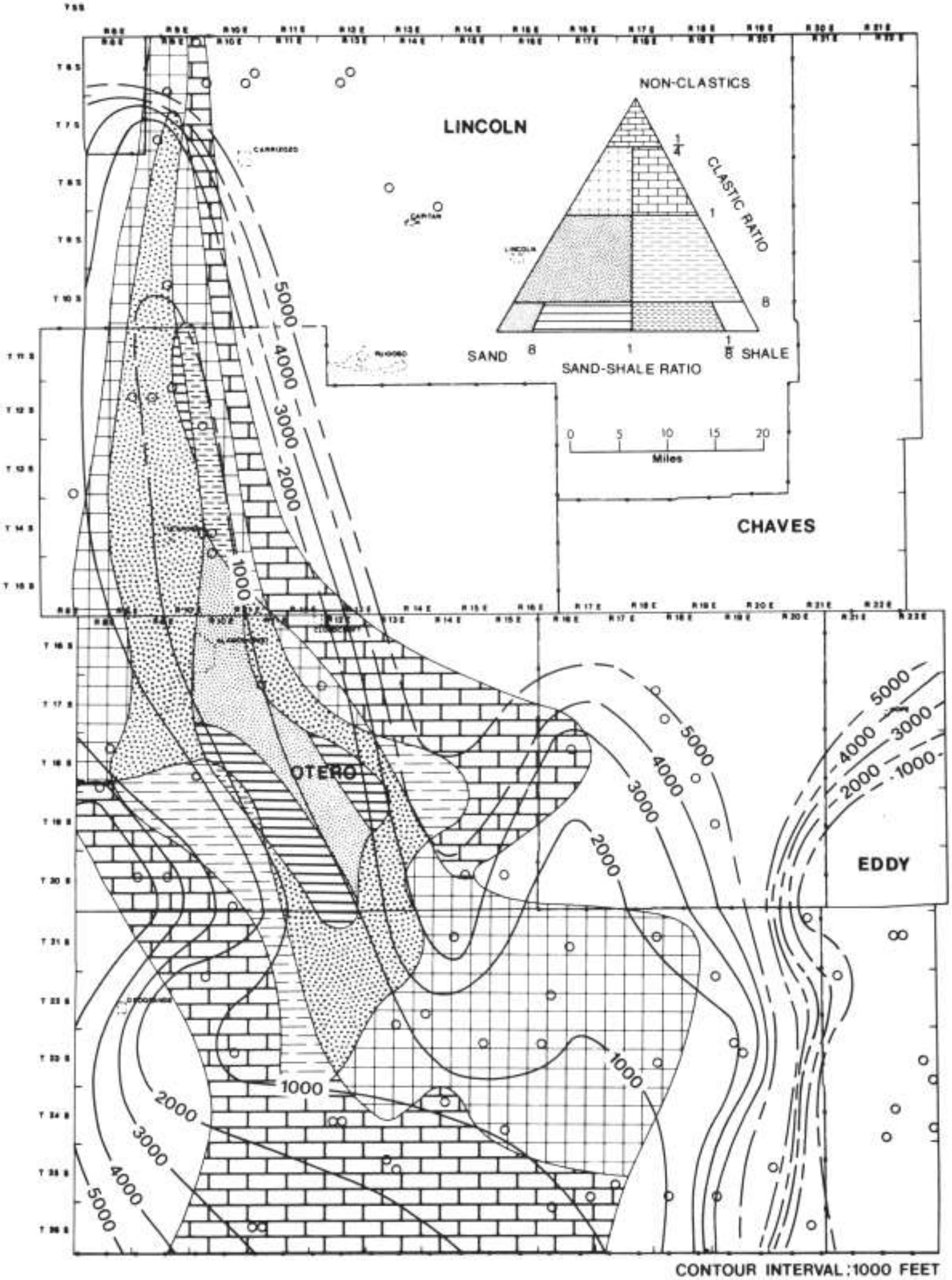


FIGURE 15—Permian isopach–lithofacies map.

may have been the feeders or precursors of the later basaltic flows of Broken Back and Little Black Peak (Smith, 1964).

The bolson deposits of the Tularosa Basin are poorly consolidated and cover the underlying Mesozoic and Paleozoic sequences. These bolson deposits consist primarily of fanglomerates, conglomerates, soft sandstones, caliche, shale, and gypsum. The Santa Fe Formation was deposited from Miocene to mid-Pleistocene time.

During the Miocene, monoclinal flexures began the uplift of the Sacramento, San Andres, and Oscura Mountains in an orogenic phase which was probably related to the initiation of the Rio Grande rift. The Rio Grande rift is a series of structurally aligned basins which developed an integrated basin-drainage system in the late Pliocene. Parallel basins and intragraben horsts distinguish the southern section of the rift (Goetz, 1980). By Pliocene time these monoclinal flexures developed into basin-and-range faults and the major uplifts rose in relation to the basins. Widespread pedimentation extended into the area from the east and deep erosion of the fault scarps bounding the Sierra Blanca volcanic pile occurred, resulting in the deposition of alluvial fill in the Tularosa Basin (Kelley and Thompson, 1964).

Quaternary

The Pleistocene was primarily a time of erosion in the Otero platform area, with some Holocene lacustrine deposits forming in the small, closed basins as well as playas which have formed between the uplifts. Terracing, slumping, solution collapse, alluvial-fan formation, arroyo development, and stream-bed deposition were active in Holocene time (Black, 1973).

In the Tularosa Basin, small lava flows and pyroclastics formed during a minor eruption of late Pleistocene or Recent age at the north end of the Jarilla Mountains. Lake Otero, which occupied the area of the present White Sands National Monument, existed during the Pleistocene and may have reached as far south as the Jarilla Mountains (Schmidt and Craddock, 1964). The lake covered a large part of the basin during times of more moist Pleistocene climates as shown by the abundant terraces in the vicinity of Alamogordo. In the present semiarid climate, the only vestige occurs as tiny Lake Lucero. The wide areas of gypsum-bearing sediments in the Tularosa Basin alluvium are the result of evaporation. It has been suggested that the gypsum leached from the San Andres Formation in the San Andres Mountains (Jicha, 1964).

Minor glaciation on Sierra Blanca Peak occurred during the Quaternary and the eruption of the Carrizozo basalt flows took place in the Tularosa Basin (Jicha, 1964).

Since the late Tertiary, rift faulting has occurred along, or close to, the present escarpments of San Andres, Sacramento, and Oscura Mountains. Periods of prolonged erosion with development of extensive pediment surfaces have alternated with intermittent periods of differential uplift during which warping occurred. Earlier erosion surfaces have been dissected and newer ones developed (Otte, 1964).

Geophysics and structure

Tularosa Basin

Geophysical, geological, and oil-well-test data show the Tularosa Basin to be structurally complex. The basin is a downdropped block of the crust bounded on both sides by range-front faults attendant to the adjacent uplifts. This Tertiary basin is superimposed upon the Paleozoic Orogrande Basin (Wilson, 1967).

Gravity data (Healy et al., 1978) show that a major gravity high trends northward, corresponding to the mountains west of the Tularosa Basin. This high, entering the area from the south, extends through North Anthony's Nose of the Franklin Mountains, the Organ Mountains, and the San Andres Mountains, and continues through the area via the Oscura Mountains. A second gravity high occurs over the Sacramento Mountains, Sierra Blanca, and Carrizo Mountain along the east side of the basin. A third major high extends northward from the Hueco Mountains through the Jarilla Mountains to a point southwest of Alamogordo. This high is apparently associated with the band of pre-Cenozoic and Cenozoic bedrock which crops out through the valley fill within the Tularosa Basin. The gravity data indicate a normal fault, down to the west, near the center of the basin, which trends northward along the block upon which these features are aligned.

A major gravity low occurs within the Tularosa Basin. This low continues from the Hueco bolson and trends north—south throughout the entire length of the valley. Tracing the low from north to south, west of Three Rivers, this low curves eastward and then southeastward through Tularosa and continues to approximately 80 mi south of Alamogordo.

Using gravity data, Healy et al. (1978) constructed several generalized geological cross sections through the Tularosa Basin. These data are especially useful in that the depth of the valley fill can be approximated and possible subsurface structures in the basin floor may be deduced. Fig. 2 shows the location of the gravity cross sections of Healy et al. (1978).

Cross section A—A' (Fig. 16), which extends northeastward from a point near North Anthony's Nose to the northeast of Newman, New Mexico, gives a calculated depth to the pre-Cenozoic bedrock of 8,000 ft near the center of the valley. Near the west end of the cross section, two faults are implied by gravity

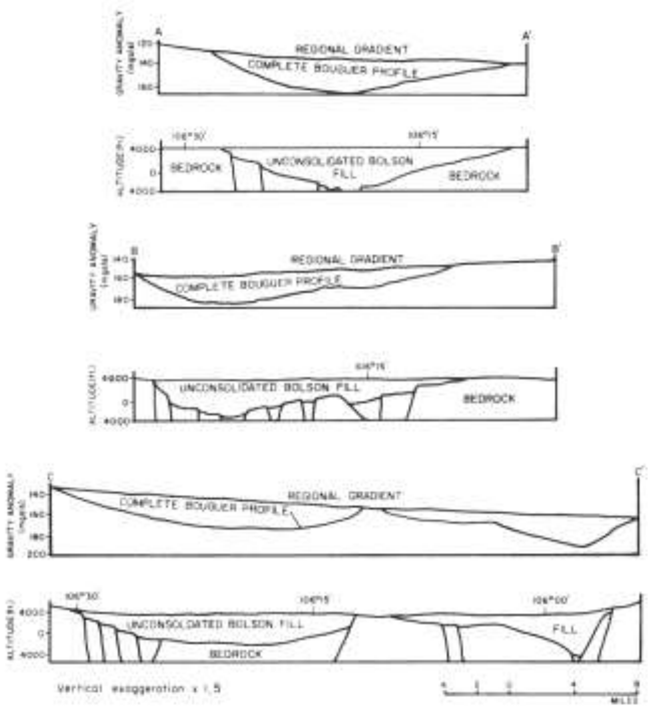


FIGURE 16—Generalized geologic cross sections of the Tularosa Basin based on analysis of gravity data (from Healy et al., 1978).

interpretation. Unresolved step faults away from the bedrock outcrop at the east end of the cross section are implied, but not shown, on the cross section.

Cross section B—B' (Fig. 16) extends from the southern San Andres Mountains to the Jarilla Mountains. The maximum depth calculated to bedrock here is 6,000 ft. A major fault or fault zone is indicated on the west end of this cross section.

Cross section C—C' (Fig. 16) extends from the San Andres Mountains northeastward near Tularosa and into the Sacramento Mountains. Here the northward extension of the Jarilla Mountain gravity high divides the Tularosa Basin into two separate basins. In this area, the western basin appears to deepen to the west along a sloping bedrock surface until it reaches the zone of faults farther to the west. However, unresolved step faults may be present. The western basin has a calculated depth to bedrock of 6,200 ft. The eastern basin is narrow and relatively deep, with faults on each side. The calculated valley thickness here is 4,500 ft and probably corresponds to the Orogrande Basin. Fig. 17 (from Daggett, 1982) shows a regional gravity map of the study area.

Figs. 18 and 19 are location maps of the area with the wells spotted on them and the lines of the borehole-mechanical-log cross sections indicated. The cross sections showing electric-log details and correlations are in Figs. 20 through 24 (in pocket).

Table 8 shows the names, locations, and total depths of the wells in the study area.

A consideration of the electric-log cross section BB' in Fig. 18 and Fig. 21 (in pocket) shows a line of well logs including the Houston Oil and Gas No. 1 State "L.G. 1453," the Houston Oil and Gas No. 1 Lewelling, and the Houston Oil and Gas No. 2 Lewelling. The Lewelling No. 1 seems to be structurally higher than the Houston No. 1 State "L.G. 1453," with beds dipping eastward between the wells. Between the Houston No. 1 Lewelling and the Houston No. 2 Lewelling is a fault with a confirmed displacement of some 6,300 ft on the top of the Yeso Formation. Examining geologic maps of the Tularosa Basin, one notes that the Lewelling No. 1 was drilled in the area of outcrops of Mesozoic rocks, and the Lewelling No. 2 was spudded in the alluvium on the other side of a major boundary-fault zone.

Cross section C—C' of Fig. 18 and Fig. 21 (in pocket) is, from east to west, of the Texaco Federal (USA) "F" No. 1 and the Texaco Federal (USA) "E" No. 1 wells released by Texaco, Inc. for this study. Texaco not only released the electric logs, but the lithologic logs and paleontological calls as well. These wells had been held tight for many years. The interpretation of the structural relationships of these wells is that of a fault

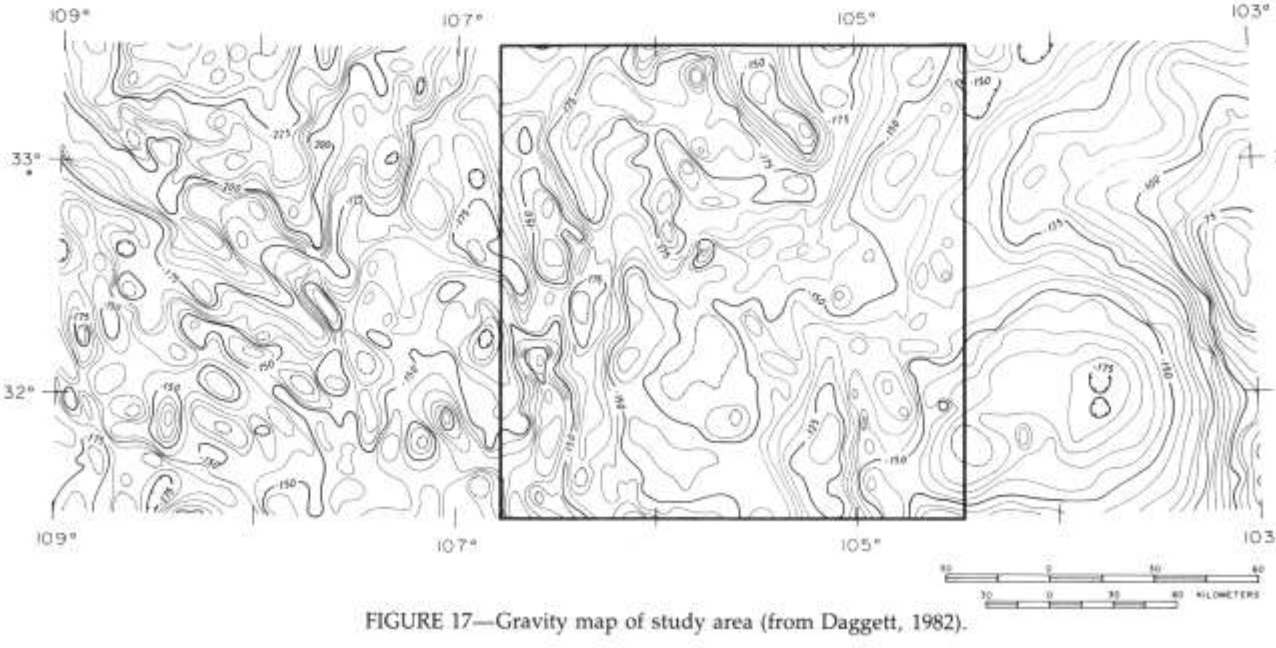


FIGURE 17—Gravity map of study area (from Daggett, 1982).

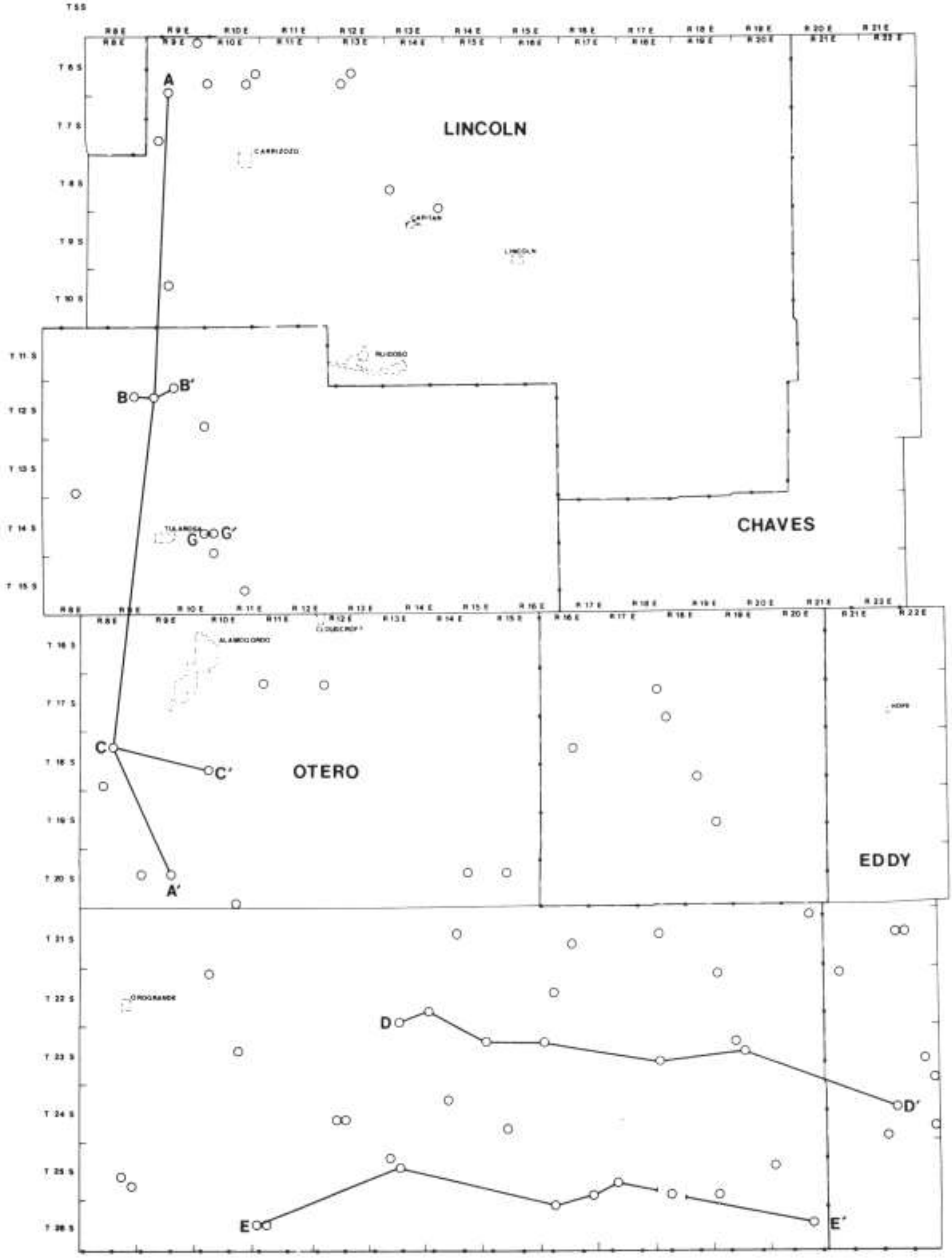


FIGURE 18—Well and cross-section locations of New Mexico portion of study area.

TABLE 8—Well names, locations, and total depths.

Well	Location	Total depth (ft)
Loveless No. 8	Sec. 1, T6S, R9E	1,005
Standard Heard Federal No. 1	Sec. 33, T6S, R9E	8,050
Bryce Dugger No. 1 Helen Federal	Sec. 23, T6S, R10E	1,250
Bryce Dugger No. 1 Edna Gallager	Sec. 26, T6S, R10E	2,059
Bryce Dugger No. 1 Federal	Sec. 30, T6S, R10E	1,500
Mark Vaughn No. 1 Crenshaw	Sec. 21, T6S, R13E	400
Roy H. Sipple, H. E. Keh No. 1	Sec. 29, T6S, R13E	1,027
Texaco Inc. No. 1D Federal	Sec. 29, T7S, R9E	7,616
Western Ranchers Oil Co. No. 1 Beecher	Sec. 19, T8S, R14E	1,342
Capoco Corp. No. 1 Spencer	Sec. 36, T8S, R14E	2,181
Rafferty No. 1	Sec. 9, T10S, R9E	864
Houston Oil & Minerals No. 2 Lewelling	Sec. 10, T12S, R9E	9,487
Houston No. 1 Lewelling	Sec. 12, T12S, R9E	9,360
Houston No. 1 State Lease 2748	Sec. 25, T12S, R9E	715
Houston No. 1 State L.G. "1453"	Sec. 5, T12S, R10E	9,852
Southern Tularosa Basin Co. No. 1	Sec. 34, T13S, R8E	3,965
Houston No. 1 Federal "A"	Sec. 24, T14S, R10E	3,690
Houston No. 1 State 3724	Sec. 36, T14S, R10E	4,579
Hodges Houston No. 1	Sec. 23, T14S, R10E	3,040
Dwight Smith No. 1 J. W. Walker	Sec. 21, T15S, R11E	555
Southern Production Company Cloudcroft Unit No. 1	Sec. 5, T17S, R12E	4,701
Yates Petroleum Company No. 1 Dunken Dome Unit	Sec. 7, T17S, R18E	5,826
Texaco Production State–Wilson No. 1	Sec. 29, T17S, R18E	4,900
Texaco Inc. 1 Federal (USA) "E"	Sec. 10, T18S, R8E	7,785
Texaco Inc. 1 Federal (USA) "G"	Sec. 33, T18S, R8E	7,660
Texaco Inc. 1 Federal (USA) "F" (NCT–1)	Sec. 30, T18S, R10E	8,288
Gulf Oil Corp. No. 1 Chaves "V"	Sec. 10, T18S, R16E	3,147
Kewanne Oil Co. F–M Unit No. 1	Sec. 26, T18S, R18E	6,562
Sun Oil Co. Pinon Unit No. 1	Sec. 19, T19S, R17E	1,911
Plymouth Oil Co. Federal D No. 1	Sec. 15, T20S, R9E	7,585
Phillips Petroleum Company No. 1 Turquoise	Sec. 18, T20S, R9E	5,437
Sun Oil Company T. J. Pearson No. 1	Sec. 35, T20S, R10E	4,468
Zapata Petroleum Corporation Federal 14 No. 1	Sec. 14, T20S, R14E	5,043
Atlantic Refining Co. State "AV" No. 1	Sec. 16, T20S, R15E	4,027
Stanolind Oil & Gas Thorn Unit No. 1	Sec. 15, T21S, R14E	4,646
Lefors Petroleum Co. No. 1 Federal	Sec. 22, T21S, R16E	2,255
Standard of Texas Scarp Unit No. 1	Sec. 18, T21S, R18E	2,664
Terra Resources No. 1–Y Burro Canyon Unit	Sec. 2, T21S, R20E	5,589
Standard Oil Co. of Texas 1 State 6548 Burro Hills	Sec. 16, T21S, R22E	11,312
Cities Service Oil Co. No. 1 Loafer Draw Unit "A"	Sec. 17, T21S, R22E	8,873
Otero Oil Co. McGregor No. 1	Sec. 5, T22S, R10E	1,730
Fred Turner Everett No. 1	Sec. 34, T22S, R13E	3,945
E. P. Campbell No. 1 Hurley	Sec. 30, T22S, R14E	2,433
Tri-Service Drilling Co. No. 1 Little Dog Federal	Sec. 6, T22S, R19E	4,130
Continental Oil Co. No. 1 H. W. Bass	Sec. 5, T22S, R21E	5,889
Kinney Oil & Gas State No. 1	Sec. 14, T23S, R10E	2,168
E. P. Campbell No. 1 Liberman State	Sec. 7, T23S, R15E	2,700
E. P. Campbell No. 1 Lois Spanel	Sec. 7, T23S, R16E	2,682
Coral Oil & Gas Co. No. 1 Warren	Sec. 19, T23S, R18E	2,363
W. R. Weaver No. 1 Thompson	Sec. 9, T23S, R19E	3,848
E. P. Campbell No. 1 McMillan Federal	Sec. 15, T23S, R19E	3,189
Humble Oil Refineries Co. No. 2 Huapache Oil Unit 1	Sec. 23, T23S, R22E	12,582
American Quasar Petroleum Co. No. 1 Huber State	Sec. 36, T23S, R22E	10,400
John Eisner No. 1 Federal	Sec. 21, T24S, R12E	1,775
Pasotero No. 1 Evans	Sec. 22, T24S, R12E	3,763
Coal Oil & Gas No. 1 AN Spanel	Sec. 9, T24S, R14E	1,873
Flynn, Welch, Yates Donahue No. 1	Sec. 28, T24S, R15E	1,692
Union Oil Co. No. 1 White	Sec. 17, T24S, R22E	6,737
British American Production Co. No. 7 Huapache Unit	Sec. 25, T24S, R22E	3,620
Franklin, Aston & Fair No. 1 Turkey Draw Unit	Sec. 31, T24S, R22E	7,400
George Mulberry State No. 1	Sec. 11, T25S, R8E	263
Holland Page J. A. Maris–State No. 1	Sec. 23, T25S, R8E	731
Union Oil Co. McMillan No. 1	Sec. 9, T25S, R13E	5,215
Transocean Oil No. 1 G. J. Ablah	Sec. 15, T25S, R13E	5,305
Fred Turner No. 1 State	Sec. 36, T25S, R16E	5,195
Pennzoil Co. No. 1 Southland "28" State	Sec. 28, T25S, R17E	2,970
Pennzoil Co. No. 1 Southland "32" State	Sec. 32, T25S, R18E	3,635
E. J. Dunigan No. 1 Alpha Federal	Sec. 31, T25S, R19E	4,998
W. W. West No. 1 West Dog Canyon Unit	Sec. 18, T25S, R20E	4,570
W. G. Wilmoth, Wilmoth No. 1	Sec. 3, T26S, R8E	206

TABLE 8 (continued)

Well	Location	Total depth (ft)
Samuel Butler E. A. Wingo Per No. 1	Sec. 17, T26S, R11E	445
Seaboard Oil Co. No. 1 Trigg-Federal	Sec. 18, T26S, R11E	5,600
Hunt Oil Co. McMillan–Turner No. 1	Sec. 5, T26S, R16E	2,175
E. P. Campbell No. 1 Spiegel-Federal	Sec. 14, T26S, R20E	4,578
	TEXAS	
Hunt Petroleum Corp. C. L. Ranch "5" No. 1	Sec. 5, Blk 67, T–1, T&P Survey	5,506
Pure Oil Co. No. 1 Hunter	Sec. 34, Blk 66, T–1, T&P Survey	6,649
Hunt Oil Co. No. 1 Dyer	Sec. 31, Blk 68, T–1, T&P Survey	2,947
Texaco Inc. Culberson "L" Fee No. 1	Sec. 45, Blk 65, T–1, T&P Survey	8,700
Hunt Petroleum Corp. C. L. Ranch No. 1	Sec. 44, Blk 67, T–1, T&P Survey	5,232
Border Exploration Co. CT–1 Hammack et al.	Sec. 20, Blk 120, PSL Survey	7,596
Border Exploration Co. J. J. McAdoo 7 No. 1	Sec. 7, Blk 119, PSL Survey	7,665

block tilted to the east. The geophysical data cited above tend to make the tilted-fault-block hypothesis reasonable, and the dips of the beds between the wells are compatible with that hypothesis.

The cross sections show the Tularosa Basin to be more than just a simple graben. Numerous step faults and intrabasinal uplifts are present within the basin. The cross sections reflect only the Tertiary structures of the basin. Preceding structural episodes that were altered by Tertiary events should also be considered (Healy et al., 1978).

Otero platform

Structurally, the Otero platform lies north of the Diablo Plateau and across the southern extension of the buried Paleozoic Pedernal uplift. The structural features of this area evolved during at least four episodes of deformation, ranging in age from Pennsylvanian to Plio-Pleistocene.

Structures were produced during uplift of the Pedernal landmass in Late Pennsylvanian time. The structural fabric of this deformation resulted mostly from folding and faulting. Much of the faulting took place along crests of the forming anticlines. It was during this period that the pre-Permian rocks were eroded, locally exposing the Precambrian rocks in the case of the Pedernal landmass.

Laramide deformation, which probably began during the Late Cretaceous, is largely responsible for many of the northeasterly to easterly trending folds. Presumably, these relatively symmetrical, gently dipping, and commonly doubly plunging folds are the result of east—west-oriented compressional stress.

Late Tertiary tectonism (Basin and Range) has produced the present structural configuration, which is a series of tilted fault-blocks consecutively less deformed and uplifted to the south and east. Generally, the tilted fault-blocks are outlined within the area by major anticlines and synclines which were formed by drape of beds folding over the fault blocks.

Late Tertiary deformational features may have been subsequently altered by an almost contemporaneous deformation or by very late (Pliocene—Pleistocene) movements (Black, 1973).

Cross section D—D', modified from an unpublished work of Ben Donegan, is of the central Otero Platform and is shown in Fig. 18 and Fig. 22 (in pocket). Cross section E—E' is of the extreme southern Otero platform region and is shown in Fig. 18 and Fig. 20 (in pocket). These two cross sections clearly show the influence of the Pedernal uplift.

In cross section D—D', the Drinkard and Lee Ranch tongues have been correlated across the section. It should be noted that the Union Oil Company No. 1 White (Sec. 17, T. 24 S., R. 22 E.) is far to the east of the other wells and shows a more complete stratigraphic section. A composite well log has been made of the Campbell No. 1 Hurley and the Turner No. 1 Everett in T. 22 S., R. 14 and 13 E., respectively.

In cross section E—E', shown in Fig. 20 (in pocket), the Hunt No. 1 McMillan—Turner (Sec. 5, T. 26 S., R. 16 E.) has been inserted to show the impact of the Pedernal uplift. No electric log was run in this well and the lithology was not plotted in detail because the available logs are quite sketchy. A mechanical adjustment is shown where the fault near 2,100 ft just east of the Transocean No. 1 Ablah (Sec. 15, T. 25 S., R. 13 E.) is offset. The flexure in the fault is merely for space and drafting reasons because it must be shown to have penetrated the Pennsylvanian. The faults shown are really fault zones rather than individual faults. In addition, there are other faults in the Pedernal uplift region (Black, 1975). In fact, the Pedernal uplift is fairly well "diced" by faults. An unconformity is shown at the base of the Wolfcampian section (Black, 1975).

According to the gamma-ray—neutron log, there is a possible Pennsylvanian section at the base of the Campbell No. 1 Spiegel (Sec. 14, T. 26 S., R. 20 E.).

The Transocean No. 1 Ablah (Sec. 15, T. 25 S., R. 13 E.), which penetrated a full stratigraphic section for the region, is represented by a simultaneously compensated neutron—formation-density log.

Salt Basin graben

The Salt Basin graben is the easternmost limit of Basin and Range tectonism and the easternmost structure related to the Rio Grande rift (Daggett, 1982). The graben is a block-faulted half-graben consisting of four segments. Each segment is offset to the west of its adjacent southern segment along faults that parallel late Paleozoic fault trends.

The graben as a whole is asymmetrical, with the

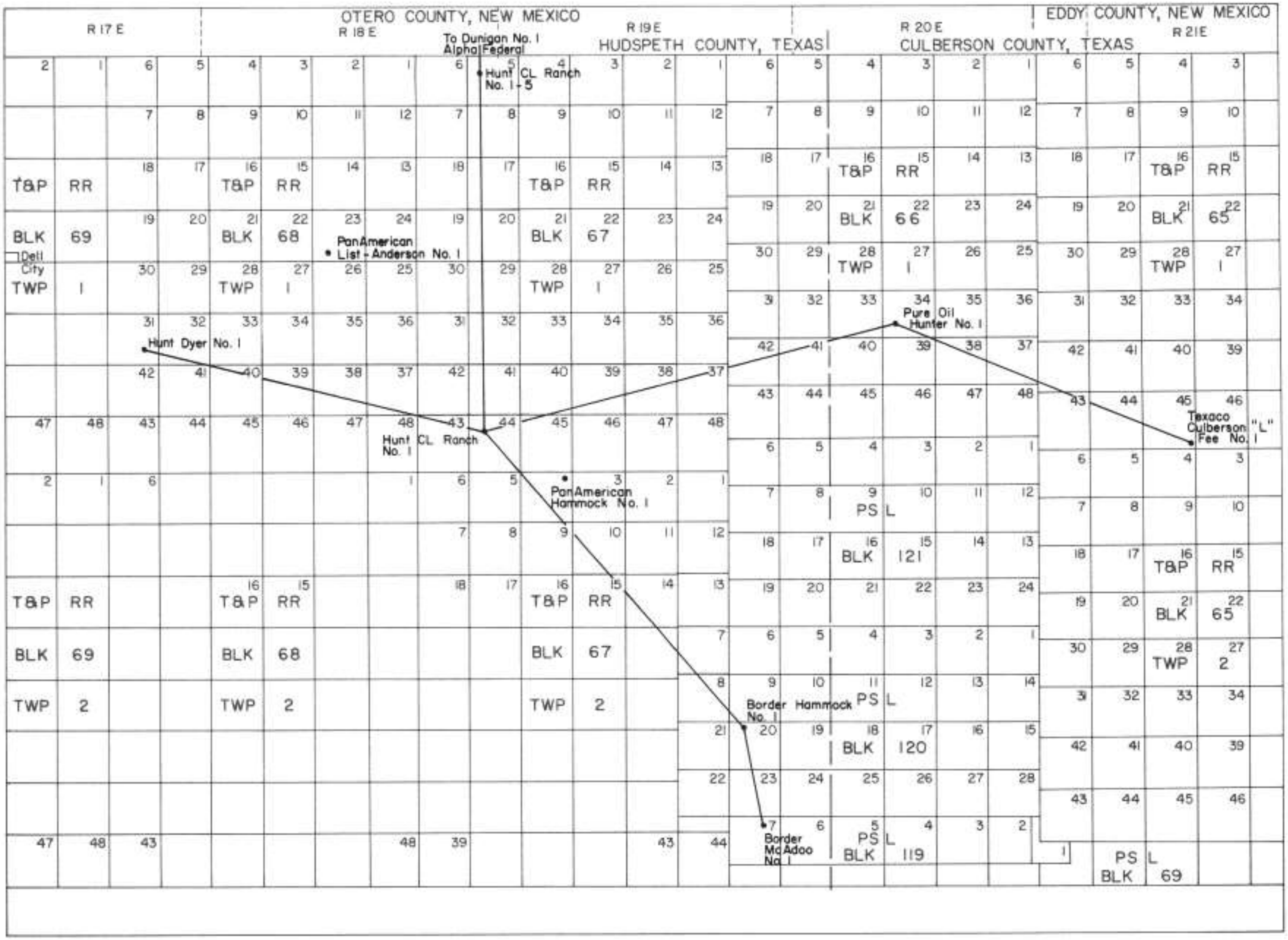


FIGURE 19—Well and cross-section locations of Salt Basin graben area, Texas.

eastern horst elevated higher than the western horst and with the floor formed by a series of southwestwest-dipping basement blocks (Goetz, 1980).

Both gravity and magnetic lows trend north—northwest along the surface extent of the graben. Model number 2 for profile A—A' of Veldhuis and Keller (1980) is an attempt to model the Salt Basin graben proper. The model clearly indicates the steeply dipping western-boundary fault and more complex faulting associated with its eastern margin. The depth to Precambrian basement in the lowest portion of the graben is interpreted to be 1.8 mi (Veldhuis and Keller, 1980).

The north—south electric-log cross section shown as G—G' in Fig. 23 (in pocket) and Fig. 19 runs from southern New Mexico to a point near U.S. Highway 62 where the highway crosses the Salt Basin graben in Texas. The fault between the Dunigan Alpha Federal No. 1 (Sec. 31, T. 25 S., R. 19 E., Otero County, New Mexico) and the Hunt Petroleum Corporation C. L. Ranch 5 No. 1 (Sec. 5, Blk. 67, T 1, T & P Survey, Hudspeth County, Texas) is small on the projection of the tops of the Abo and Yeso Formations, and could not be checked on the San Andres Formation top because no samples are available for the upper 2,310 ft of the Hunt well. Farther to the south, particularly between the Hunt Petroleum Corp. C. L. Ranch No. 1 (Sec. 44, Blk. 67, T 1, T & P Survey, Hudspeth County, Texas) and the Border Oil Hammack et al. No. 1 (Sec. 20, Blk. 120, PSL, Hudspeth County, Texas), the beds dip quite steeply; no fault is thought to be present.

The east—west electric-log cross section shown as H—H' in Fig. 24 (in pocket) and Fig. 19 runs from the Hunt Oil Company No. 1 Dyer (Sec. 31, Blk. 68, T 1, T & P Survey, Hudspeth County) to the Texaco Culberson "L" Fee No. 1 (Sec. 45, Blk. 65, T 1, T & P Survey, Culberson County, Texas). The No. 1 Dyer well is in the center of the graben, as is the Hunt Petroleum Corp. No. 1 C. L. Ranch (Sec. 44, Blk. 67, T 1, T & P Survey, Hudspeth County) that shows a considerable section of alluvium in the upper part of the well. The Pure Oil Company No. 1 Hunter (Sec. 34, Blk. 66, T 1, T & P Survey, Culberson County, Texas) lies on the west side of the Guadalupe Mountains, just to the east of the Salt Basin graben boundary fault. A cross section similar to H—H' is shown diagrammatically in a recent publication of the West Texas Geological Society (Matchus and Jones, 1984).

Oil and gas potential

To be sure, not everyone will agree with our correlations. In every case in this report we used completion reports, mud logs, electric logs, personal communications, published data, and our own observations for tops and calls. In many instances, fusulinid data have been used to subdivide the Pennsylvanian and Permian.

Tularosa Basin

Considering the drill-stem tests of the Houston Oil and Minerals Lewelling No. 1 (Sec. 12, T. 12 S., R. 9 E.) and the Hodges Houston No. 1 (Fig. 18; Fig. 23—in pocket), it becomes apparent that the Tularosa Basin is an area which bears hydrocarbons. The question that remains is whether the oil industry will be able to conduct exploration throughout the entire basin, including White Sands Missile Range, that will define the quantity and nature of the hydrocarbons.

Cross section A—A' in Fig. 18 and Fig. 20 (in pocket) is a north—south section from the Standard of Texas No. 1 Heard Federal (Sec. 33, T. 6 S., R. 9 E.) to the Plymouth No. 1 Federal (Sec. 15, T. 20 S., R. 9 E.). Admittedly, the wells are widely spaced, but the cross section does show the stratigraphy in a north—south direction through the extreme eastern side of the Tularosa Basin.

Unfortunately, detailed stratigraphy of the Mesozoic and Cenozoic rocks of the Tularosa Basin subsurface is poorly known. The calls that have been made for this cross section are largely from completion cards, electric logs, and mud logs.

The Houston Oil and Minerals Lewelling No. 1 (Sec. 12, T. 12 S., R. 9 E.) and the Hodges Houston No. 1 (Sec. 23, T. 14 S., R. 10 E.) along the eastern side of the Tularosa Basin in the Three Rivers area are the most promising wells in the basin to date. Several tests of Pennsylvanian and Permian strata have recovered natural gas. The largest volume tested was from the Lewelling No. 1, where maximum recovery was slightly over 430 MCFPD from the 8,000-8,015-ft Desmoinesian (Strawn) interval.

Results of the four-point tests are as follows (Foster, 1978):

	July 6, 1974	July 9, 1974
Choke	*Recovery (MCFPD)*	*Recovery (MCFPD)*
25/64"	430.1	138.4
20/64"	304.2	133.6
16/64"	257.7	139.7
11/64"	178.6	134.8

In a final test of the Desmoinesian zone on 20 July 1974, the well flowed at a rate of 168.3 MCFPD on a 25/64" choke with a tubing pressure of 30 psi. Chemical analysis of the gas showed 82.33% methane, 15.88% carbon dioxide, and 1.2% nitrogen. It is worth noting that carbon dioxide and nitrogen were introduced into the well during completion attempts (Foster 1978).

In the Atokan (Derryan) interval of the Lewelling No. 1 several tests were conducted from 8,572 to 8,598 ft and a final test yielded 12 MCFPD.

Another zone tested in the Lewelling No. 1 is the Wolfcampian section from 5,140 to 5,170 ft, where a test gave 18 MCFPD.

In the Hodges Houston No. 1 (Sec. 23, T. 14 S., R. 10 E.) a test of a sandstone in the Missourian (Canyon) section from 2,433 to 2,444 ft yielded 16 MCFPD of 98% methane gas.

In an area like the Tularosa Basin, water analysis is critical. While little has been recorded on chemistry of the water recovered during Pennsylvanian tests, a test in the Houston Oil and Minerals No. 1 Federal "A" (Sec. 24, T. 14 S., R. 10 E.), which is near outcrops of Pennsylvanian rocks, gave water with a chlorine content of 35,000 ppm. On the other hand, chlorine content of the water from tests of the Texaco No. 1 Federal (USA) F (Sec. 30, T. 18 S., R. 10 E.) and the No. 1 Federal (USA) G (Sec. 33, T. 18 S., R. 8 E.) was relatively low, indicating the introduction of fresh water. The tests reported from the Pennsylvanian of the Texaco wells are interpreted to be from the Canyon? (Missourian) and the Strawn (Desmoinesian) sections (Foster, 1978).

An exhaustive list of the oil and gas shows noted throughout the Tularosa Basin is given in Foster (1978). The testing of pre-Pennsylvanian rocks has not been very extensive or successful. There have been some oil and gas shows, but a great problem is that many of the potential reservoirs have been flushed by fresh water along the eastern edge of the basin. However, there have been many tests in which salt water has been recovered as well. For example, some tests of Mississippian formations and the Fusselman, Montoya, and El Paso Formations have produced salt water. It should be further noted that there is little data on the chemical content of water from the deeper formations of the central Tularosa Basin, but it is very salty where it has been tested (McLean, 1975).

The Pennsylvanian and Permian certainly are prime objectives of any search for hydrocarbons. In addition to the impressive test data from the Houston Oil and Minerals Lewelling No. 1 and Hodges Houston No. 1, there have been other indications of hydrocarbons in this part of the stratigraphic section (Foster, 1978).

Mesozoic rocks have not shown much promise of hydrocarbons. Foster (1978) mentions a couple of shows in Mesozoic rocks.

In summary, despite flushing of some reservoirs, the stratigraphic section of the Tularosa Basin is favorable for oil and gas exploration because source beds and reservoir beds are abundantly present. Stratigraphic traps of the depositional-pinchout types and reefs (Otte, 1959; Wilson, 1967, 1974; Toomey et al., 1977) should be present. Unconformity traps as well as anticlinal and fault traps are indicated. Seismic exploration will be necessary in areas not yet shot, e.g., the White Sands Missile Range, to delineate many of the traps.

Otero platform

Black (1975) compiled a list of oil and gas shows in this area. While there have been many hydrocarbon shows and numerous drill-stem tests, none have been really significant as far as indicating production possibilities. The Fusselman Formation of Silurian age and the Permian units, chiefly the Abo Formation, have had the greatest number of shows.

Analogies have been drawn between the pre-Permian hydrocarbon production of the Central Basin platform in the Permian Basin and the production potential of pre-Permian rocks on the the west and east flanks of the Pedernal uplift (Black, 1975). Black believes that the Permian section can act as a seal at the unconformity with the pre-Permian section and cites Central Basin platform fields as examples. He stresses the importance of pre-Permian structures of the Central Basin platform and the fact that they trap hydrocarbons from source rocks such as the lower Paleozoic Simpson and Woodford Formations and probably from Mississippian and Pennsylvanian formations. Black believes the lower Paleozoic rocks of the Orogrande Basin to constitute a similar source-rock potential from which hydrocarbons may migrate to traps along the flanks of the buried Pedernal uplift.

Black (1975) prepared a paleoreconstruction of a section from the northwest shelf of the Delaware Basin westward across the Huapache monocline, the Pedernal uplift, and onto the east flank of the Orogrande Basin to show the relationship of the pre-Permian Paleozoic section to the deeper oil-generating areas to the west and east of the buried Pedernal uplift. It is asserted that the potential for hydrocarbon migration from the Delaware and Orogrande Basins exists.

The Central Basin platform was buried by effective source and sealing beds. By contrast, following uplift and truncation of the Otero platform, the Hueco Formation was deposited and the Hueco in this area is apparently not an effective source or seal.

If it is true that source beds on the Otero platform itself are not abundant, then a potential source of hydrocarbons would very likely have to be in the Delaware and/or Orogrande Basins. Black (1975) discusses this possibility.

Hills (1984) notes three chief time intervals of hydrocarbon generation in the Delaware Basin: (1) Middle Ordovician, later Devonian, and Mississippian; (2) Middle Pennsylvanian; and (3) Early and middle Permian. Importantly, he attributes the effective seal of the hydrocarbons to the deposition of thick evaporite strata during the Late Permian, which preserved the hydrocarbons and facilitated their migration to porous carbonate reservoirs in the surrounding shelves. The Otero platform has no such effective evaporite seals.

Plio-Pleistocene uplift and erosion of the Guadalupe and Brokeoff Mountains exposed the Permian section as low as the Abo Formation and hydrodynamic flushing of many of the reservoirs of the Permian section occurred. It is possible that the lesser inflow of water west of the Guadalupe—Brokeoff Mountains may have allowed oil and gas to accumulate on the east flank of the Pedernal uplift. This possibility is particularly true in the pre-Permian rocks, where the buried Pedernal uplift could act as a barrier to hydrodynamic inflow from the exposed Paleozoic section in the Sacramento Mountains (Black, 1975).

In contrast, the accumulations of oil and gas in the

Delaware Basin have been largely undisturbed since the mild tectonic activity at the end of the Permian, being practically unaffected by the Laramide and subsequent deformation (Hills, 1984).

The Abo Formation reef trend, which is oil-productive in Eddy and Lea Counties to the east, probably trends across the Guadalupe and Brokeoff Mountains to the northern Salt Basin graben. Although the Abo reef has not been identified in wells in the Salt Basin graben, the reef trend is defined in wells drilled to the east in Eddy County, and both back-reef and basin facies have been encountered in wells drilled in the graben area.

In summary, the comparative lack of source and sealing beds and the influx of fresh water combine to diminish the chances of the Otero platform being an oil and gas province.

Salt Basin graben

While it appears that source, reservoir, and sealing beds are present in the Salt Basin graben, no hydrocarbons have been produced in either the New Mexico or Texas portions of the graben. Numerous drill-stem tests have been conducted and far too many indicate fresh-water flushing of the reservoirs.

The drill-stem test of the Hunt Petroleum Corporation C. L. Ranch No. 1 well recovered fresh-watercut mud (FWCM) in a test of the Permian Hueco Formation from an approximate interval of 3,825-3,903 ft. The Border Exploration Company CT-1 Hammack et al. yielded fresh water in three tests from the Pennsylvanian at test intervals of 7,040-7,596, 6,380-7,040, and 6,400-6,450 ft. These are but examples of many fresh-water tests.

The Salt Basin graben resulted from Basin and Range deformation. Goetz (1980) provides evidence that Quaternary (Holocene?) faulting is abundant in the area.

The severe structural deformation of the region appears to have allowed massive fresh-water flow into the reservoirs; consequently, the potential for hydrocarbons in the province appears to be less promising than had been hoped in the 1970's.

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Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, µm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

**Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

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Contents of Pocket


E
West
E'
East
SEABOARD OIL
NO.1 FEDERAL TRIGG
18-26S-11E
TRANSOCEAN NO. 1. ABLAH
15-25S-13E
HUNT
McMILLAN-TURNER
5-26S-16E
TURNER NO.1 STATE
36-25S-16E
PENNZOIL
NO.1 SOUTHLAND STATE "28"
28-25S-17E
CAMPBELL NO 1. SPIEGEL
14-26S-20E
YESO
ABO
HUECO
TOP ABO
SAN ANDRES
(?)
HUECO (?)
EL PASO
POWWOW
PENN.
PERCHA
MISS.
FUSSELMAN
MONTOYA
BLISS
PENN.
FLEXURE IN FAULT AT 2100' IS OFFSET FOR SPACE REASONS ONLY - SEE REPORT TEXT
IN FUSSELMAN AT TD
IN PC AT TD
IN PC AT TD
IN FUSSELMAN AT TD
IN PENN(?) AT TD
TD 5597
TD 5308
TD 5195
TD 2970
TD 4560
1000
2000
3000
4000
5000
SEA LEVEL
A
North
A'
South
STANDARD OF TEXAS
NO.1 HEARD
33-6S-9E
Schlumberger
GAMMA RAY
TEXACO FEDERAL (USA) E NO. 1
10-18S-8E
PLYMOUTH OIL
FEDERAL NO.1 D
15-20S-9E
SEE Fig. 21 FOR UNITS IN THIS INTERVAL
ALLUVIUM
SAN ANDRES
SAN ANDRES (?)
YESO
TOP ABO
ABO
WOLFCAMP
UPPER PENN.
DES MOINES
ATOKA
ATOKA - MORROW
MISS.
PERCHA
FUSSELMAN
MONTOYA
EL PASO
BLISS
IN PC AT TD
TD 6048
6000
IN BLISS AT TD
IN EL PASO AT TD
A-A' MODIFIED FROM WORK BY BEN DONEGAN
GRAPHIC LOG SYMBOL LEGEND
SEDIMENTARY ROCKS
— D. (Dolomite)
— No Samples
— L. (Limestone)
— A. (Anhydrite)
— Gy. (Gypsum)
— Salt
— bk. Sh. (black Shale)
— Sh. (Shale other than r or bk; i.e. g=gray, gn=green, etc.)
— r. Sh. (red Shale)
— Ss. or St. (Sandstone or Siltstone)
— r. Ss. or St. (red Sandstone or Siltstone)
— Cg. (Conglomerate, pebbles mostly of sedimentary rocks and minerals)
— Bre. (Breccia, fragments mostly of sedimentary rocks and minerals)
— Ig. or Mc. Cg. or Bre. (Igneous or metamorphic Cg. or Bre., pebbles or fragments mostly of Ig. or Mc. rocks and minerals; includes Granite Wash and Arkose)
— Coal
— C. (Chert)
IGNEOUS ROCKS
— Phanerites, acid: granite, syenite, monzonite, etc.
— Phanerites, basic: diorite, gabbro pyroxenite
— Aphanites, acid: rhyolite, trachyte, latite, felsite
— Aphanites, basic: dacite, andesite, basalt
METAMORPHIC ROCKS
— Foliates: slate, schist, gneiss, etc.
— Non-foliates: quartzite, marble, hornfels, serpentine, etc.
ROCK TYPE MODIFIERS
— Limy or Calcitic
— Cherty or Siliceous
— Sandy or Silty

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CIRCULAR 198 FIGURE 21 (B-B' & C-C')

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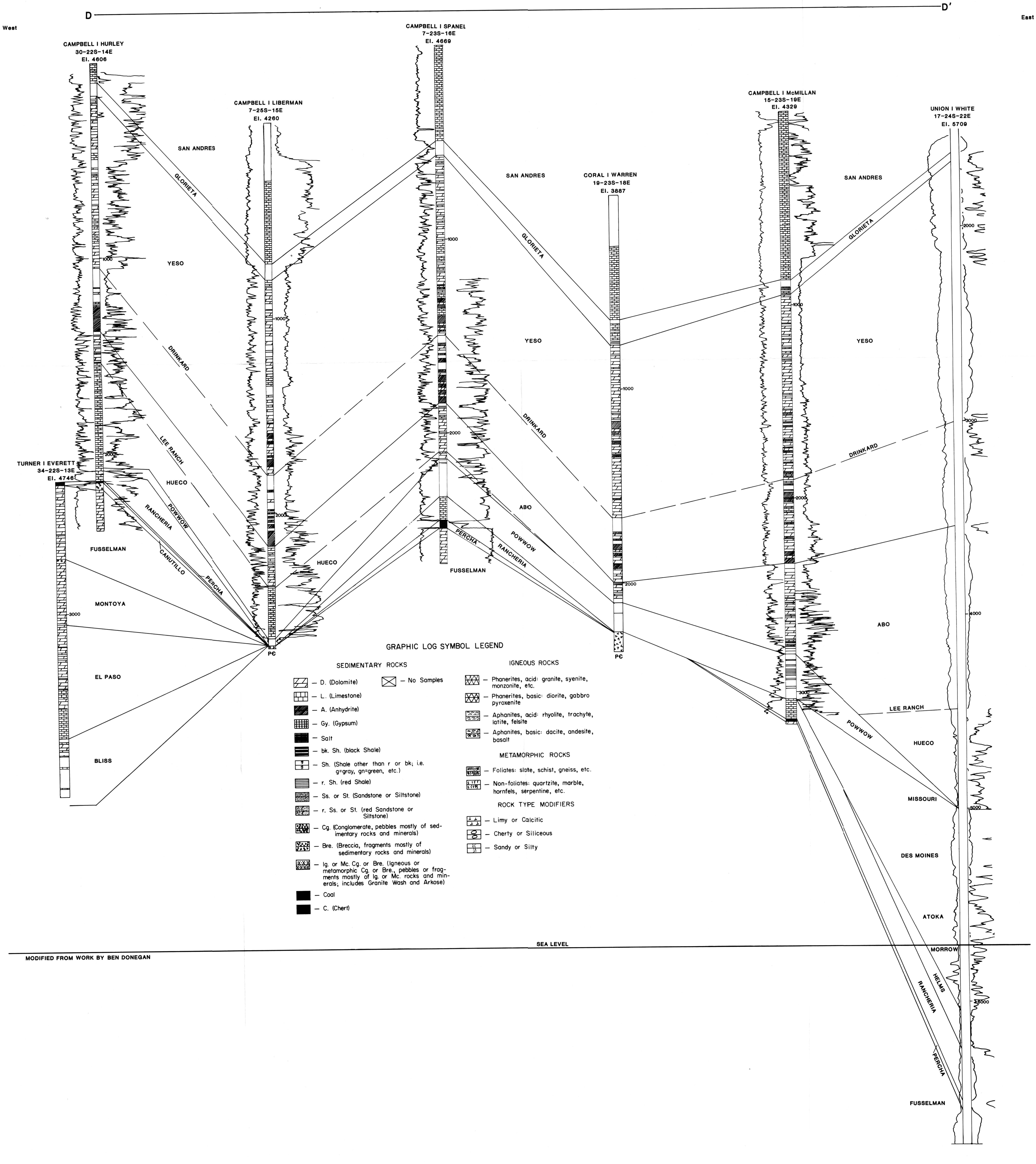
CIRCULAR 198 FIGURE 22 (D-D')



MODIFIED FROM WORK BY BEN DONEGAN


G
North
G'
South
DUNIGAN ALPHA FEDERAL NO. 1
31-25S-19E
OTERO CO., NEW MEXICO
HUNT C.L. RANCH NO. 1-5
5, BLK 67, TI, T&P SURVEY
HUDSPETH CO., TEXAS
HUNT C.L. RANCH No. 1
44, BLK 67, TI, T&P SURVEY
HUDSPETH CO., TEXAS
BORDER HAMMACK ET AL NO. 1
20, BLK 126, PSL
HUDSPETH CO., TEXAS
BORDER McADOO 7 NO. 1
7, BLK 119, PSL
HUDSPETH CO., TEXAS
ALLUVIUM
SAN ANDRES
YESO
ABO
POWWOW
BARNETT
MISS. LS.
WOODFORD
FUSSELMAN
ALLUVIUM
SAN ANDRES
YESO
ABO
?
?
ALLUVIUM
YESO
SAN ANDRES
ABO
HUECO
STRAWN
ATOKA
MORROW
BARNETT
CANUTILLO
FUSSELMAN
ALLUVIUM
GOAT SEEP
CHERRY CANYON
YESO
ABO
WOLFCAMP
CISCO-CANYON
STRAWN
ATOKA
MORROW
BARNETT
CANUTILLO
FUSSELMAN
CAPITAN LS.
CHERRY CANYON
BONE SPRINGS
WOLFCAMP
CISCO
CANYON
STRAWN
ATOKA
MORROW
BARNETT
MISS. LS.
WOODFORD
CANUTILLO
FUSSELMAN
SEA LEVEL
1000
2000
3000
4000
5000
6000
7000
F
West
F'
East
HODGES HOUSTON NO. 1
23-14S-10E
OTERO CO., NEW MEXICO
HOUSTON OIL FEDERAL "A" NO. 1
24-14S-10E
OTERO CO., NEW MEXICO
ABO
LABORCITA
HOLDER
BEEMAN
GOBBLER
(BUG SCUFFLE)
SEA LEVEL
GRAPHIC LOG SYMBOL LEGEND
SEDIMENTARY ROCKS
— D. (Dolomite)
— No Samples
— L. (Limestone)
— A. (Anhydrite)
— Gy. (Gypsum)
— Salt
— bk. Sh. (black Shale)
— Sh. (Shale other than r or bk; i.e. g=gray, gn=green, etc.)
— r. Sh. (red Shale)
— Ss. or St. (Sandstone or Siltstone)
— r. Ss. or St. (red Sandstone or Siltstone)
— Cg. (Conglomerate, pebbles mostly of sedimentary rocks and minerals)
— Bre. (Breccia, fragments mostly of sedimentary rocks and minerals)
— Ig. or Mc. Cg. or Bre. (Igneous or metamorphic Cg. or Bre., pebbles or fragments mostly of Ig. or Mc. rocks and minerals; includes Granite Wash and Arkose)
— Coal
— C. (Chert)
IGNEOUS ROCKS
— Phanerites, acid: granite, syenite, monzonite, etc.
— Phanerites, basic: diorite, gabbro pyroxenite
— Aphanites, acid: rhyolite, trachyte, latite, felsite
— Aphanites, basic: dacite, andesite, basalt
METAMORPHIC ROCKS
— Foliates: slate, schist, gneiss, etc.
— Non-foliates: quartzite, marble, hornfels, serpentine, etc.
ROCK TYPE MODIFIERS
— Limy or Calcitic
— Cherty or Siliceous
— Sandy or Silty


H
West
H'
East
GUADALUPE PEAK
CAPITAN
Generalized surface topography
GOAT SEEP
VICTORIA PEAK
CHERRY CANYON
BRUSHY CANYON
BONE SPRINGS
PURE OIL COMPANY
HUNTER NO. 1
34, BLK 66, T-1, T & P SURVEY
CULBERSON CO., TEXAS
TEXACO INC.
CULBERSON "L" FEE NO. 1
45, BLK 65, T-1, T & P SURVEY
CULBERSON CO., TEXAS
HUNT OIL CO.
NO. 1 DYER
31, BLK 68, T21, T & P SURVEY
HUDSPETH CO., TEXAS
HUNT PETROLEUM CORP.
C.L. RANCH NO. 1
44, BLK 67, T-1, T & P SURVEY
HUDSPETH CO., TEXAS
ALLUVIUM
YESO
FUSSELMAN
GOAT SEEP
CHERRY CANYON
ABO
HUECO
STRAWN
ATOKA
MORROW
BARNETT
CANUTILLO
POWWOW
CISCO
CANYON
MISS. LS.
WOODFORD
MONTOYA
SIMPSON
ELLENBERGER
WOLFCAMP
SEA LEVEL
1000
2000
3000
4000
5000
6000
7000
8000
GRAPHIC LOG SYMBOL LEGEND
SEDIMENTARY ROCKS
— D. (Dolomite)
— L. (Limestone)
— A. (Anhydrite)
— Gy. (Gypsum)
— Salt
— bk. Sh. (black Shale)
— Sh. (Shale other than r or bk; i.e. g=gray, gn=green, etc.)
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— Ig. or Mc. Cg. or Bre. (Igneous or metamorphic Cg. or Bre., pebbles or fragments mostly of Ig. or Mc. rocks and minerals; includes Granite Wash and Arkose)
— Coal
— C. (Chert)
— No Samples
IGNEOUS ROCKS
— Phanerites, acid: granite, syenite, monzonite, etc.
— Phanerites, basic: diorite, gabbro pyroxenite
— Aphanites, acid: rhyolite, trachyte, latite, felsite
— Aphanites, basic: dacite, andesite, basalt
METAMORPHIC ROCKS
— Foliates: slate, schist, gneiss, etc.
— Non-foliates: quartzite, marble, hornfels, serpentine, etc.
ROCK TYPE MODIFIERS
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