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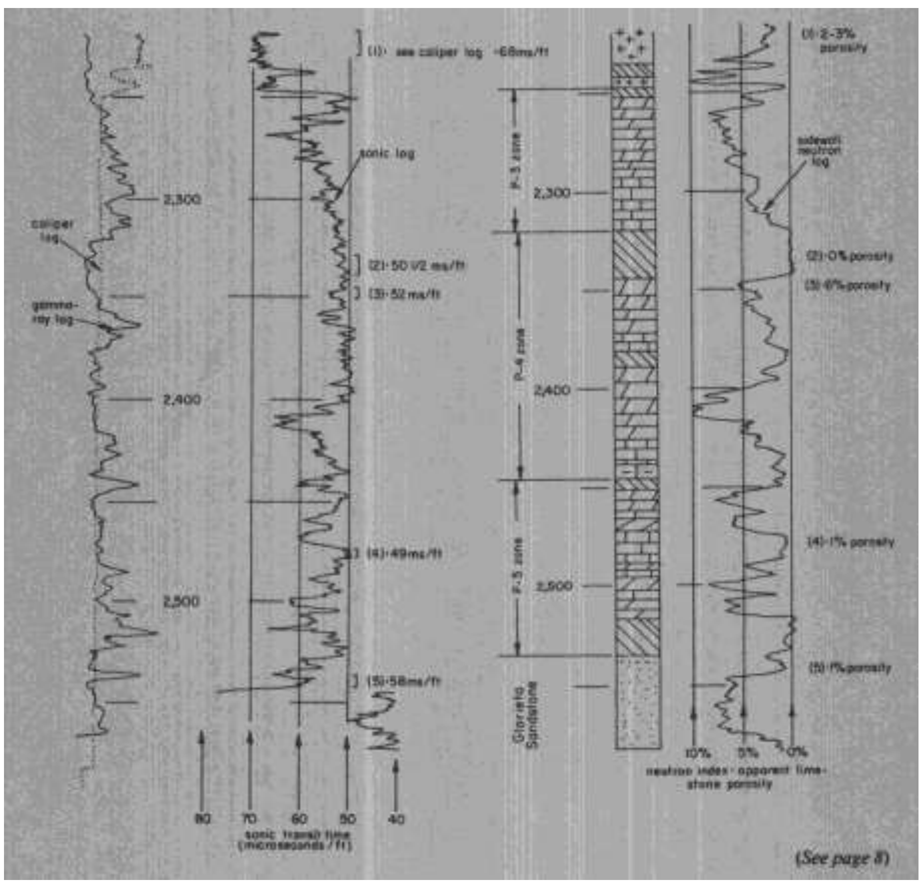
Porosity zones of lower part of San Andres Formation, east-central New Mexico

by
William D. Pitt
and
George L. Scott



(See page 8)

New Mexico Bureau of Mines & Mineral Resources

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Preface

This report is concerned with the lithologic variations within the lower part of the San Andres Formation in east-central New Mexico and the relationships of these variations to the potential occurrence of oil and gas. The genesis and spatial relationships of dolomite are emphasized because dolomite is the dominant reservoir rock for oil in the lower San Andres.

ACKNOWLEDGMENTS—It is a pleasure to cite all the geologists who have been helpful to the writers of this report. They include Walter V. Boyle of the Shell Oil Company, who furnished useful core analyses and descriptions; Edward Matchus of the Union Oil Company of California; W. E. Murrah of Exxon Corporation and his associates; W. J. Stewart of Texaco, Incorporated; and geologists housed in the Petroleum Building of Roswell, New Mexico, who have helped by contributing to many stimulating discussions. Financial support provided by the New Mexico Energy Institute at the New Mexico Institute of Mining and Technology is appreciated.

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Portales, New Mexico, and
Roswell, New Mexico
December 1979

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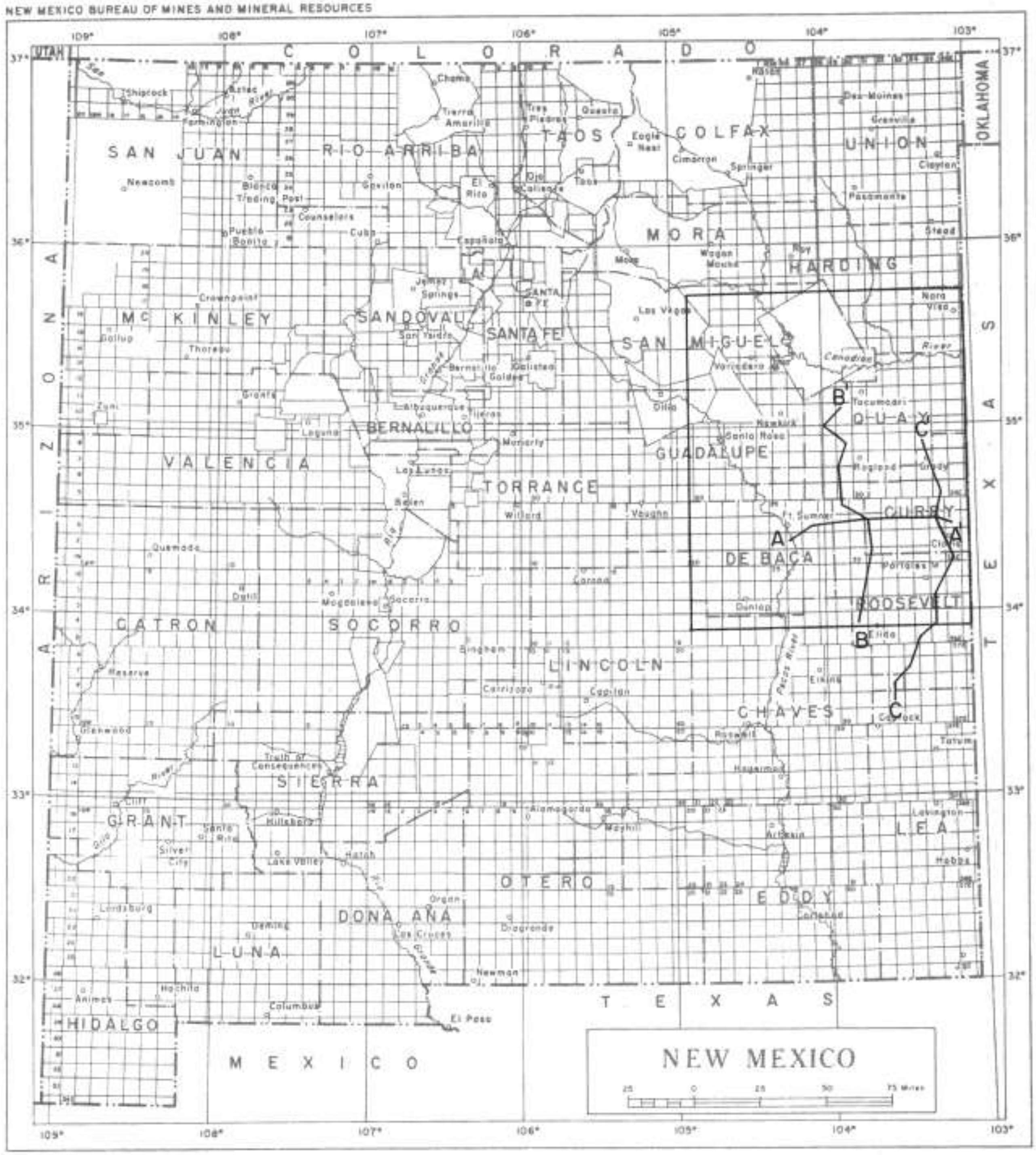

FIGURE 1—INDEX MAP SHOWING LOCATION OF STUDY AREA.

Abstract

The lower part of the San Andres Formation in east-central New Mexico consists of three cyclical zones, commonly known as the P-3, P-4, and P-5 porosity zones. Each of these typically consists of a thin, widespread evaporite at the top, carbonate rocks in the middle, and a thin, shaly carbonate-rock zone at the base. Locally, halite may replace anhydrite. Most of each zone consists of carbonate rocks, and dolomite normally underlies the upper anhydrite and may be more than one hundred feet thick. The dolomite may contain one or more layers of anhydrite and in most places is underlain by limestone. Lithofacies studies of the lower San Andres indicate that where the carbonate rock consists entirely of dolomite, an above-average amount of evaporites is present. Lithofacies studies also indicate that porosity trends are mappable and such studies help to determine favorable areas for petroleum exploration. The lower San Andres of east-central New Mexico was deposited along a north- to northeast-trending coastal area that prograded southward and eastward, except during the deeper-water beginning of each cycle, when shale or limestone normally was deposited. The northern and western limit of traceable San Andres zones appears to be a gradational facies boundary where the San Andres becomes more evaporitic. Porosity in the older P-4 and P-5 zones persists farther north than in the P-1, P-2, and P-3 zones, demonstrating the general southward shift of facies with time.

Introduction

Purpose of report

This report presents a detailed lithologic analysis of the lower part of the San Andres Formation (Permian), located on the northwest shelf of the Permian Basin. Included are lithofacies, isopach, structure, and porosity maps and three regional cross sections. The San Andres Formation for many years has been a primary objective in the search for oil and gas in eastern New Mexico and in west Texas (fig. 1). Thus, this report should prove useful in planning future petroleum exploration programs for the San Andres Formation in east-central New Mexico.

Methods of study

The lithologies of the lower San Andres in individual wells were determined by examining samples and cores, by reviewing sample logs and core descriptions made by other geologists, and by interpreting geophysical well logs. The net thickness of each rock type is tabulated in table 1 (pocket). From this table lithofacies maps were compiled for each of the three porosity zones, the P-3, P-4, and P-5 zones. Cross sections also were prepared.

Most of the lithologies were determined by crossplotting, a log-interpretation technique using parameters from sonic, neutron, and density logs. An example of crossplotting is shown on fig. 2, in a lithologic-determination chart published by Schlumberger Corporation. This crossplot chart and similar ones published by other well-service companies present fairly accurate determinations of lithology. Fig. 3 shows the cross plots we made. We determined the lithologic sequence in some wells by analyzing well samples and old SP (self potential)-resistivity logs.

Core descriptions and analyses furnished by Shell Oil and Texaco were used where available. Correlation with logs from nearby wells was used to aid determination of the lithologic sequence in some cases. In all, 107 wells were analyzed; data collected from these tests represent the control points of the maps that accompany this report.

Five maps were constructed for each of the three zones of the lower San Andres showing: 1) the percentage of dolomite determined by the ratio of net thickness of dolomite over the total thickness of carbonate rocks

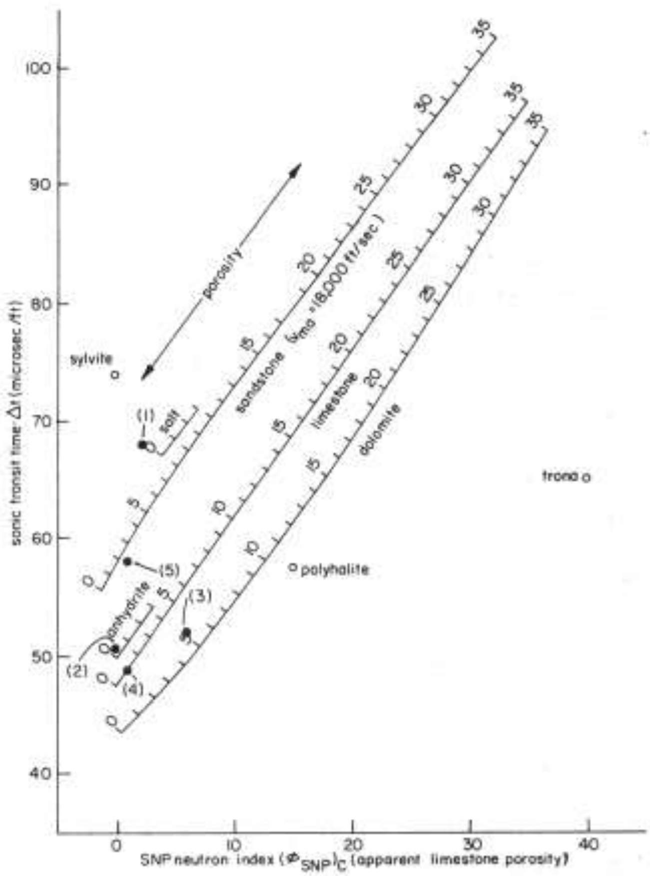

FIGURE 2—LITHOLOGIC DETERMINATION CROSS-PLOT CHART.

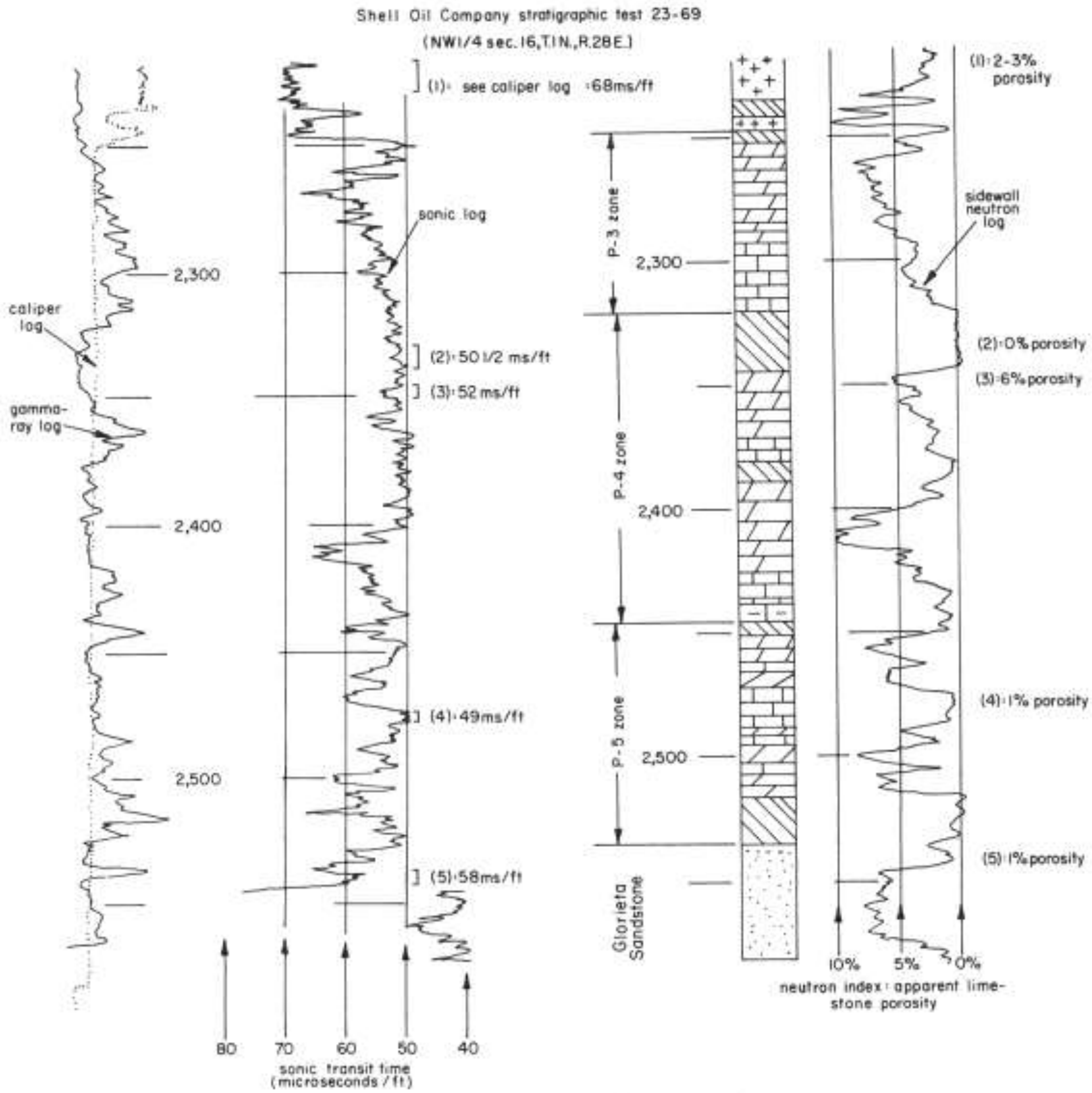

FIGURE 3—Lower San Andres Formation log intervals, showing intervals of cross-plot lithologic determinations.

in the individual zone; 2) the total thickness of evaporites (excluding dolomite); 3) the percentage of salt determined by the ratio of net thickness of salt to the total thickness of evaporites in the individual zone (a separate map was prepared only for the P-3 zone—for the P-4 and P-5 zones the percentage of salt in selected wells is shown on the evaporite thickness maps); 4) porosity maps showing the total net thickness of intervals with porosity greater than 10 percent; and 5) structural contour maps (one on the top of the dolomite in the P-3 zone and the other on the top of the Pi marker zone).

Location and regional geology

The rectangular-shaped study area shown in fig. 1 extends from T. 3 N. to T. 18 N., and from R. 19 E. to R. 36 or 37 E. at the Texas border. Included are all or parts of Quay, Roosevelt, Curry, Chaves, Guadalupe, DeBaca, San Miguel, and Harding Counties in east-central New Mexico. The area lies in the Great Plains province, a region characterized by flat to gently rolling terrain that is locally capped by mesas and buttes. Exposed rocks, from Permian to Recent in age, belong to the Triassic, Jurassic, and Cretaceous Systems. Both Triassic and Cretaceous rocks crop out over many square miles in the study area, in contrast to the Jurassic rocks which occur only in narrow belts along the edges of mesas and buttes. Cretaceous rocks are mostly marine deposits and tend to be gray in color, in contrast to the more brightly colored continental deposits of the Triassic and Jurassic.

Many oil tests have been drilled in this part of New Mexico. Although all the wells have been dry holes, they have provided considerable stratigraphic information. Currently, wells are being logged in great detail; seven recent tests have been cored through all or part of the lower part of the San Andres (Permian). With a thorough synthesis and analysis of this information, several oil and gas fields may be discovered.

Table 1 tabulates most of the data collected and utilized in constructing the maps that accompany this report.

Stratigraphy

Lithologic characteristics

Characteristics at type locality

The type locality of the San Andres Formation is in the western part of the San Andres Mountains of south-central New Mexico. In this locality the San Andres is described as consisting of a basal yellowish sandstone 32 ft thick, and a gray, medium-bedded to massive, fetid and fossiliferous limestone. At the type locality the interval is 578 ft thick (Gratton and LeMay, 1969). Kottlowski and others (1956) write that the San Andres at its type locality "appears to be merely the older, lower half of the thicker subsurface San Andres of southeastern New Mexico."

Subsurface characteristics in study area

The general log characteristics and lithology of the San Andres Formation in the subsurface are shown on fig. 4. The formation, about 1,150 ft thick, is overlain by clastic and evaporitic beds of the Artesia Group and is underlain by the clastic and evaporitic beds of the Yeso Formation. The upper part of the San Andres Formation in the report area consists mainly of anhydrite and salt.

Approximately 400 ft from the top of the San Andres is a siltstone bed, 5-10 ft thick, which is informally referred to by petroleum geologists as the "Pi marker" (fig. 4). This bed is remarkably persistent throughout the subsurface of east-central New Mexico and as such has considerable utility in log correlations.

Kelley (1971) has mapped the San Andres Formation on the surface in the area to the south. He named the uppermost part of the San Andres Formation the Fourmile Draw Member and referred to it as "the evaporitic part of the San Andres." This member generally seems to correspond in the subsurface to that part of the San Andres above the P-1 zone. Kelley's next lower unit, the Bonney Canyon Member, is roughly equivalent to the P-1 and P-2 zones. He designated the lower part of the outcropping San Andres Formation as the Rio Bonito Member. His Rio Bonito is generally correlative with that part of the San Andres between the P-3 and the top of the Glorieta Member of the San Andres Formation. The Glorieta Sandstone Member occurs at the base of the San Andres over most of the report area. This sandstone unit varies in thickness from a few feet in the southeast to over 450 ft in the northwest part of the report area (Milner, 1978).

The term "slaughter zone," which for many years has been applied to the oil-producing dolomite in the lower part of the San Andres Formation, originated from the reservoir unit in the large Slaughter and Levelland fields of west Texas. The slaughter zone is generally correlative with the P-1 and P-2 zones of the report.

Facies relationships

Regional

Facies changes are common throughout the San Andres Formation in both the outcrop and subsurface of east-central New Mexico. The lower part of the San Andres Formation can be divided into four facies in the outcrop belt: 1) a limestone facies in the northern and central San Andres Mountains; 2) a limestone-sandstone facies, west of the San Andres Mountains; 3) an

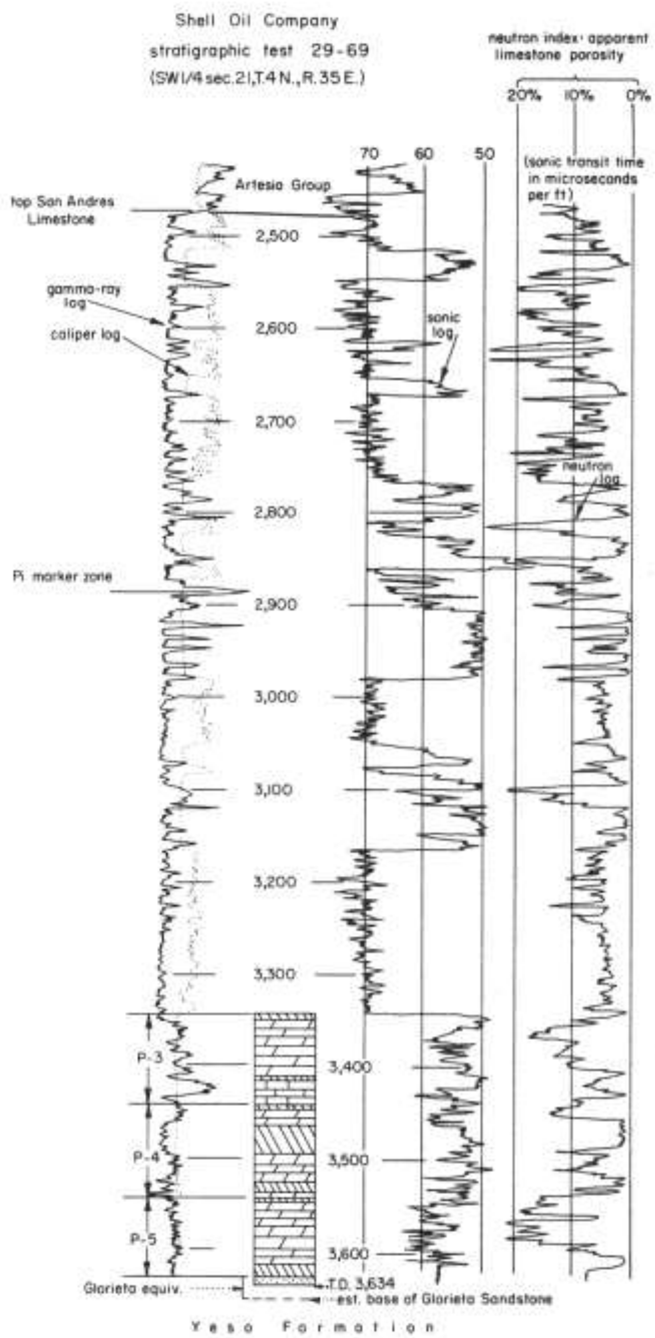

FIGURE 4—Typical log of San Andres Formation of east-central New Mexico.

extensive evaporite facies that extends eastward and northward from Socorro; and 4) an arenaceous facies in both outcrop and subsurface along the Sierra Grande arch near Las Vegas and Roy, New Mexico (Jacka and Franco, 1975). These facies changes along the Delaware Basin margin have been discussed by King (1946), Boyd (1958), and Tait and others (1962). Foster and others (1972) summarized the subsurface geology of east-central New Mexico, suggesting that the San AndresGlorieta formations represent a shore-shelf environment showing a "marked facies change from dominant sandstone in the northwest (of east-central New Mexico) to carbonate and mixed carbonate evaporite to the east and south." The San Andres-Glorieta formations were described as having "quite remarkable" facies changes in east-central New Mexico which "deserve considerable detailed analysis."

Depositional cycles

As shown on fig. 5, the typical depositional cycle of the lower San Andres Formation consists of four lithologies that aggregate 40-150 ft in thickness. The lowermost unit, which represents the beginning of each cycle, consists either of a thin shale or shaly carbonate bed from 3 to 10 ft thick. The next higher unit consists of shaly, fossiliferous (largely crinoidal) limestone which ranges from 10 to 50 ft in thickness. In many wells, this unit contains several dolomite beds, and in some wells the unit is entirely dolomite. The third, or next higher, unit is dolomite, which in many places is porous. In a few wells, this unit is only slightly dolomitized and is predominantly limestone. The uppermost (or fourth) unit of the cycle is an evaporite. In the southern part of the report area the fourth unit is anhydrite; northward, the anhydrite typically changes to halite.

In the southern part of the report area, the P-3, P-4, and P-5 zones each contain this typical cyclical devel

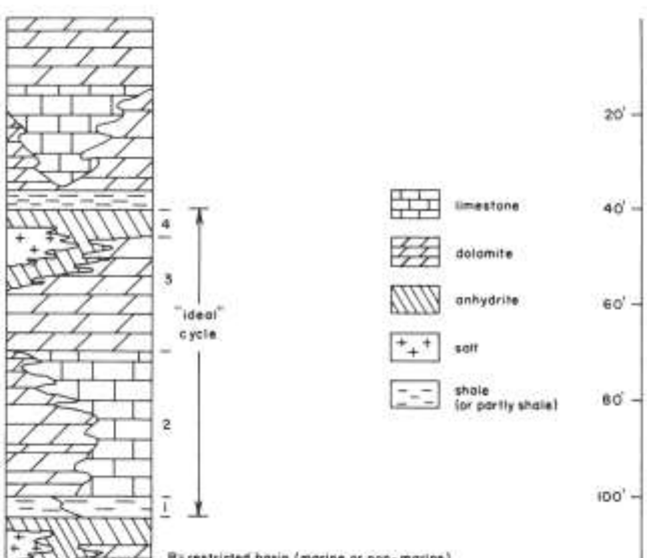

FIGURE 5—TYPICAL LITHOLOGIC SEQUENCE OF LOWER SAN ANDRES DEPOSITIONAL CYCLES.

opment. Northward, however, evaporite beds occur in carbonate beds near the middle of the cycle, creating subcycles similar to the typical overall cycle. These relationships are displayed on the cross section (in pocket).

P-1 AND P-2 ZONES—Gratton and LeMay (1969) subdivided the Slaughter dolomite of the San Andres Formation in southeast New Mexico into four carbonate-porosity zones, separated by anhydrite beds having "demonstrated capability of isolating production." These subdivisions generally conform to usage by most petroleum geologists, showing very little convergence among the several porosity zones and demonstrating a large amount of lithologic change both horizontally and vertically. This conclusion is confirmed by the writers of this report. Gratton and LeMay (1969) noted that the P-1 and P-2 zones both lose porosity as dolomite is replaced by anhydrite in a northward direction. North of the area studied by Gratton and LeMay, much anhydrite and salt are correlative with the P-1 and P-2 zones (cross sections *A-A'* and *C-C';* in pocket); clearly, the percentages of anhydrite and salt both increase northward in the P-1 and P-2 zones. This increase is shown on the cross sections of this report, as well as in the cross section of Gratton and LeMay (1969).

P-3 ZONE—As shown by fig. 6, the isopach of the P-3 zone, the P-3 zone ranges in thickness from 60 to 140 ft in the report area. Near the Pecos River in the northwest part of the area, near-surface evaporites of the San Andres are partly dissolved by ground water beneath and near the floodplain of the Pecos River. Probably for this reason, the P-3 zone, as well as the underlying P-4 and P-5 zones, is not traceable as far north near the Pecos River as it is east of the river valley. The zone thickens to the north and west near the west edge of the study area, as well as southward along the southern edge of the area.

The P-3 zone (and P-4 and P-5 zones as well) consists of an upper layer of anhydrite, underlain mostly by carbonate rocks. The total dolomite thickness of the P-3 zone ranges from less than 25 to more than 100 ft in east-central New Mexico, as shown on fig. 7. In the P-3 zone the carbonate rocks are mostly dolomite, except in the area that is directly east of Portales, New Mexico, where carbonates are predominantly limestone. The carbonates are almost entirely dolomite in the southwestern and western part of the study area. Elsewhere on fig. 7, the 100-percent-dolomite areas are found only in much smaller, local areas. Delineation of the dolomite-rich areas is important; statistically, they are more porous than areas containing a higher proportion of limestone.

The stratigraphic entrapment of hydrocarbons in the San Andres Formation of east-central New Mexico is dependent upon the porosity distribution, especially in the areas of updip porosity pinchouts. Fig. 8 shows the thickness of the P-3 zone having porosity of 10 percent or higher. The more porous areas shown on this map are mostly in central Roosevelt County. The highly porous areas occur in trends that extend eastward from DeBaca and Chaves Counties to Roosevelt and Curry Counties.

FIGURE 6—Isopach map of P-3 zone; contour interval equals 20 ft, depths of well measurements shown in feet.

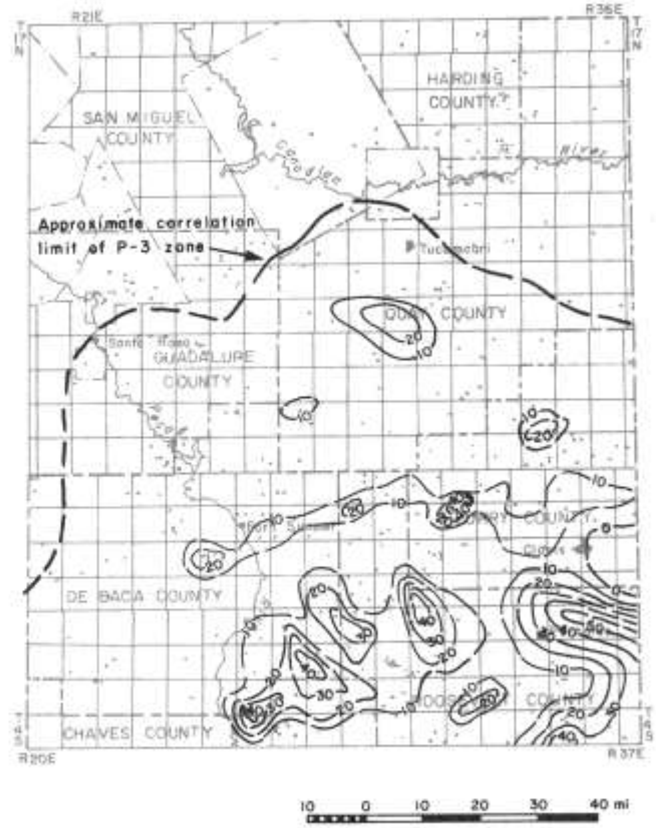

FIGURE 8—Thickness in feet of P-3 zone with 10+ percent porosity; contour interval equals 10 ft.

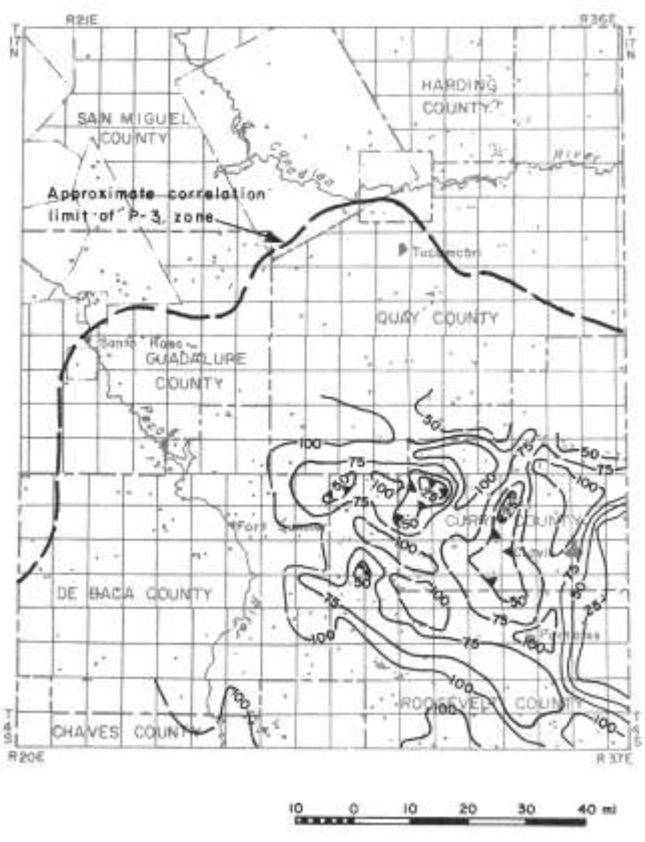

FIGURE 7—Percent of dolomite in P-3 zone; contour interval equals 25 percent.

FIGURE 9—Evaporite thickness of P-3 zone; contour interval equals 10 ft, percent of salt present shown by %.

FIGURE 10—Percent of salt within evaporites of P-3 zone; contour interval equals 25 percent.

FIGURE 12—Percent of dolomite in P-4 zone; contour interval equals 20 percent.

FIGURE 11—Isopach map of P-4 zone; contour interval equals 20 ft, depths of well measurements shown in feet.

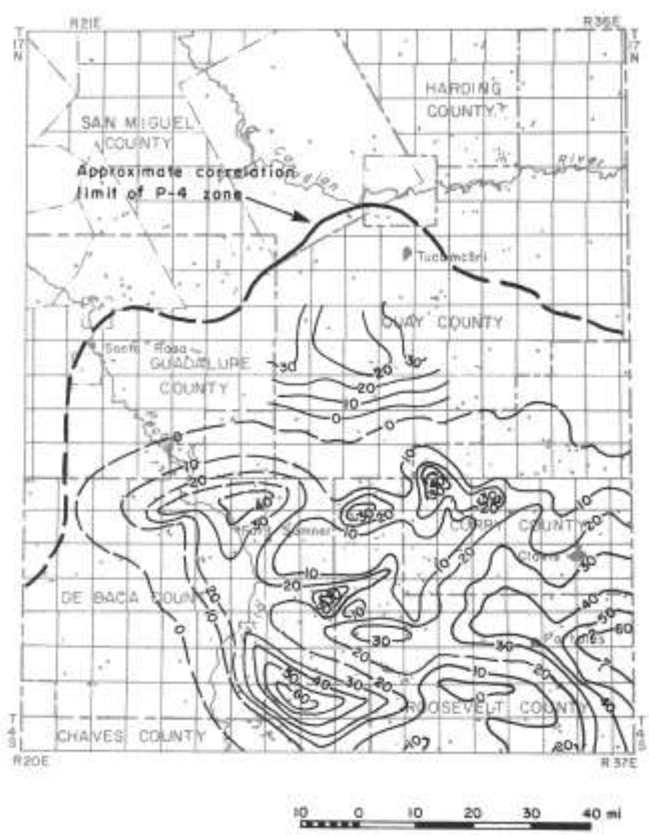

FIGURE 13—Thickness in feet of P-4 zone with 10+ percent porosity; contour interval equals 10 ft.

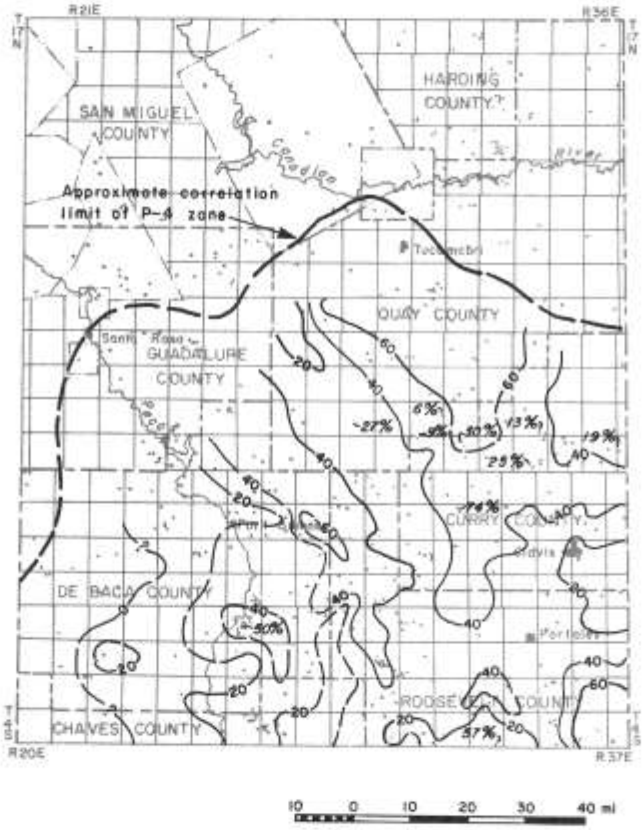

FIGURE 14—EVAPORITE THICKNESS OF P-4 ZONE; contour interval equals 20 ft, percent of salt present shown by %.

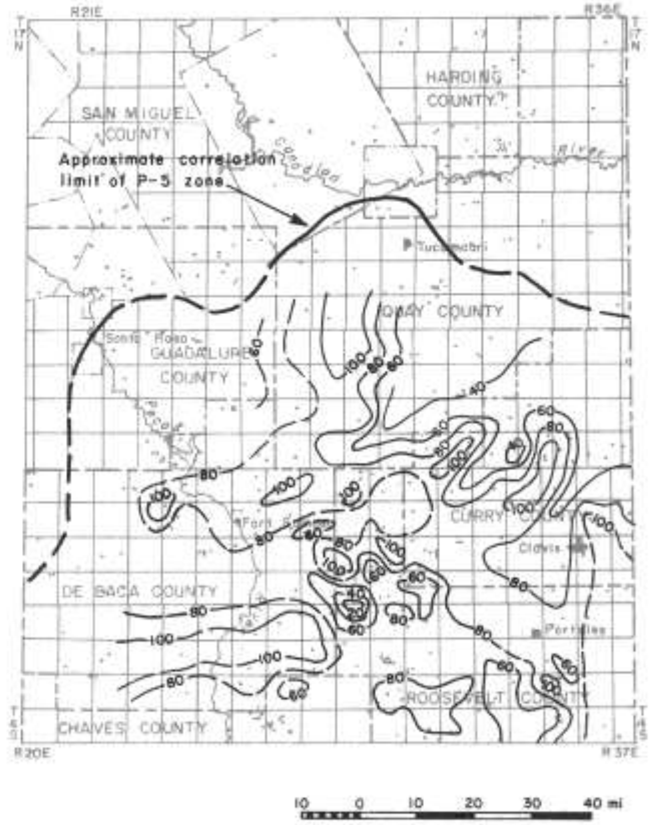

FIGURE 16—PERCENT OF DOLOMITE IN P-5 ZONE; contour interval equals 20 percent.

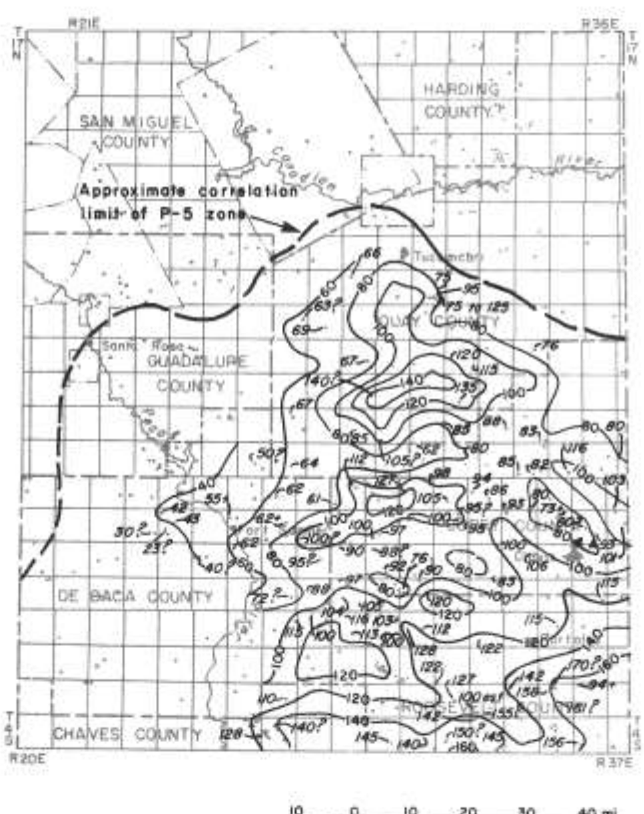

FIGURE 15—ISOPACH MAP OF P-5 ZONE; contour interval equals 20 ft, depths of well measurements shown in feet.

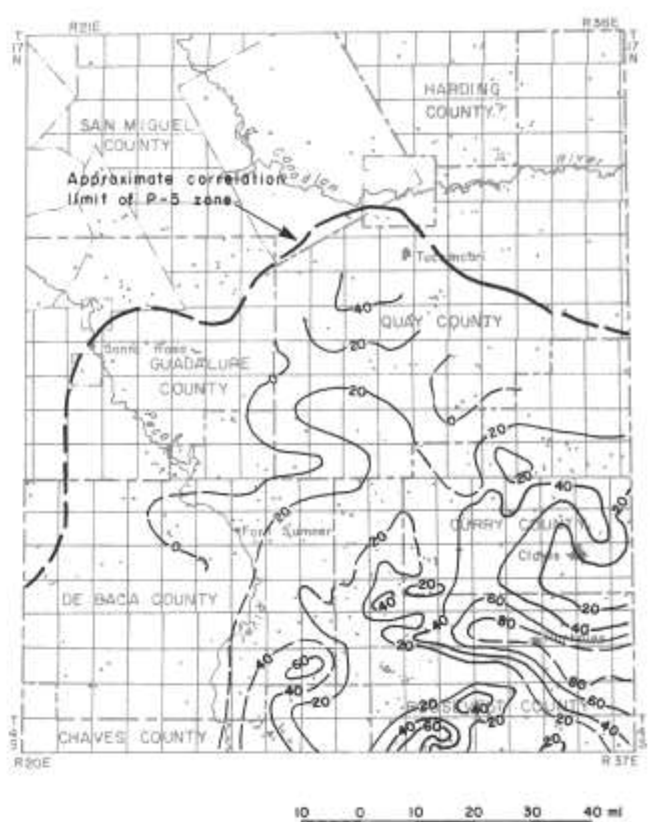

FIGURE 17—THICKNESS IN FEET OF P-5 ZONE WITH 10+ PERCENT POROSITY; contour interval equals 20 ft.

A map showing the thickness of the P-3 zone having 5 percent and higher porosity, rather than one with a 10 percent cutoff, may prove to be more useful in delineating updip pinchout porosity; such a map can be constructed using the 5 percent data tabulated in table 1.

Minor amounts of anhydrite and salt are found in the P-3 zone except in the north-central and western parts of the area, where the evaporites thicken. For example, in western Quay County evaporites are up to 130 ft thick (fig. 9). The evaporite sequence locally consists almost entirely of halite northeast of Clovis in Curry County. This halite-rich area also is a thinner-than-average area for evaporite thickness (figs. 9 and 10). The overall thickness of evaporites increases sharply northwestward from T. 6 N., in the central part of the map area, and the thickness of the evaporites in the P-3 zone seems to increase where the total P-3 zone is thicker. The percent of salt within the evaporites of the P-3 zone increases notably northwestward from Ft. Sumner, as does the thickness of the P-3 zone.

P-4 ZONE —The P-4 zone ranges in thickness from less than 80 to more than 140 ft southeast of Portales and in southern Quay County. The zone is traceable as a discrete unit only as far north as northern Quay County because key dolomite marker beds change to anhydrite and also because of local dissolution of evaporites by ground water. The P-4 zone thickens notably southwestward along the southwest part of the study area, and northeastward along the northeast border of the map area (fig. 11).

The dolomite of the P-4 zone ranges in thickness from 80 to 140 ft in the study area. The zone is less dolomitic in the southwestern part of the study area than is the P-3 zone (figs. 7 and 12), but it contains a high percentage of dolomite elsewhere in the study area, especially in northeast Roosevelt County, in western Quay County, and in central DeBaca County.

Areas of marked porosity in the P-4 zone occur in the Portales area and eastward, in northeast Chaves (and parts of adjacent counties), and along a trend extending eastward from Ft. Sumner to eastern Curry County (fig. 13). Porous zones also are found in central Quay County.

The total amount of evaporites in the P-4 zone ranges from less than 20 ft thick in southwest Roosevelt County and most of DeBaca County to over 60 ft in southeast Roosevelt County and in Quay County (fig. 14). A thick bed of anhydrite is developed in the middle of the P-4 zone in the northern half of the study area as shown on cross sections *B-B'* and *C-C'* (in pocket).

P-5 ZONE —The P-5 zone ranges in thickness from less than 40 ft west of Ft. Sumner and the Pecos River to over 160 ft southeast of Portales and in southern Quay County (fig. 15). The zone thins westward from eastern to western DeBaca County, and thickens southward in central Roosevelt County, along the southern edge of the study area.

Several dolomite trends are found in the study area with an east-to-west trend in southern DeBaca County; another extends eastward from the Pecos River near Ft. Sumner into central Curry County (fig. 16). Highly dolomitic areas with a north-to-south trend are found in western Quay County and in northeast Roosevelt County.

The only large areas containing markedly porous rock in the P-5 zone are in central and northeast Roosevelt County (fig. 17). Elsewhere, there are local areas that are quite porous, such as southwest of Tucumcari in Quay County. The evaporites of the P-5 zone, in contrast with those of the P-3, thin northwestward across DeBaca and Guadalupe Counties (fig. 18). The evaporites of the P-5 zone are thickest southeast of Portales and in a band extending westward from Portales.

Depositional environment

The calcareous sediments of the San Andres Formation were deposited in a warm, shallow sea. Belts of marine and other shallow-water depositional environments migrated southward, representing a progression of environments from marine waters below low tide, through tidal waters, and then into an environment of high salinity that was generally above high tide. More features of the supratidal environment (Lucia, 1972) are reflected in these sediments than in any of the others. This prograding of the shoreline southward was not a steady progression southward; rather, it was marked by oscillations of environments. Each of the five major depositional cycles represented by the P-1, P-2, P-3, P-4, and P-5 zones of the lower San Andres comprises a change from subtidal waters at the base of each cycle (where limestones were deposited) through intertidal and then supratidal waters wherein anhydrite and halite were deposited. During the initial deeper-water phase of each cycle, the shoreline must have migrated locally northward or northwestward as a transgressive pulse. Milner (1978) indicated that the Glorieta in east-central New Mexico was deposited along north- to northeast-trending coastlines and that these coastlines were dominated by eastward- and southward-prograding barrier-island complexes during the low sea-level stands. Sea-level rises brought westward and northwestward transgression and a reworking of regressive deposits. Similarly, Barone (1976) described the depositional environment of the lower San Andres of the northwest shelf as consisting of depositional cycles—each cycle representing an advance of a succession of environments. Barone divided each cycle into a lithologic sequence that he believed represented a sequence of depositional environments. More detailed work with cores and samples will be required to reconcile the depositional environments of Barone (1976) with the cyclic concept described in this report.

The lithologies within the lower San Andres were deposited within several distinct nearshore environments. These environments, in order of landward progression

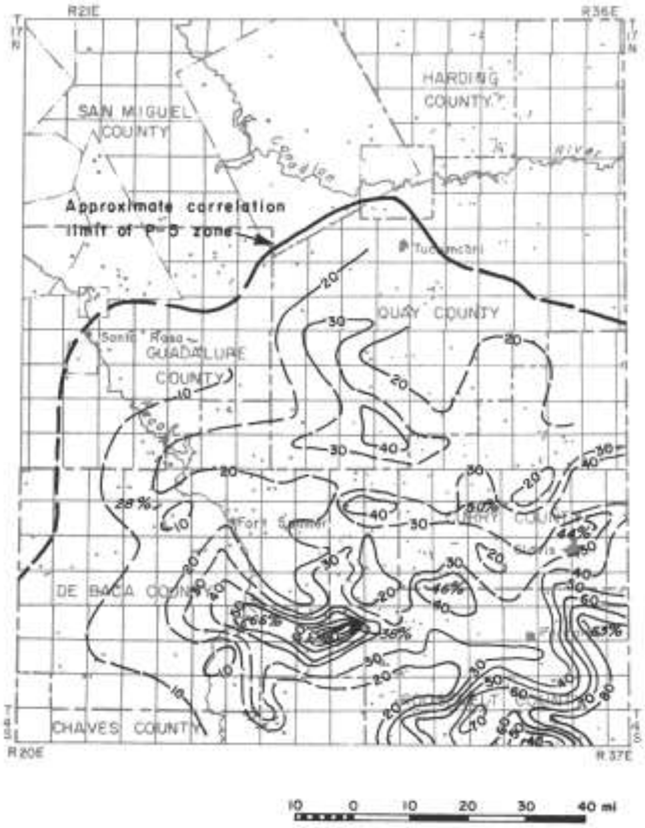

FIGURE 18—EVAPORITE THICKNESS OF P-5 ZONE; contour interval equals 10 ft, percent of salt present shown by %.

and increasing elevation, were: subtidal marine, intertidal, lagoonal, and supratidal-hypersaline. These environments formed a lateral, coexisting band of environments that migrated northward, then southward, repeatedly. Each cycle is a well-defined oscillation of these depositional environments; the beginning of each cycle represents a transgression and the end of each cycle represents regression (fig. 5). Throughout the time interval of the lower San Andres, these depositional environments migrated slowly southward. The north-to-south cross sections of fig. 19 (in pocket) illustrate the fact that the dolomite beds in P-4 and P-5 extend farther northward than those in the P-3 and P-2. These cross sections show that most of the lower San Andres changes lithologically from carbonate rocks in the south to mostly anhydrite and salt in the northern part of the study area. The upper part of the P-1 zone, for example, changes from anhydrite and dolomite to mainly salt in cross section *C-C*'. Similarly, the P-2 zone becomes anhydrite and salt north of T. 1 S. in *C-C'*

The southward migration of salt-depositing basins within the lower San Andres also supports the concept that San Andres depositional environments as a whole migrated southward. The southern wedge margin of halite in the P-5 zone, the oldest zone of the lower San Andres, is seen between T. 5 N. and T. 8 N. on cross section *C-C*'; that of the P-3 zone is found between T. 5 S. and T. 4 S.; the P-2 zone, between T. 3 S. and T. 1 N.; and the P-1 zone, the youngest zone, between T. 7 S. and T. 5 S.

Origin of dolomite

We believe that the dolomite of the lower San Andres in east-central New Mexico was formed secondarily in close association with aragonite soon after deposition. As we constructed the three cross sections that accompany this report, we assumed that locally dolomite grades laterally into limestone. This lateral gradation as well as the general stratigraphic position in depositional cycles of dolomite above and limestone below implies that dolomite was formed from calcite or aragonite penecontemporaneously with the deposition of calcareous sediments. The dolomite of these cycles, therefore, corresponds to the "S-dolomite" of Dunbar and Rogers (1957) or to "syngenetic" dolomite of Friedman (1969) and Dunbar and Rogers (1957), showing clear stratigraphic control in the form of vertical alternation and intertonguing or facies-change of dolomite with respect to limestone.

The origin of dolomite has been a subject of much discussion. Adams and Rhodes (1960) believed that extensive reflux dolomitization must be the primary process of dolomitization. In this process, precipitation of gypsum produces a dolomitizing fluid which moves down through the underlying sediment as shown in fig. 20. F. J. Lucia (1972) claims that extensive reflux dolomitization is characteristic of evaporitic shoreline carbonate deposits. Four facts made apparent in this study seem to support this theory: 1) within each cycle, dolomite usually underlies anhydrite; this was noticed by Gratton and LeMay (1969); 2) where limestone is present it is overlain by dolomite, suggesting the downward movement of dolomitizing fluid through the overlying hypersaline environment represented by the anhydrite; 3) the areas in which all carbonate rocks are dolomitized are areas (sabkhas?) where a greater percent of the total cyclical sequence consists of evaporites—the thicker anhydrite beds may have required more time for deposition and would thus furnish more time for movement of dolomitizing fluids and the

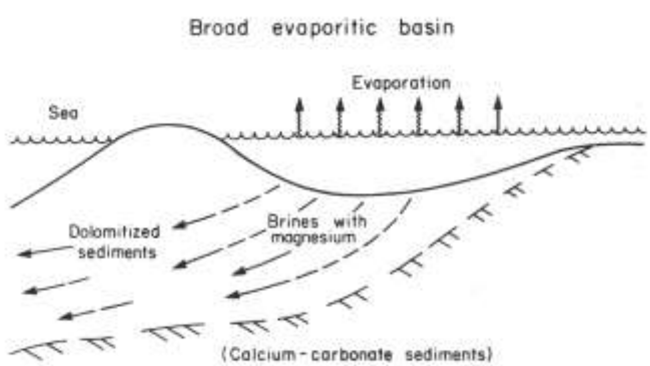

FIGURE 20—SEEPAGE-REFLUXION MODEL, FROM BASIN IN THE SUPRATIDAL ZONE TO THE SEA.

dolomitizing of all the underlying limestone; and 4) broad saline basins, the source of dolomitizing fluids according to the reflux theory, could result in the thin dolomite beds that cover many square miles.

Another theory, the seawater-dolomitizing theory, also seems to have some factual support. The seawater-dolomitizing theory, supported by Hsü and Siegenthaler (1969), suggests that seawater is the dolomitizing fluid and that seawater performs its dolomitizing by currents moving landward and upward through porous calcareous sediments toward an evaporating surface within a lagoon or near-shore evaporitic basin. Hsü and Siegenthaler (1969) believed that this landward movement of interstitial water, a process they called "evaporative pumping," was caused by surface tension at the surface of evaporation. Two facts support this explanation of widespread dolomitization: 1) dolomitizing does occur by landward-moving currents in modern seas and lagoons, such as along the shore of Andros Island in the Bahama Banks; here, however, only a narrow band of dolomitized sediments is found. Seepage refluxion, on the other hand, has not been observed in any modern environment, a fact that favors the seawater-dolomitizing theory; and 2) seawater does contain large amounts of magnesium ions, the ions needed to dolomitize aragonite sediments on a large scale.

Dolomite-forming environment

Cross sections in this study demonstrate that many thin, widespread dolomite beds occur in the lower San Andres. These broadly occurring dolomites underlie beds of anhydrite; hence, the widespread nature of these particular dolomites must be related to widespread and uniform hypersaline conditions. These widespread hypersaline conditions are best explained by broad basins having uniform hypersalinity. A logical assumption is that these broad lagoons or basins were close to the open sea so that they could receive freshets of seawater containing the necessary magnesium for dolomitization. The depositional model of Adams and Rhodes (1960) appears to be more compatible with this environment.

Structure

Larger structural features

Most of the report area is within the northwest shelf of the Permian Basin. The northwest corner of the study area is part of the northeast-trending Sierra Grande uplift and the northeast corner is part of the southern part of the Bravo dome (fig. 1). A small northwest-trending basin, the Cuervo Basin, is east-northeast of Santa Rosa in Guadalupe County. The Tucumcari Basin is present in the vicinity of Tucumcari, New Mexico. Both the Cuervo and Tucumcari Basins subsided more rapidly than adjacent areas during Permian-Pennsylvanian time and received a greater thickness of sediments.

Local structure

Faulting

Largely because of regional eastward tilting during Tertiary time, beds in the subsurface of east-central New Mexico now strike northeastward and dip toward the southeast (figs. 21 and 22). Most faults in the area strike northeastward; however, some faults in Guadalupe County in the northwest quadrant strike northwestward, as shown on the top Pi marker map on fig. 21. One noteworthy example of a large fault in the study area is the Bonita fault of southern Quay County, which has a throw of about 600 ft. Foster and others (1972) show other faults on their map of the Precambrian of east-central New Mexico, most of which trend northwestward.

Folding

Comparing figs. 21 and 22, the top Pi marker zone and the top P-3 zone maps, one sees a marked similarity: both show a north-south to north-northeast strike and an average dip east-southeastward of about 50 ft per mile.

Many of the wells in the area were drilled on anticlinal structures. A number of the surface anticlines may or may not extend below surficial rocks. At least one anticline in the area, in the southern half of T. 1 N., R. 30 E., has enough closure to appear either as a structural nose or as an anticline on all mappable horizons from the Precambrian to the surface. Many anticlines in this area are mappable by surface examination; Winchester (1933) showed some of these on the state map of New Mexico.

Structure and facies distribution

Todd (1976) noted that "facies patterns produced by the rapid progradation in the comparatively shallow San Andres marine environment reflect deep structure and can provide a useful exploration tool." A clear relationship between facies and structure contours, however, could not be demonstrated in this study. The isopach and facies contours strike mostly east-west. As previously noted, structure contours of both the top P-3 porosity zone and the top Pi marker show a north-south to northeast strike. No real correlation was discovered between the contoured features of figs. 21 and 22, or between local structures and lithofacies maps. A noteworthy exception is the small anticline in the southeast part of T. 7 N., R. 30 E.; this anticline is located on a thin area of the P-3 isopach map (fig. 9).

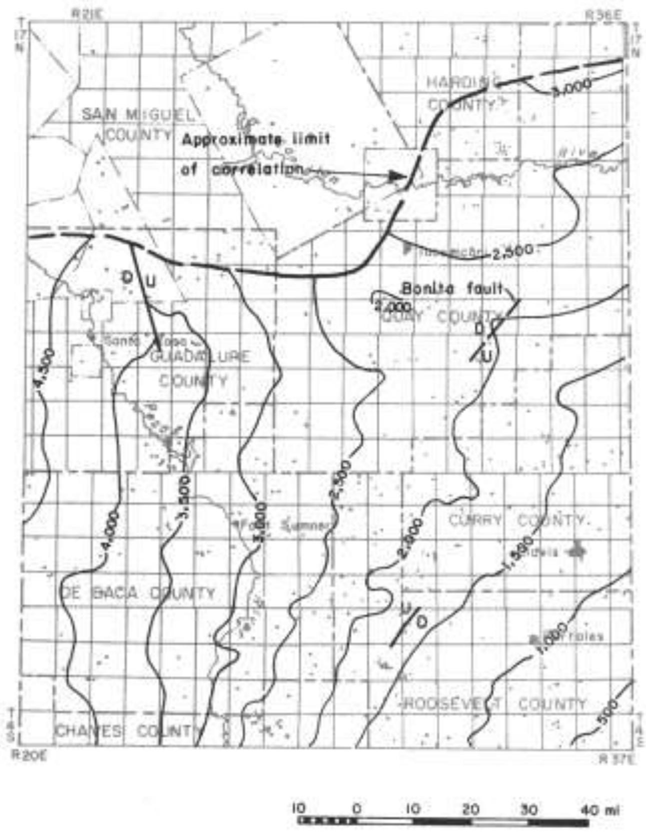

FIGURE 21—TOP P1 MARKER ZONE (5–10-ft-thick siltstone bed); contour interval equals 500 ft.

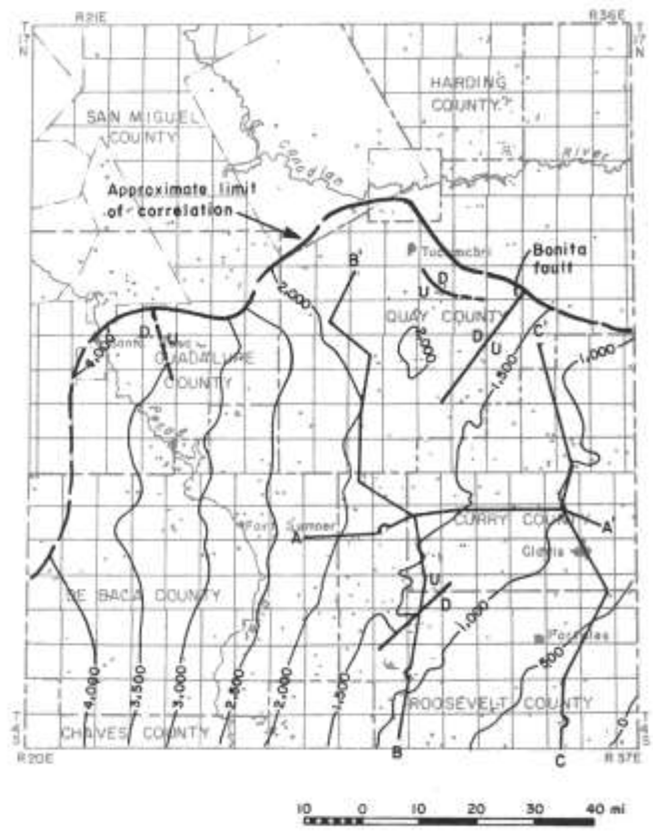

FIGURE 22—TOP P-3 (POROSITY) ZONE; contour interval equals 500 ft, lines of cross sections (fig. 19) shown.

Petroleum potential

Factors in oil accumulation

South of the report area, the oil entrapped in the San Andres seems to be related to four factors:

1) wedge-belts of porosity, wherein the entrapment is found at or slightly downdip from a porosity pinchout;

2) structure, either in the form of an anticline, a nose, or a structural terrace (a subtle change in the rate of dip may be the only indication of structure);

3) hydrodynamic conditions, manifested in tilted oil-water contacts, such as those described by Gratton and LeMay (1969) for the Chaveroo field; and

4) diagenetic accumulation; Wilson (1977) defined a diagenetic trap as "a paleotrap in which . . . the closure has been rotated from its original attitude . . . it results from late tilting of an early oil-bearing structure." The oil itself does not migrate from the tilt structure because the edges of the trap, especially in carbonate reservoirs, continue to be altered by cementation and other kinds of postdepositional diagenesis. Wilson pointed out that the carbonate reservoirs of Iraq are porous in the areas of oil accumulation where the oil preserved the original porosity. In the synclines adjacent to the anticlinal accumulation areas, the reservoir rock has been entirely sealed by cementation and other diagenetic processes.

All of these oil-entrapment factors may contribute to the making of a particular oil trap; normally two or more of them are factors in the making of an oil or gas trap in the San Andres.

Exploration methods

Discovering San Andres oil requires the use of several exploration methods. These methods clearly are useful in finding oil occurrences in other parts of the Permian Basin, as they are in other basins of the world.

Permeability variations

Two aspects of permeability are considered in looking for oil: where the permeability is present and where it disappears. Finding updip limits of permeability is a major concern because wedge-belts of permeability long have been a means of finding stratigraphic oil traps. Figs. 8, 13, and 17 delineate areas of maximum porosity.

All types of dolomite porosity are common in the San Andres, including cavernous, large and small intercrystalline, and pinpoint vugs.

Gratton and LeMay (1969) point out that P-1 and P-2 porosity zones lose porosity and permeability where dolomite grades into anhydrite, going from south to north. Elsewhere, pinchout of permeability may occur by less permeable limestone interfingering with more permeable dolomite. Permeable dolomite itself may disappear by progressive thinning within a largely evaporitic sequence, or by salt locally filling vugs in dolomite.

Evaporites have two important functions in localizing oil: 1) they act as a seal, preventing both updip and cross-strata migration of fluids; and 2) they may also help to cause secondary permeability in carbonate sequences by supplying the ions needed in dolomitization (Lucia, 1972).

Oil shows

Evaluating oil shows is a critical factor in finding oil in any basin or in any kind of reservoir. Perhaps the most important oil show in the region is represented by the Santa Rosa asphalt pit, located about 6 mi north of Santa Rosa, New Mexico, in T. 9 N., R. 21 E. This asphalt pit has been estimated to have over 90 million bbls of oil (Budding, 1980). The oil probably migrated from the San Andres Formation during post-Triassic time, possibly along fractures. Faults and other kinds of fractures represent possible avenues of oil migration. If this large amount of oil did come from the San Andres Formation, the obvious question arises: why would we not expect commercial accumulations of oil elsewhere in the San Andres Formation of east-central New Mexico?

Many shows of oil and gas have been reported from the San Andres in wells in the report area. Table 1 shows wells that have reported oil shows. Scout tickets and other well records contain detailed information about these shows.

Source beds

Generally, the limestones of the San Andres are dark-colored, argillaceous, and contain many thin, black, calcareous shale beds. We believe that the limestones of the subsurface intertongue with dolomites, the normal reservoir rock of the San Andres, as shown on the accompanying cross sections (in pocket). If so, their intertonguing juxtaposition certainly would foster the movement of oil from source to reservoir rock.

Conclusions

Stratigraphy and fades relationships

The lower San Andres Formation of east-central New Mexico contains three zones with significant thicknesses of porosity. These zones are here designated the P-3, P-4, and P-5 zones. The zones consist mostly of dolomite with smaller amounts (in order from greatest amount to least) of limestone, anhydrite, halite, and shale. Each zone represents one major depositional cycle. As shown on fig. 5, the cycle begins (at its base) with the deposition of a thin layer of clay that locally is calcareous; this unit 1 is overlain by dark limestones up to 50 ft in thickness (unit 2); locally these limestones are dolomites. Unit 2 is overlain by dolomites which may grade locally into salt or limestone (unit 3). The uppermost unit, unit 4, consists of anhydrite that represents "moments in geologic time during which the generally regressive San Andres sea was at maximum withdrawal" (Gratton and LeMay, 1969). Each of the three lower San Andres cycles represents deposition within a succession of near-shore environments from subtidal and normal marine waters to hypersaline waters. Construction of 10 lithofacies maps demonstrates that these lithologies do change in horizontal directions, a fact that indicates that belts of porous rocks lie adjacent to nonporous ones.

Evidence herein suggests but does not prove that dolomitization of the lower San Andres was the result of penecontemporaneous, seaward-moving saline water, a movement direction in keeping with the seepage-reflux-ion theory.

Structure

East-central New Mexico is part of the northwestern shelf of the Permian Basin. Rocks generally strike north-south to northeastward and dip gently eastward at the rate of 50 ft per mile. Here also are small basins, such as the Tucumcari Basin, and uplift areas, such as the northeast-trending Sierra Grande uplift. Faulting is minor both in density per unit area and in the amount of throw. One fault, the Bonita fault, in southern Quay County, is a major fault because it has a throw of 600 ft.

Potential

East-central New Mexico for many years was, and still can be considered to be, a potential future oil province. This conclusion is based upon the following:

1) the Santa Rosa asphalt deposit, located about 6 mi north of Santa Rosa, New Mexico, contains the equivalent of more than 90 million bbls of oil; the oil probably migrated during Triassic and later time, probably along fractures that stem from the oil's likely source, the San Andres. Similar accumulations of San Andres oil must exist elsewhere in east-central New Mexico;

2) the area contains many wells having oil and gas shows;

3) porosity maps show areas of sufficient porosity in the lower San Andres; equally significant is that these same maps indicate areas of updip limits of porosity;

4) local structures are recognizable by structural mapping on San Andres and older horizons;

5) several wells in the area did yield liquid hydrocarbons; and

6) Littlefield field, about 40 mi east of the New Mexico-Texas state line, is onstrike with this area and presumably represents similar accumulation conditions.

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Contents of pocket

TABLE 1-TABULATION OF WELL DATA

FIGURE 19-SOUTH-TO-NORTH CROSS SECTION ***A-A'***
SOUTH-TO-NORTH CROSS SECTION ***B-B'***
WEST-TO-EAST CROSS SECTION *C-C'*

Typefaces: Text in 10 pt. English Times, leaded two points
References in 8 pt. English Times, leaded one point Display heads in 24 pt. English Times

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Binding: Saddlestitched with softbound cover

Paper: Cover on 65-lb. Carnival light green
Text on 60-lb. white offset

Quantity: *1000*

TABLE 1—TABULATION OF WELL DATA USED IN COMPILING FIGS. 6–18.

Well No.	Well	¼ Sec.	Sec.	Twn.	Rge. (E.)	P-3 depositional zone (thickness in ft)							P-4 depositional zone (thickness in ft)							P-5 depositional zone (thickness in ft)						Elev. top P-3 dol.	Well No.
						Porosity							Porosity							Porosity							
						>5%	>10%	dol.	ls.	anh.	salt	Shows	>5%	>10%	dol.	ls.	anh.	salt	Shows	>5%	>10%	dol.	ls.	anh.	salt		
1	J. Sandefer-1-Vaughn	NW	21	1 S.	26	12	10?	18	0	7	22	SG	35	30	43	12	30	30		51	29	56	4	22	45	2,582	1
2	Cities Serv.-1-Hobson	NE	12	1 S.	27	26	10	60	0	20	0	SG	40?	10?	70	20	37	0		—	—	35	0	40	0	2,044	2
3	J. McAdams-1-White		4	1 S.	28	46	25	70	0	4?	0	SO	56	15	50	40	30	—		38	8	44	20	10	—	1,973	3
4	Shell Strat. Test 45-70		4	1 S.	29	28	4	62	0	26	0		46	2	52	28	14	0		29	4	—	25	44	0	1,643	4
5	Shell Strat. Test 39-69	SE	1	1 S.	30	51	22	53	12	24	0		69	11	83	15	30	0		67	34	73	12	21	0	1,446	5
6	Shell Strat. Test 14-69	SW	19	1 S.	31	56	25	40	24	22	0		64	36	58	38	36	0		57	36	10	61	30	0	1,248	6
7	Leede-1-State	NW	16	1 S.	31	58	45	48	0	18	0		37	10	59	23	26	0		23	11	42	38	34	0	1,224	7
8	So. Pet.-1-Hensley		17	1 S.	31	22	2	38	14	31	0		58	23	57	21	35	0		57	29	82	14	35	0	1,232	8
9	Humble-1-Rea	SW	29	1 S.	33	41	11	51	14	26	0		83	40	61	30	36	0		90	82	68	16	34	0	820	9
10	Humble-1-N.Mex. CT	NW	15	1 S.	35	65	52	72	0	24	0		87	9	73	20	26	0		76	29	62	12	37	0	675	10
11	Hanson-1-Shackleford	NE	17	1 S.	36	—*	—*	20	60	20	0	SO	—	—	55	40	20	0		—	—	80	0	35	60?	585	11
12	Talbert-1-Andre	SE	20	2 S.	22	—	—	—	—	20	0		—	—	80	0	20?	0		—	—	35?	0	10?	0	3,972?	12
13	Danciger-1A-State	NE	8	2 S.	26	—	—	70	0	50	0		—	—	20	70	20	0		—	—	70	0	10	—	2,540	13
14	Sandefer-1-McClain	SE	21	2 S.	28	50	40	50	0	22	0	SO	72	29	69	42	34	0		63	60	64	0	48	0	1,748	14
15	Tidewater-1-Best		27	2 S.	29	25?	18?	50	0	—	—		20+	20	50	55	20	—		28?	18?	62	25	35	—	1,475	15
16	Getty-1-Best		14	2 S.	31	38	21	49	15	—	—		60	23	86	22	24	0		52	16	60	24	30	0	1,060	16
17	Sunray-1-State AK		14	3 S.	27	33	28	50	0	—	—		78	64	50	60	37	0	SO, SG	73	31	40	28	11	0	1,854	17
18	Phillips-1-VintherA		25	3 S.	30	53	15	62	0	—	—		58	25	67	39	36	—		35	30	68	12	12	—	947	18
19	Continental-1-Lee		22	3 S.	32	45	6	60	0	—	—		36	0	44	66	25	—		91	23	90	11	16	—	685	19
20	Exxon-1-Warnica		30	3 S.	33	48	25	56	0	42	17		34	4	8	65	46	—		81	44	49	30	48+	—	617	20
21	Signal-1-Bell		33	3 S.	33	—	—	85	0	—	—		—	—	88	20	20	0		—	—	10	75	65	—	638	21
22	Getty-1-Ainsworth		7	3 S.	34	48	4	36	29	—	—		58	0	70	20	44	—		78	23	46	37	58	—	504	22
23	Sloan-1-Lovern		4	3 S.	35	60	—	95	10	—	—	SO	65	0?	77	30	25	—		35	0?	52	40	23	—	398	23
24	Sunray-1-Capps	NW	8	3 S.	35	—	—	27–	39	—	—		—	—	44	46	28	—		—	—	56	0	22	0	303	24
25	Smith Dev.-2-Davis	NW	3	4 S.	26	78+	46+	86+	12+	—	—		—	—	—	—	—	—		—	—	—	—	—	—	2,208	25
26	Leonard-1-White		9	4 S.	27	44?	8?	82	0	—	—		25?	7?	90	30	18	—		44?	28?	92	28	32	—	1,947	26
27	Nearburg-1-Gratton		18	4 S.	27	23?	4?	72	0	—	—		45?	3?	48	57	28	—		93?	55?	87	25	20	—	2,019	27
28	Skelly-1-Boone	SE	26	4 S.	30	—	—	90	0	10	—		—	—	38	72	8	—		—	—	80	30	32	—	870	28
29	Gulf-1-Stevenson		22	4 S.	31	65	34?	84	—	18	—		0	0	23	75	12	—		57	0?	81	15	55	—	872	29
30	Spartan-1-36-State		36	4 S.	31	27?	2?	64	17	24	—		13	5?	19?	80	12	—		59?	35?	65	20	50	—	826	30
31	Skelly-1-McCowan		34	4 S.	31	49	4	82	18	35	—		43	12	30	70	37	—		87	73	80	28	39	—	891	31
32	Austral-1-Sadler	NE	29	4 S.	32	36?	12?	70	15	18	—		15?	8?	45	55	25	—		89?	81?	75	10	58	—	687	32
33	Amerada-1-Lieb		6	4 S.	33	47	6	56	0	16	—	SO	22	9	39	76	26	—	SO	72	23	54	30	72	—	630	33
34	Leede-1-Dunn		4	4 S.	34	40	4	50	30	30	—		63	8	80	15	40	—		48	12	55	32	60	—	411	34
35	Eastland Drlg.-1-Victor		34	4 S.	35	75	44	69	3	30	—		52	23	45	51	35	—		68	24	80	15	41	—	169	35
36	Midcont.-1-Strickland	SW	9	4 S.	35	32	27	80	11	28	—	SO	41	10	55	29	34	—	SO	42	17	48	35	80	—	280	36
37	Delaware-1-Allison		29	4 S.	36	71	30	86	0	33	2		57	21	86	0	71	—		37	10	83	0	75	—	91	37
38	Sandefer-1-Spencer		25	1 N.	28	61	23	61	0	7	—		59	49	59	29	44	—		28	22	38	34	27	—	1,889	38
39	McAdams-1-Federal		24	1 N.	27	—	—	70	0	10	—		—	—	48	37	30	—	SO	—	—	43	17	10	—	2,253	39
40	Shell Strat. 23-69		16	1 N.	28	41	19	40	27	5	—		59	14	57	36	32	—		37	7	38	27	24	—	2,099	40
41	So. Pet.-1-State L		5	1 N.	29	32	9	57	9	16	—		33	2	81	0	45	—		57	33	48	0	53	—	1,820	41
42	Shell Strat. 1-69		20	1 N.	29	40	2	43	26	35	—		75	32	80	0	41	—		24	5	38	44	32	—	1,736	42
43	Hanson-1-Williams Ranch	NE	6	3 S.	36	12	5	12	48	20	—		66	49	44	50	49	—		70	70?	70+	—	—	—	340	43
44	Texaco-1-Fed. NCT		3	1 N.	31	41	6	61	6	9	—		48	5	68	20	39	—		49	22	61	14	26	0	1,422	44
45	Sunray-1-Crenshaw		14	1 N.	31	44	5	77	0	10	—	SO	49	18	86	0	37	—		37	11	43	32	27	23	1,392	45
46	Shell Strat. 25-69		18	1 N.	31	58?	37?	76	0	11	—		28?	6?	88	0	40	—		40?	14?	43	30	18	—	1,454	46
47	Shell Strat. 41-69		26	1 N.	29	31	8	42	28	27	—		52	10	75	24	33	—		33	14	38	54	18	—	1,617	47
48	Osmond-1-Haynes		24	1 N.	36	—	—	21	60	20	—	SO	—	—	40	52	18	—	SO	—	—	70	0	48	—	608	48
49	Hawkins-1-Myrick	SW	17	2 N.	25	30?	22?	72	0	22	20	SO	37?	25	59	20	10	—	SO, SG	0?	0?	8	20	18	—	3,006	49
50	Texaco-1-Powell	NE	7	2 N.	26	45	9	68	0	15	—		42	32	74	10	28	—		29	7	28	0	26	—	2,700	50
51	Haschke-1-Elliott		14	2 N.	28	—	—	75	0	5	0	SO	—	—	78	0	20	—	SO?	—	—	88	0	8	—	2,038	51
52	Shell Strat. 43-69		27	2 N.	30	26	0	62	18	10	10		48	18	84	0	43	—		64	29	68	0	27	—	1,563	52
53	Shell Strat. 2-69		5	2 N.	29	17	0	36	7	15	—		34	3	25	27	74	—		44	27	45	19	29	—	1,900	53
54	So. Un. Gas-1-Lucas		5	2 N.	30	—	—	80	0	12	—	SO	—	—	95	0	20	—	SO	—	—	70?	0?	17?	—	1,679	54
55	So. Pet.-1-Keeter		2	2 N.	33	49	10	43	42	3	—		35	4	48	8	55	—		45	17	40	47	18	—	1,246	55
56	Shell Strat. 11-69		35	2 N.	33	42	3	33	50	8	—		65	34	68	12	37	—		70	41	53	22	20	—	1,076	56
57	Shell Strat. 28-69		12	2 N.	34	62	11	68	17	5	—		49	17	65	0	38	—		61	32	52	26	32	—	1,028	57
58	Genl. Crude-1B-Federal		25	3 N.	23	—	—	82	0	45		SO	—	—	85?	10	10	—	SO	—	—	22?	0?	12	—	3,205	58
59	Genl. Crude-1A-Federal		6	3 N.	24	27	3	68	0	42	26		76	32	56	25	18	—	SO	19	6	24	0	5	13	3,364	59
60	Union Oil-1-Brahan	NW	16	3 N.	24	4	0	67	0	41	18		12	0	69	14	15	—	SO, SG	30	13	29	8	7	—	3,191	60
61	Sun Oil-1-USA CT		14	3 N.	27	25?	10?	86	12	11	9		48?	17?	75	4	24	—		51?	24?	46	6	13	—	2,365	61
62	Pure-1-Federal		31	3 N.	28	—	—	75	0	10	—	SO	—	—	55	0	40	—	SO	—	—	32	45	25	—	2,285	62
63	Shell Strat. 38-69		4	3 N.	29	64	32	60	10	23	—		46	30	41	16	52	—		50	31	—	—	—	—	1,969	63
64	Franklin Pet.-1-Gephart	NW	28	3 N.	30	—	—	70	0	15	—	SO	—	—	74	0	40	—		—	—	48	25	30	—	1,765	64
65	Shell Strat. 24-69		29	3 N.	30	33	2	54	0	32	—		59	6	68	0	42	—		79	31	68	10	27	—	1,761	65
66	Cit. Serv.-1A-Swink		8	3 N.	31	18	0	28	29	34	5		27	12	39	22	36	—		46	18	42	24	38	—	1,649	66
67	Shell-1-Stephenson		2	3 N.	32	54?	40?	70	0	18	—		30?	22?	45	10	45	—		49?	27?	44	20	30	—	1,502	67
68	K and F-1-Ramey	NE	13	3 N.	32	—	—	48	30	5	28	SO	—	—	47	25	12	35	SO	—	—	40	35	10	10	1,364	68
69	Consol.-2-Ramey		13	3 N.	32	15	8	80	10	35	—		36	24	41	14	41	—		67	44	70	0	12	—	1,273?	69
70	Shell Strat. 12-69		6	3 N.	34	11	0	5	79	13	—		36	18	42	22	48	0		85	30	64	0	29	—	1,224	70
71	Shell Strat. 17-69		10	3 N.	35	70	11	68	8	15	—	SO	35	8	38	23	44	—		57	22	50	51	54	—	1,008	71
72	Steinberger-1-Haskins		21	3 N.	36	—	—	88	0	0	—	SO	—	—	72	0	25	—	SO	—	—	30	0	15	12	738	72
73	Shell Strat. 31-69		26	3 N.	36	11	0	14	66	0	9		62	25	80	8	23	—		55	42	68	0	29	—	810	73
74	Shell Strat. 18-GPA		5	3 N.	37	52	11	60	—	8	—		41	16	48	4	42	—		52	21	52	15	48	—	832	74
75	So. Pet.-1-Spearman		15	3 N.	37	10	2	12	72	0	8		45	16	46	38	25	—		23	13	51	20	30	—	778	75
76	Sandefer-1-Good-State		21	4 N.	27	24	0	57	0	20	26		53	36	65	0	42	—		42	7	46	0	18	—	2,383	76
77	Shell Strat. 9-69		11	4 N.	29	2	0	14	36	37	17	SO	40	3	43	20	38	—	SO	30	10	43	8	23	—	1,952	77
78	So. Pet.-1-Brown		30	4 N.	29	17	0	18	52	15	25		32	9	46	24	48	—		48	26	46	6	8	—	2,005	78
79	Tenneco-1-Mosley		12	4 N.	31	20	4	11	54	11	0		40	38	39	31	42	0		46	33	52	0	27	—	1,649	79
80	Cities Serv.-1-Widener		17	4 N.	31	23?	10?	70	0	18	0	SO	2?	0?	55	21	30	0	SO	46?	36?	37	22	27	—	1,597	80
81	Tenneco-1-Dougherty		28	4 N.	32	27	3	8	57	24	—	SO	23	12	51	0	50	—	SO	57	34	52	22	22	—	1,580	81
82	Shell Strat. 36-69		18	4 N.	33	47	6	65	0	25	5		22	4	32	24	48	4		24	5	36	31	32	—	1,420	82
83	Shell Strat. 27-69		22	4 N.	33	51	14	77	8	13	0		36	32	40	30	47	0		56	48	54	12	34	—	1,283	83
84	Shell Strat. 29-69		21	4 N.	35	56	13	60	17	14	0		35	10	58	0	48	0		55	50	60	5	19	—	1,009	84
85	So. Pet.-1-Harrell		5	5 N.	31	47	3	38	19	26	4		30	4	38	28	40	4		28+	13+	29+	26+	2+	—	1,744	85
86	Marathon-1-State 16		16	5 N.	31	—	—	53	0	18	0		26	15	33	36	34	0		45	22	37	24	33	—	1,812	86
87	Franklin-1-Green		10	5 N.	32	19?	4?	54	0?	28	0		20?	1?	68	0	43	18		56?	24?	62	0	26	—	1,415	87
88	Tenneco-1-Garrett		31	5 N.	34	20	0	52	43	12	0		42	5	51	6	50	0		37	13	16	52	24	—	1,271	88
89	Texas Gulf-1-Garrett		34	5 N.	34	38	—	76	0	9	0		42	—	58	0	40	10		46	—	65	0	25	—	1,260	89
90	Shell Strat. 17-69	NW	10	5 N.	35	38?	6?	21	51	18	0		33?	0?	48	32	26	0	—	54+	22+?	46+	5+	5+	—	1,038	90
91	Shell Strat. 13-69		34	5 N.	35	67	8	79	0?	9	0		48	17	68	4	42	0		52	10	35	30	33	—	950	91
92	Un. Prod.-1-Jones		18	5 N.	37	—	—	20	50	17	0		—	—	41	42	30	7	—	—	—	25	25	30	—	899	92
93	Shell Strat. 4-69		10	6 N.	27	38	19	4	0	70	44		28	0	37	48	38	0		39	20	39	12	18	—	2,264	93
94	Shell Strat. 8-69		21	6 N.	29	15	0	48	0	20	8		16	0	54	22	30	11		52	29	44	6	28	—	1,950	94
95	Stephens-1-Lee		32	6 N.	30	25?	—	110	0	22	0		—	—	50	5	35	0		—	—	25+	37+	45+	—	1,797?	95
96	Shell Strat. 15-69		13	6 N.	31	19	0	18	24	31	0	SO, SG	4	0	35	28	50	3	—	10	0	34	25	20	—	1,704	96
97	Shell Strat. 21-69		23	6 N.	33	19	2	24	38	17	0		25	2	28	27	38	21		41	20	30	26	28	—	1,315	97
98	Exxon-1-Brown		35	6 N.	34	56	29	49	16	22	0		30	14	54	0	46	7		64	25	52	16	22	—	1,329	98
99	Shell Strat. 7-69		23	8 N.	29	11	8	39	0	31	0		49	19	62	0	34	20		30	8	52	0	15	—	1,890	99
100	Shell Strat. 34-69		13	9 N.	27	5	3	6	—	32	98		34	30	25	6	18	0	SO	36	19	36	5	23	—	2,054	100
101	Shell Strat. 5-69		22	9 N.	28	17	8	13	0	42	31		39	15	69	0	18	38		37	35	37	0	28	—	1,903	101
102	Amoco-1-Baker	NE	29	9 N.	30	36	33	38	0	20	0		32	17	42	11	36	0		31	20	26	17	29	0	1,856	102
103	Shell Strat. 6-69		8	10 N.	29	29	4	32	0	14	14		35	15	50	23	34	0		46	44	46	0	20	—	1,664	103
	ADDITIONAL WELLS																										
104	Shell Strat. 22-69	NE	22	1 S.	29	57	34	65	0	6	13		55	31	55	23	40	0		30	13	34	44	33	—	1,551	104
105	Steinberger-1-V. Mae	NW	4	1 S.	30	—	—	5	85	—	—		—	—	40?	70	—	—		—	—	50?	50?	—	—	1,510	105
106	Dorsey-1-Nash	SW	17	1 S.	32	—	—	66	0	26	0		—	—	37	49	29	0		—	—	61	18	32	—	1,164	106
107	Leede-1-McGee		1	3 S.	31	48	5	53	0	—	—		55	0	58	54	26	0		74	24	46	19	13	—	883	107

*Parameter is not determinable on logs available.
+ Data shown is minimum.
? Data is uncertain.
— Data unavailable or uninterpretable.

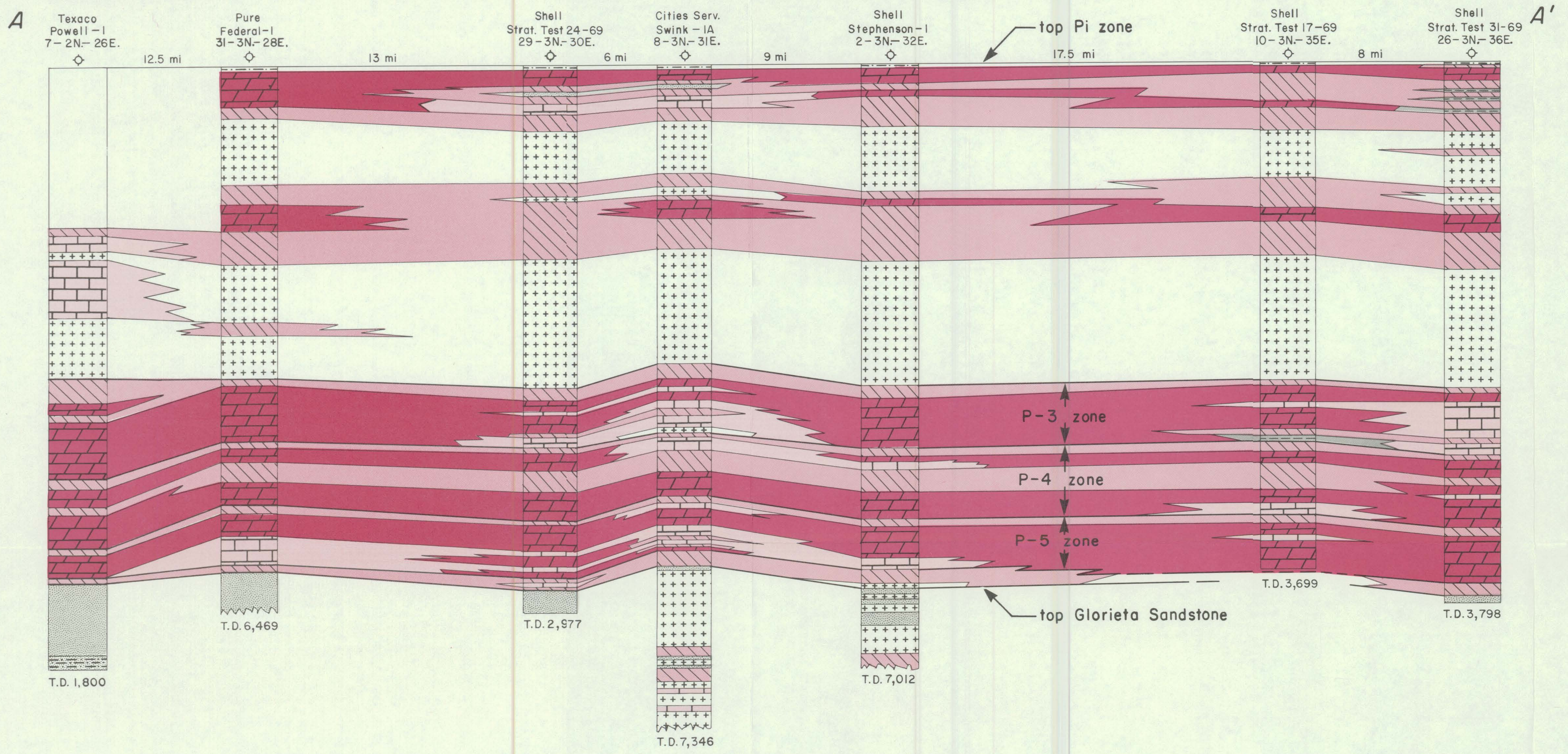
SO: show of oil
SG: show of gas
anh.: anhydrite
dol.: dolomite
ls.: limestone

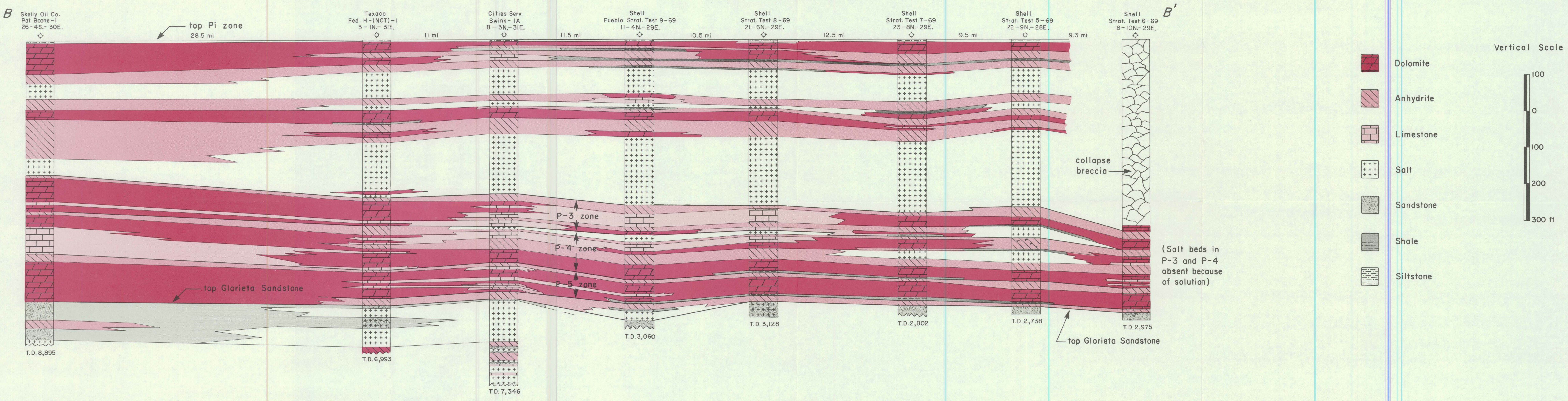
FIGURE 19

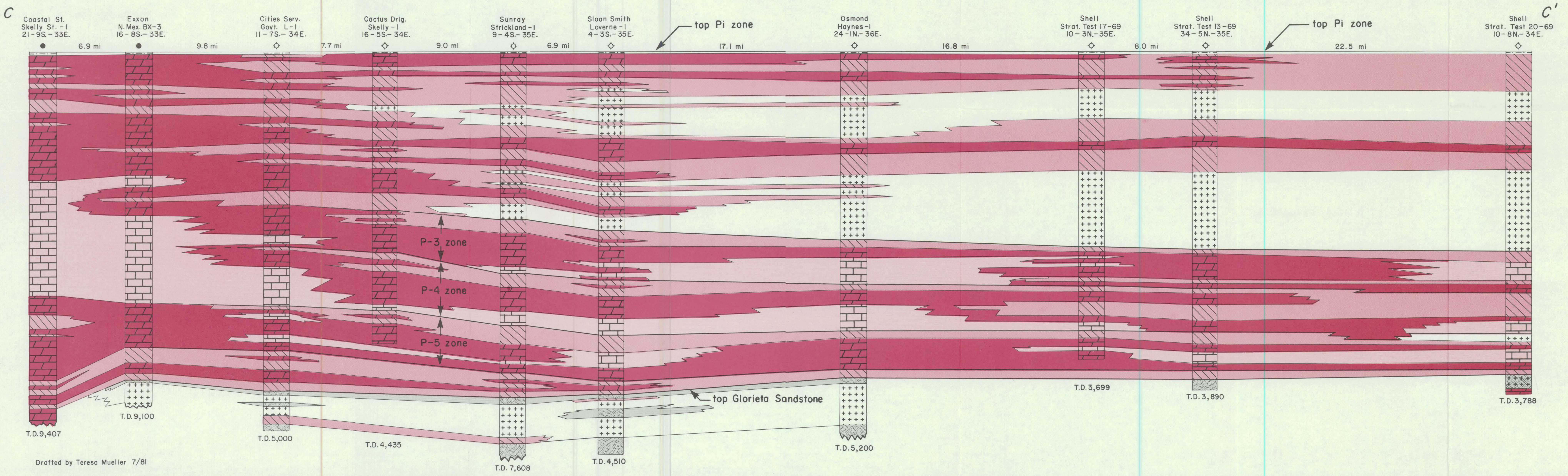
Porosity zones in lower part of San Andres Formation, east-central New Mexico

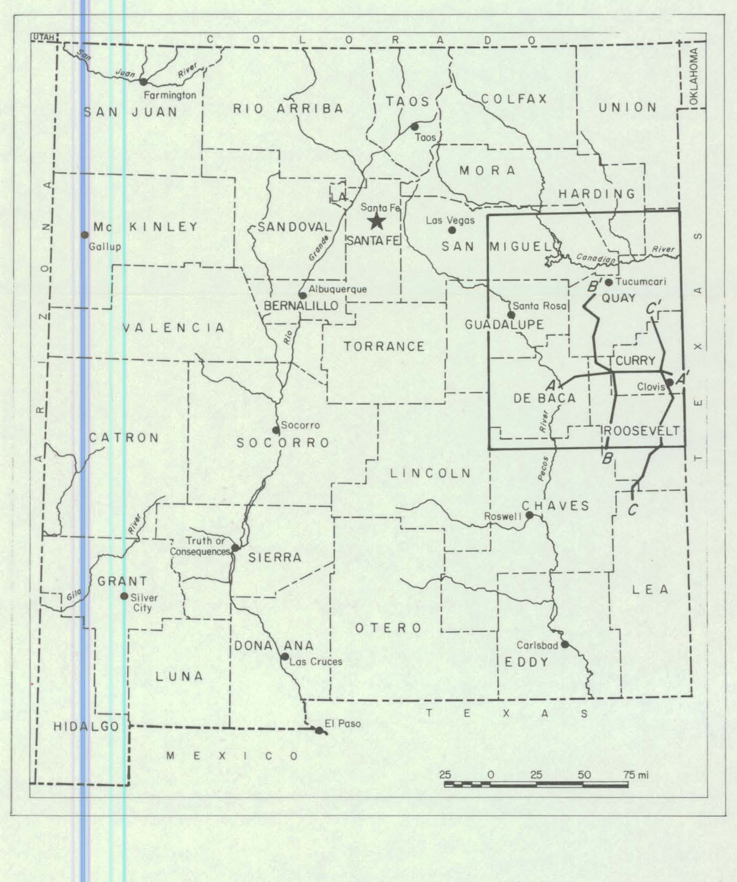
by William D. Pitt and George L. Scott

1981









INDEX MAP SHOWING LOCATION OF STUDY AREA.