Waste Isolation Pilot Plant

Compliance Certification Application

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STRATIGRAPHY AND ASSOCIATED TECTONICS OF THE UPPER PERMIAN CASTILE-SALADO-RUSTLER EVAPORITE COMPLEX, DELAWARE BASIN, WEST TEXAS ANDSOUTHEAST NEW MEX
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The University of New Mexico, Ph.D., 1966
Geology

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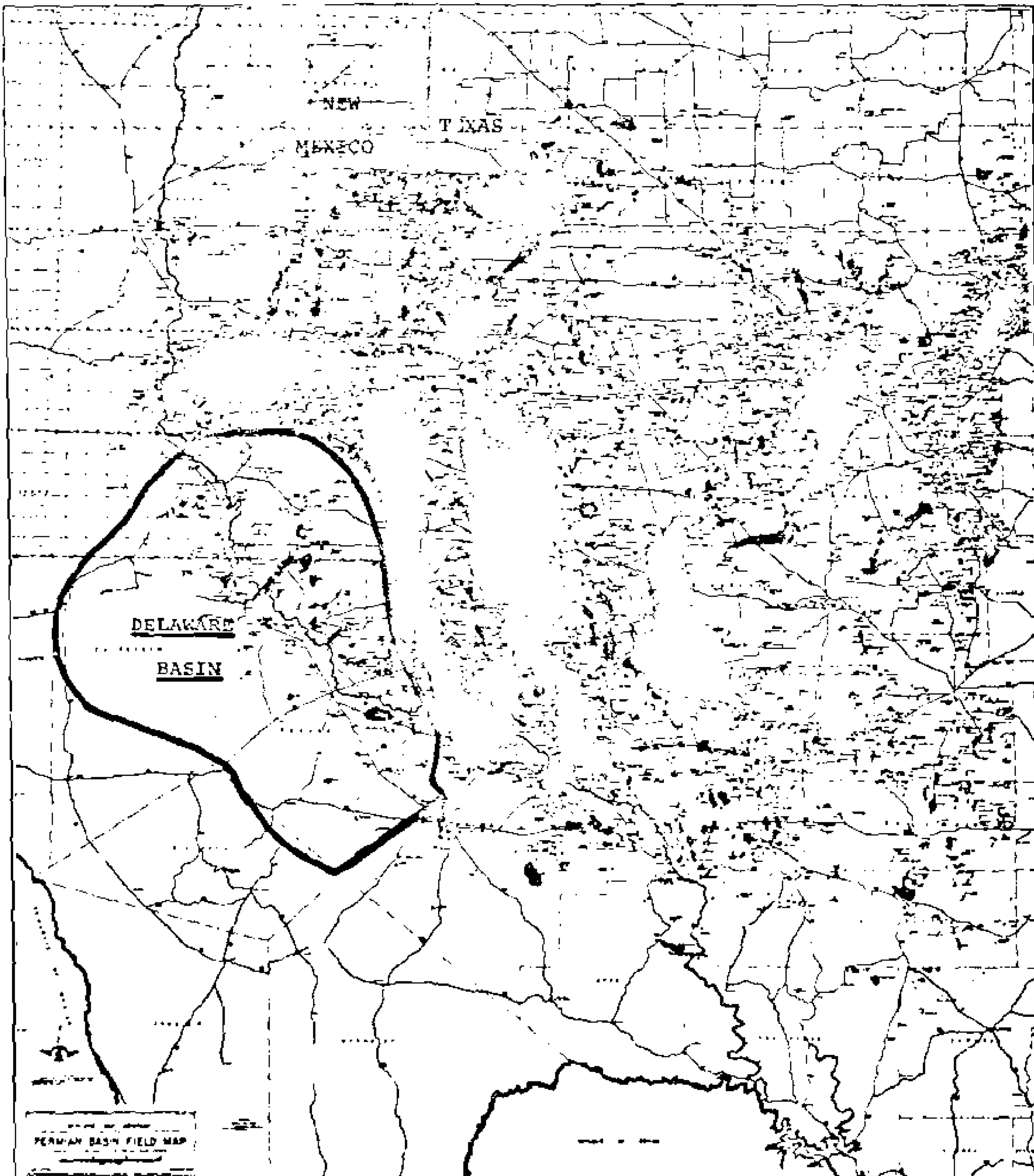

Frontispiece

Permian Basin Field Map

STRATIGRAPHY AND ASSOCIATED TECTONICS OF THE UPPER PERMIAN CASTILE-SALADO-RUSTLER EVAPORITE COMPLEX, DELAWARE BASIN, WEST TEXAS AND SOUTHEAST NEW MEXICO

By

Henry Irwin Snider

A Dissertation

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy in Geology

The University of New Mexico

1966

This dissertation, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of The University of New Mexico in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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STRATIGRAPHY AND ASSOCIATED TECTONICS OF THE UPPER PERMIAN CASTILE-SALADO-RUSTLER EVAPORITE COMPLEX, DELAWARE BASIN, WEST TEXAS AND SOUTHEAST NEW MEXICO

By
Henry Irwin Snider

Committee

Roger Y. Anderson
CHAIRMAN

Edgar L. Cruft

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ABSTRACT

The Delaware basin of west Texas and southeast New Mexico is roughly pear-shaped with a northwest-southeast length of about 140 miles and a width of 100 miles in the northwest tapering to 60 miles in the southeast--an area of about 10,000 square miles. In late Permian time the basin was essentially encircled by a carbonate depositional environment or reef zone.

The Upper Permian evaporite complex within the Delaware basin consists of Castile, Salado, and Rustler Formations. The Castile Formation contains laminated calcareous anhydrite, halite, and limestone. The Castile Formation was subdivided into seven units: Anhydrite I, Halite I, Anhydrite II, Halite II, Anhydrite III, Anhydrite IV, and Anhydrite V. The lowest four units can be traced over two-thirds of the basin. The upper three units can only be differentiated in the eastern part of the basin. The Salado Formation consists of halite and anhydrite with minor clastics, magnesite, and potassium minerals in the north and east parts of the basin. In the south and west parts of the basin, the Salado consists mainly of anhydrite, dolomite, and clastics. The Rustler Formation contains anhydrite, dolomite, clastics, and halite.

Castile and Salado rocks have similar features interpreted as large-scale cyclic trends superimposed upon seasonal fluctuations. Laminations in the Castile anhydrite represent

seasonal fluctuations, whereas larger cyclic trends can be generalized as sulfate-chloride successions during Castile and Salado deposition. Clastic-anhydrite and dolomite successions in Rustler rocks may be a continuation of the large-scale cycles. Assuming that laminations in the Castile and Salado Formations are annual, Castile time lasted about 260,000 years and Salado time about 150,000 years. Analysis of large-scale cycles throughout Guadalupe and Ochoa Series rocks supports the concept of transgression and regression of seas with concurrent deepening and shallowing of basin water.

Prior to evaporite deposition, environmental conditions favored reef growth surrounding the Delaware basin. The reef, in turn, affected the physiographic setting of the west Texas area producing a lagoon, the Delaware sea, within the encircling reef. Lagoonal conditions were also prevalent landward from the reef, the so-called "back-reef" areas. High evaporation rate with long-continued supply of ocean water gave rise to the sequence of anhydrite and halite of the Castile. Sulfate-rich waters may have entered the Delaware basin from the Midland basin through inlets breaching the reef. During Salado and Rustler time, evaporites were deposited over the area comprised of the Delaware basin, the Midland basin, and the Central Basin platform.

Tectonic features within the Delaware basin are the intrabasin shelf, the intrabasin shelf margin, and the Ochoa trough. The intrabasin shelf was a slowly subsiding area in the western part of the basin. The intrabasin shelf margin appears to have been an area influenced by the Huapache flexure in the northwestern part of the basin and by the eastern flank of the Toyah uplift in the eastern and southeastern parts of the basin. The Ochoa trough was a more rapidly subsiding area between the intrabasin shelf and the Central Basin platform.

The distribution of halite may reflect tectonism during Castile time. Little to no halite is found on the intrabasin shelf, while thick halite beds are found in the Ochoa trough. Halite units of the Castile Formation may have overlapped to the south due to differential subsidence or "tilting" southward of the Ochoa trough. A reversal of this tilting occurred in Salado time.

Evidence of local movement in Castile units is abundant. Four models are analyzed to account for salt structures found: 1. salt movement contemporaneous with deposition--"down building"; 2. post-depositional halite piercement; 3. post-depositional lateral movement of upper halite over lower halite stock, dome, or anticline; and 4. gravity flow of upper halite over a lower halite structure--"anticline on anticline." Tectonic "triggering" is suggested as the major cause of Castile halite movement. Regional movement resulting in structures similar to "salt pillows" or "salt stocks" is believed to have occurred in the northeast part of the Delaware basin in Lea County, New Mexico.

INTRODUCTION

Purpose and Scope

The purpose of this investigation is to describe and interpret the Upper Permian Castile-Salado-Rustler evaporite sequence and associated tectonics of the Delaware basin, west Texas and southeast New Mexico. Previous stratigraphic and sedimentational studies of the Upper Permian evaporite sequence in the Delaware basin include: Udden, 1924; Lang, 1935, 1937, 1938, and 1939; Adams, 1944; R. H. King, 1947; and C. L. Jones, 1954. Structural studies include those by Kroenlein, 1939, and Hills, 1942. The evaporite stratigraphic record is studied here to analyze basin development contemporaneous with sedimentation. It is possible to analyze the structural behavior of the Delaware basin during Upper Permian evaporite deposition because; first, the stratigraphic record is almost complete in areas within the basin; and second, the sequence of evaporites, especially in the Castile Formation, is relatively simple and can be correlated readily.

To achieve the purpose of tectonic analysis, the Castile Formation is described in detail. Lesser emphasis is placed on the Salado and Rustler Formations, inasmuch as facies changes within these formations add many local complexities to regional tectonic patterns. The Rustler is considered as one unit, whereas the Salado is subdivided into three parts and correlated over the basin where possible. Emphasis here is also placed upon the cyclic aspects of the rocks described. Investigation of the cyclic aspects of the Guadalupe Series rocks, which precede Castile deposition, and Salado Formation rocks, which overlie the Castile, was stimulated after reading Udden's (1924) study of the remarkably long and clear record of cyclic sedimentation in the laminated anhydrite of the Castile Formation. Udden (1928, p. 58) further emphasized the value of cyclic studies as follows:

> "A most important element in history is time, and not only relative time but time in cycles and periods of known duration. I am convinced that we make a mistake if we say that anything less than this should be looked for. Not that I believe that we can ever attain to measuring the number of years or larger time units in geology, but we ought to come much nearer to accomplishing this than we are at the present time. We can hardly claim to yet have made a beginning in this line of research."

This study is the first in a series to be done on the evaporite sequence in the University of New Mexico Geology Department toward establishing cyclic trends and paleoclimatic conditions in late Permian time.

Geography

The Delaware basin lies in southeastern Eddy and southern Lea Counties, New Mexico, and in northern and eastern Culberson, Reeves, Loving, western Ward, western Winkler, and northwestern Pecos Counties, Texas (Figs. 1 and 2). The area is roughly elliptical in outline with the major axis running northwest-southeast about 140 miles from northwest of Carlsbad, New Mexico, toward Pecos and Fort Stockton, Texas. The Delaware basin covers an area of about 10,000

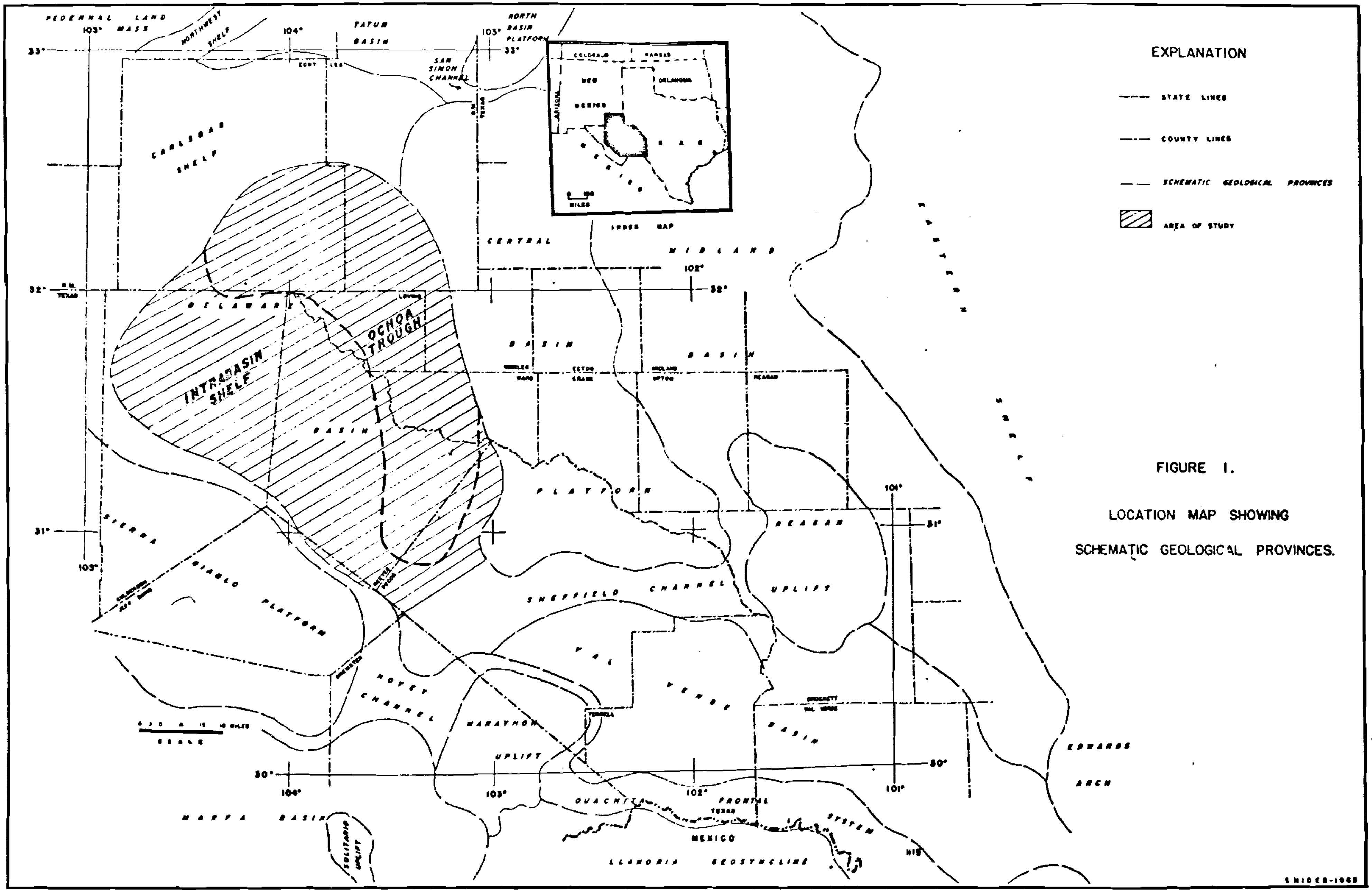

FIGURE 1.

LOCATION MAP SHOWING

SCHEMATIC GEOLOGICAL PROVINCES.

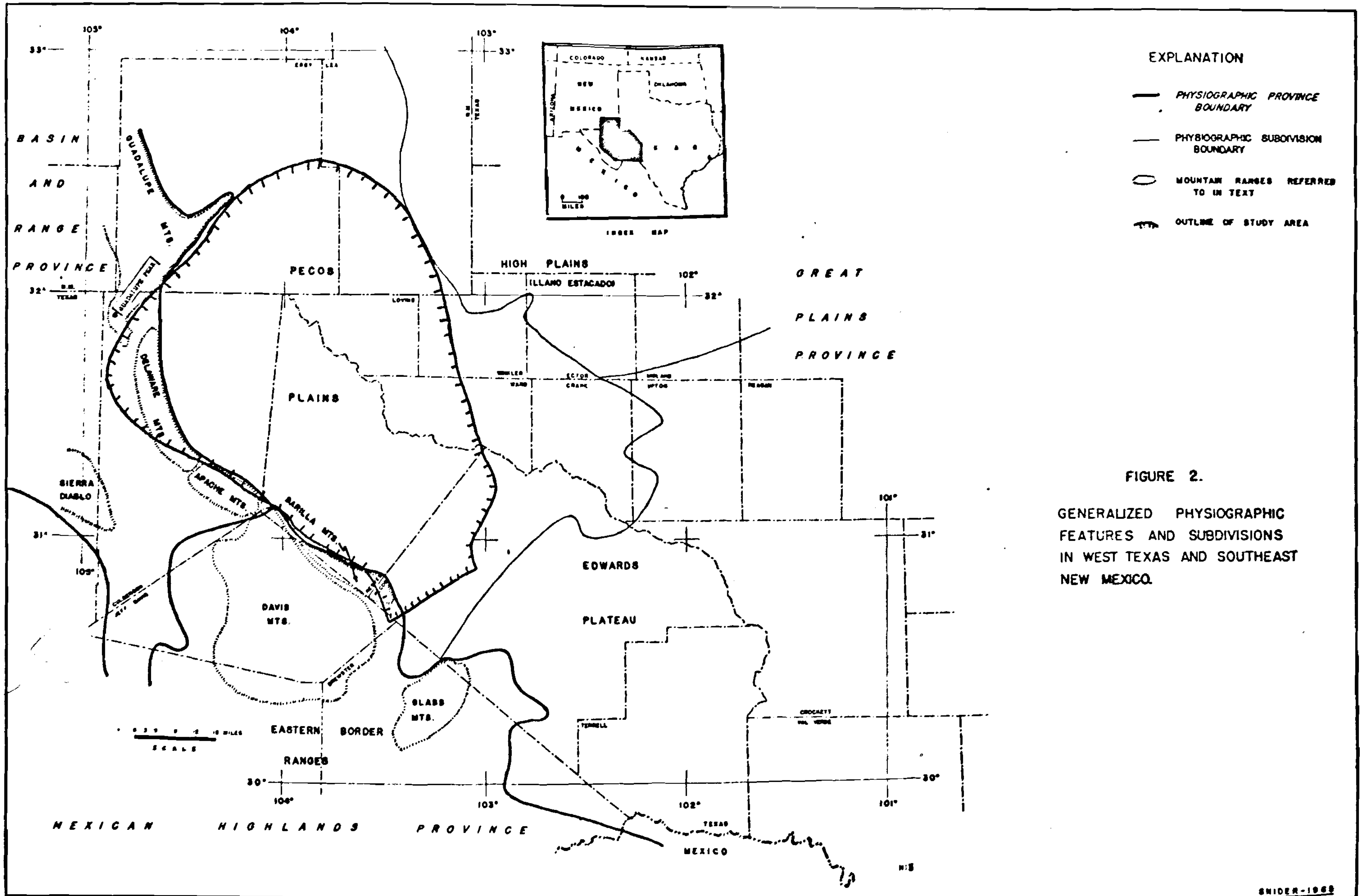

FIGURE 2.

GENERALIZED PHYSIOGRAPHIC FEATURES AND SUBDIVISIONS IN WEST TEXAS AND SOUTHEAST NEW MEXICO.

square miles in the southern part of the Pecos Plains or Pecos Valley of the Great Plains physiographic province (P. B. King, 1937, p. 2-5; Ogilbee and Wesselman, 1962, p. 10-13; and Fenneman and Johnson, 1946) (Fig. 2).

The basin is bounded on the south by the Glass, Barilla, and Davis Mountains of the Eastern Border Ranges of the Mexican Highland Province, and on the west and southwest by the Guadalupe, Delaware, and Apache Mountains of the Basin and Range Province. The original Delaware basin, however, probably extended westward as far as Sierra Diablo in the present Basin and Range Province. Relief within most of the Delaware basin area is low to moderate, with altitudes ranging from about 2350 feet near the Pecos River in Pecos County, Texas, to more than 3800 feet in Lea County, New Mexico; Guadalupe Peak, 8751 feet, is the highest point in the region.

Geologic Concepts and Setting

The delineation of the geological provinces in west Texas and southeast New Mexico started with the study of the limestones and dolomites exposed in the Guadalupe, Apache, Davis, and Glass Mountains and Sierra Diablo.[1] These rocks were recognized as Permian in age and later postulated to be of reef origin based on the fossils found. The geomorphology of the region, Trans-Pecos Texas and environs, was studied and the area to the east and north of the mountains recog-

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[1] Documented accounts of geological work in the Trans-Pecos area are given by P. B. King (1948) and J. M. Hills (1955).

nized as a topographic feature, the Toyah Basin. Shallow drilling into Permian strata encountered regionally similar lithologic areas. Areas made up predominantly of limestone in subsurface were interpreted as resembling the areas of exposed carbonate rocks of the Guadalupe Mountains and the Sierra Diablo platform. These limestone areas were named the Carlsbad shelf, Central Basin platform, and Eastern shelf. In one of the first structural analyses Bybee (1931) compared these limestone areas with the limestones in "block-faulted" Franklin Mountains, Hueco Mountains, and Diablo Plateau. The non-limestone areas were interpreted by Bybee as similar to the down-faulted troughs, Hueco Bolson and Salt Flat, in extreme west Texas. The areas between limestone "blocks" were found to contain Permian evaporites and were named the Delaware basin in the west between the Guadalupe Mountains and the Central Basin platform and the Main Permian basin (Midland basin) in the east between the Central Basin platform and the Eastern shelf. Finally, drilling to greater depths led to stratigraphic and basement igneous and metamorphic rock studies. Results show the Delaware and Midland basins to have been subsiding areas in which more sediments accumulated, especially in Permian time, than on the surrounding shelves or platforms.

The Delaware basin of southeast New Mexico and west Texas is a tectonic and lithologic province of the Permian basin, an area within the United States containing Permian sediments extending from Kansas in the north to the Texas-

Mexican boundary in the south. The southern end of the Permian basin has been subdivided into schematic geological provinces based upon tectonic and lithologic differences. The Delaware, Midland, Val Verde, Marfa, and Tatum basins are areas containing relatively thick sections of Paleozoic rocks compared with the shelf, uplift, and platform areas (Fig. 1). The Val Verde and Marfa basins have undergone post-Permian uplift and erosion which stripped off the strata of interest in this study; therefore, these basins are outside the scope of this study except for the tectonic trends shown in these areas that have also influenced sedimentation and tectonism in the Delaware basin.

The shelf, uplift, and platform areas, in addition to being less negative tectonically, are also different lithologically. The Sierra Diablo platform, the Central Basin platform, and the Eastern shelf are chiefly limestone areas (Bybee, 1931). The Carlsbad shelf has limestone, anhydrite, and clastics in Upper Permian rocks but relatively little salt below the salts of the Salado Formation.

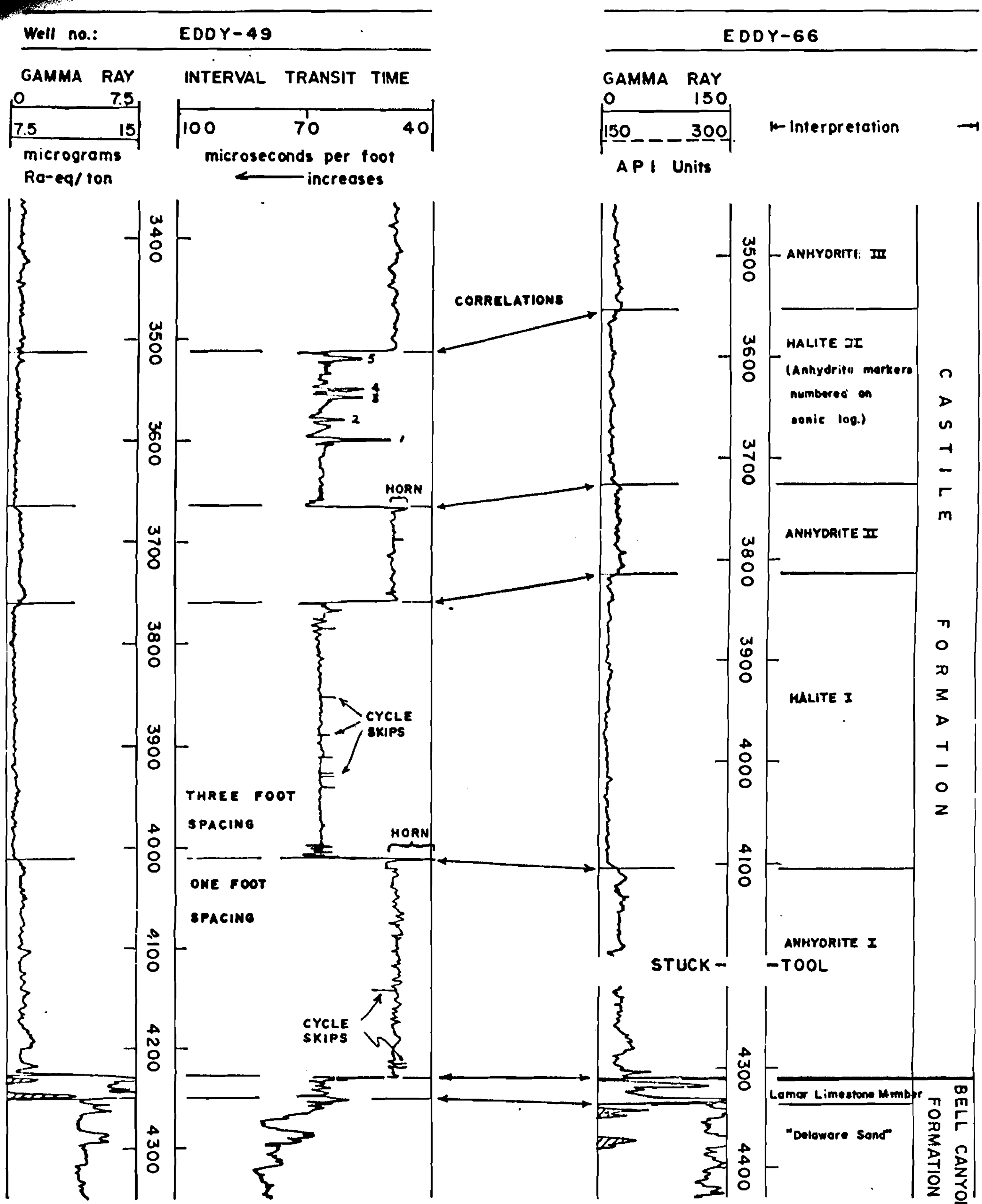
The Delaware basin is outlined to the south by the limestone-dolomite rocks of Upper Permian age in the Glass, Davis, and Apache Mountains, and to the west by the limestone-dolomite rocks of Upper Permian age in the Guadalupe Mountains and Sierra Diablo. The subsurface basin margin to the north and east consists of limestone-dolomite rocks of the Carlsbad shelf and the Central Basin platform (geological provinces are shown in Fig. 1; physiographic features in Fig. 2).

The Delaware and Midland basins show similar sequences of marine, clastic, and evaporite rocks but are separated by the Central Basin platform, mainly a limestone area.

In summation, the Delaware basin, covering an area of about 10,000 square miles, is a tectonic and lithologic province outlined in late Permian time at the basin margin by a limestone-dolomite environment, the "Capitan reef front", and separated from the genetically related Midland basin by the Central Basin platform.

Methods of Study

With the advent of logging the acoustic properties of lithologic units in subsurface about 1957, sonic or acoustic logging has been utilized in the Delaware basin for correlation of formations and lithologic interpretation (West Texas Geological Society, 1960, p. 93-94). The basic tool for this study was the sonic-gamma-ray log (Sonic Log, Acoustic Log, Continuous Velocity Log or CVL, Acoustilog). Figure 3 gives sonic-gamma-ray and gamma-ray logs showing correlations and lithologic interpretations of lower Castile anhydrite-halite units. Other data available were generalized stratigraphic sections from twelve oil fields in the Delaware basin (Herald, 1957), scout ticket information (Brooks, 1964), sample logs, and cross-sections. Gamma-ray, neutron, electric, caliper, and density (gamma-gamma) logs were used to supplement sonic-gamma-ray log data. The general sonic and gamma-ray properties were derived by studying the logs in



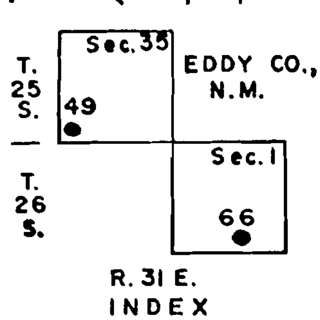


FIGURE 3. SONIC-GAMMA-RAY AND GAMMA-RAY LOGS FROM EDDY COUNTY, NEW MEXICO, SHOWING CORRELATIONS AND LITHOLOGIC INTERPRETATIONS OF CASTILE ANHYDRITE-HALITE UNITS.

areas where detailed sample descriptions were available, i.e., sample log of evaporite sequence vs. sonic-gamma-ray log (Fig. 4, in pocket, Loving-M vs. Loving-43). Theory and applications of electric well logs are given by Pirson (1963) and Schlumberger Well Surveying Corp. (1958).

Sonic-gamma-ray logs first were studied from Loving, western Ward, and northeastern Reeves Counties, Texas, with lithologic control from generalized geologic sections from nine oil fields in this area. Further lithologic control was maintained using sample logs from Lang (1935, 1939), from Adams (1944), and from cross sections of the West Texas Geological Society (1949). During the study, logs were constantly checked against cross sections, scout information, and generalized stratigraphic sections.

The physical properties shown on a sonic-gamma-ray log are the interval transit time, the reciprocal of the velocity of energy transmission through the rock, and the gamma-ray count. Characteristic interval transit times and velocities for the rocks in the Delaware basin are:

Solid Rock Type	Interval Transit Time (in u sec/ft)	Velocity (in ft/sec)
Halite	66-70	15,000±
Anhydrite, in Castile	49-53	20,000±
Anhydrite and gypsum, other	53-58	18,000±
Limestone and dolomite	40-45	21,000-26,000
Sandstone, siltstone, and shale	63-167+	6,000-16,000

The characteristic velocities shown are for a rock with very low porosity and little interstitial fluid. Velocity of a rock generally will decrease with an increase of porosity and fluid content since velocities of fluids are significantly lower than those of rocks. For example, the velocities (V) of some fluids and gas (Pirson, 1963, p. 227) are:

V water -- 5000 ft/sec from 0-2000 ft in depth
5200 ft/sec from 2000-4000 ft in depth
5400 ft/sec from 4000-6000 ft in depth

V oil -- 4300 ft/sec and varies with the type of oil

V gas -- 1200 ft/sec and varies mostly with pressure and temperature

V salt water is 10 to 20 percent greater than V fresh water.

Minor variations in sonic curves are mainly due to velocity differences at rock boundaries, tilted sondes, and differential borehole size, producing "horns" and "cycle-skips" (Fig. 3). Pirson (1963, p. 223) noted that gas-cut mud also tends to "cycle skip". A newer method of sonic logging, the BHC (bore-hole compensated) sonic system, nullifies cycle-skips and horns.

Gamma-ray curve characteristics are especially useful in determining the Rustler Formation boundaries and lithologic changes in the lower part of the Castile Formation. Units of measurement for gamma-ray curves are the API gamma-ray unit and micrograms of radium--equivalent per ton (μgm-Ra-eq/ton). The API gamma-ray unit is defined as 1/200 of the difference in log deflection between zones of low and high radiation in the gamma-ray radiation pit of the University of Houston (Pirson, 1963, p. 180). One µgm-Ra-eq/ton is approximately equivalent to 16.5 API units (Pirson, 1963, p. 181).

The Dewey Lake and Triassic redbeds above the Rustler Formation have a relatively high gamma-ray count, with a sharp deflection to low values occurring at the top of the highest Rustler anhydrite. The whole Rustler Formation section has a characteristic gamma-ray curve (Fig. 4, in pocket). Beneath the Rustler, the Salado rocks generally show extremely low gamma-ray counts except for potash, siltstone, and shale layers. In the lower Castile, the gamma-ray counts for both halite and anhydrite are low (2 to 25 API units), but the halite count is generally 7 to 15 API units lower than the anhydrite count. Figure 3 shows correlations and lithologic interpretations in the lower part of the Castile Formation based upon gamma-ray curves from two wells about 1.5 miles apart in Eddy County, New Mexico. It should be noted that the relative difference of gamma-ray counts reflects the lithologic changes. General range of counts for two gamma-ray curves of Upper Permian rocks in the Delaware basin is given on the following page in absolute units; however, each log shows a different range due to differences in sensitivity, calibration, and log zero reference line (wells from Fig. 7, in pocket).

Rock Type	Gamma-Ray Count (API Units)	
Wells:	Lea-41 (Low)	Lea-37 (Moderate)
Halite, lower part of Castile Formation	2-5	9-11
Halite, other	8-12	12-21
Anhydrite	10-12	18-22
Carbonates	20-35	30-45
Clastics	40-80	50-90
Potash salts and bentonite	75-150+	85-150+

Problems in interpreting lithologic character from sonic-gamma-ray logs are:

1. A bed must have a minimum thickness before the characteristic velocity is reached due to the configuration of the receivers in the measuring device. In a two-receiver system, the bed must have a thickness greater than the spacing between receivers, i.e., with 3-foot spacing, the beds must be more than 3 feet thick.

2. A characteristic velocity may be due to mixtures of several minerals and/or fluids in a rock, whereas several combinations of minerals and/or fluids may give rise to the same velocity. As an example, an interval transit time of 60 microseconds/foot may be due to halitic anhydrite, or limestone with a velocity of 23,000 ft/sec with 12 percent porosity filled with water, or 50 percent anhydrite, 50 percent dolomite with 10 percent porosity filled with water.

3. Cycle skipping in parts of the section with thin

marker beds limits correlations.

4. Hole enlargements due to excessive solution of salt or to caving will give velocities lower than normal.

The simplicity of lithology in the sequence shown by the intensive study of samples and cores by Adams (1944), the lateral continuity and uniformity in lithology of units throughout the Delaware basin, and the advanced technology in logging methods have overcome most complications due to the problems mentioned.

Wells used in this study are denoted by county (i.e., Lea-36). Figure 5 (in pocket) shows well locations and lines of cross section. Well data are given in the Appendix and in Figure 6 (in pocket).

Correlation Technique

The following technique for correlation was used. First, sonic-gamma-ray logs of wells near the Pinal Dome Oil, Means well No. 1, were checked against the description of the Rustler, Salado, and Castile Formations by Lang (1935, 1939). Preliminary observations were made on 252 well logs in and near the Delaware basin area as outlined by King (1942). A preliminary total evaporite sequence thickness map was made. Well logs for 380 more wells were obtained for areas that had poor well control or for areas that showed critical variations in regional trends. In some areas having dense well coverage, such as oil fields and potash-producing areas, several well logs were obtained to check local variations. Well logs were then laid out side by side and the marker beds correlated. Generally 15 to 20 logs were correlated, with the last 2 or 3 being used as references for the next 15 to 20 logs.

The logs were studied from a reference area in Loving County, Texas, and Lea County, New Mexico, near the Pinal Dome well. After 30 to 40 wells had been correlated, a closed traverse was made to the original log used (usually well log Loving-33). The correlations of the interpreted lithologic units obtained from sonic-gamma-ray logs were checked against published descriptions, scout-ticket reports, sample logs from published reports, and published driller's logs. Gamma-ray, gamma-ray-neutron, gamma-ray-electric, and electric logs were used to fill in areas where sonic-gamma-ray logs were not available. These logs were also checked against scout-ticket information and sample logs wherever possible. Scout-ticket information for many wells has been checked against final map interpretation, such as Anhydrite I thickness interpreted from the base of the lowest salt to the top of the Lamar Limestone Member. No major discrepancies were found. In some logs, part of the log contained gamma-ray information only. If the characteristic gamma-ray curve for the Rustler Formation was not readily picked, information from published sources was checked. As a last resort, the less reliable scout-ticket information was used.

Little difficulty was encountered in correlating marker beds within the area of the Delaware basin having well-developed sequences of anhydrite and halite in the Castile and Salado Formations. Halite marker beds, such as Halite I, Halite II, halite beds in Anhydrite IV and Anhydrite V (Table 2 and Fig. 4), and anhydrite beds in the Salado Formation (Figs. 7, 8, 9, and 10) are readily traceable. In areas such as Eddy and Lea Counties, New Mexico, where Anhydrite IV and Anhydrite V are not well developed, the sequence of anhydrite and halite beds was checked by correlating the number of anhydrite and halite beds in the Castile while reading up the log and then by correlating the anhydrite and halite beds in the Salado while reading down the log. In most instances the same contact was reached. When there was a discrepancy, the characteristic velocity of the Castile anhydrite usually allowed determination of the Castile-Salado contact. If no conclusive results from analysis of the sequence or velocity characteristics were reached, the gamma-ray characteristics were used. Finally, if no other method was available, the Castile-Salado contact was placed at the top of an anhydrite bed by interpolating the regional trends from the closest well logs available. Similarly, in the case of the Salado-Rustler contact in areas where the Salado and Rustler have similar lithology in a sequence of halite beds and interbedded clastics, gamma-ray characteristics and interpolation were used to choose the contact.

Terminology

King (1942, p. 544) described the need for terms "to express the environment and structural relations of the different provinces of Permian time." He defined these terms as follows:

> "The places of greatest subsidence are. . . referred to as basin areas, and the rocks laid down in them as having a basin facies. Throughout Permian time, such provinces had more or less well defined edges, where the most abrupt changes in facies took place. These are termed marginal areas. During some, but not all of Permian time, the deposits laid down in the marginal areas were limestone reefs. Where these are prominently developed, the margin may be termed the reef zone, and the shelf behind it the back-reef area.
>
> Beyond the basins were regions of less subsidence, or, from time to time, of actual uplift. These provinces are referred to as shelf areas, and the rocks laid down in them as having shelf facies. Between some of the basins were relatively long, narrow shelf areas, apparently more active tectonically than the other shelves. These are referred to as platforms. Several of the basins were connected around the ends of the platforms by narrow depressions that are called channels."

One major difficulty with this type of nomenclature is that interpretation of environments through the regional structural relations is not valid for all units within a sequence of rocks. There is a need for more definitive terms to express strictly structural relationships within the Delaware basin. The following terms are used in this work:

trough, an elongate, linear or arcuate, regional depression;

intrabasin shelf, a region within a basin of less subsidence than a trough; and

intrabasin shelf margin, an area between an intrabasin shelf and a trough.

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Stimulating discussions were held with Dr. Vincent C. Kelley, on salt movements and structural relationships; with Dr. Sherman A. Wengerd, on salt tectonics and sedimentational aspects; with Mr. Charles B. Read, on stratigraphic and depositional relationships; and with Dr. Douglas W. Kirkland, on the geologic history of the evaporites.

Pubco Petroleum Corporation kindly made their files available, and Mr. James L. Albright helped interpret some of the electric logs. Mr. Ted Wilson and the West Texas Electrical Log Service gave exceptional service and help in well-log orders. The Midland Map Company kindly furnished several base maps and gave permission to use their Permian basin field map.

Finally, the writer acknowledges the assistance of his wife, Dorothy, for typing the manuscript, for proofreading, and for encouragement and dedication while this work was in progress.

STRATIGRAPHY

General Statement

Several formations (Table 2) of Permian rocks in the Delaware basin are important in the current investigation. The Brushy Canyon, Cherry Canyon, and Bell Canyon Formations of the Delaware Mountain Group show the cyclical pattern of sedimentation prior to evaporite deposition and evidence of changes in water depth. The Delaware Mountain Group, a sequence of clastic beds with interbedded limestone, is bounded at its base by an unconformity and changes rapidly through a short, vertical transition zone to the overlying Upper Permian evaporite sequence of the Castile, Salado, and Rustler Formations, consisting mainly of anhydrite, halite, limestone, and dolomite. The Dewey Lake Redbeds overlie the Rustler Formation but, being in sharp contrast with the evaporite sequence, are beyond the scope of this work.

Paleozoic rocks in the Delaware basin have a total thickness of more than 33,000 feet (Table 1). Rocks representing every system in the Paleozoic are probably present. Rocks of the Permian System have a maximum thickness of about 19,450 feet, or about 60 percent of the total section. Within the Upper Permian Series of the Delaware basin one finds one of the world's thickest sequences of cyclic evaporite rocks--the Castile-Salado-Rustler complex--with a maximum thickness of 4,682 feet found in subsurface in southern Lea County, New Mexico. Cyclical deposition is prominently displayed in rocks from the Brushy Canyon Formation of the Delaware Mountain Group through the Rustler Formation of the Upper Permian Series--a thickness of more than 7,700 feet, almost 40 percent of the Permian section or about one-fourth of the total Paleozoic section. Varve-like laminations are found in strata from the Bone Spring Group, Leonard Series, to the Rustler Formation, Ochoa Series, a thickness of more than 10,000 feet.

The stratigraphic discussion that follows is divided into three parts: 1. Guadalupe Series; 2. Ochoa Series; and 3, cyclic aspects and conditions of deposition. The second part, the Ochoa Series, contains a general description of the evaporite rocks, discussions on correlations outside and within the Delaware basin, and problems in interpretation of depositional conditions in addition to formation descriptions.

The Castile Formation is emphasized in this report for two reasons: first, the least concentration of study in the past has been on the Castile; and second, the simple lithologic sequence lends itself to a detailed analysis of basin development and tectonism during and after deposition. The Salado Formation is subdivided into lower, middle, and upper units, where possible, for correlation studies and for analysis of apparent tectonic activity during Salado deposition. The Rustler is considered as a unit for correlation and tectonic studies.

Table 1. Stratigraphic table of Paleozoic rocks of the Delaware basin, west Texas and southeast New Mexico. (Modified from Vertrees and others, 1959.)

System	Series		Stratigraphic units	Thickness (in feet)
Quaternary to Triassic				
Permian	Upper[a]	Ochoa	Dewey Lake Redbeds	0-600±
			Rustler Formation	0-550±
			Salado Formation	0-2000±
			Castile Formation	0-2000±
		Guadalupe	Delaware Mountain Group	
			Bell Canyon Fm.	700-1200±
			Cherry Canyon Fm.	1000±
	Lower[a]		Brushy Canyon Fm.	0-1000±
		Leonard	Bone Spring Limestone	800-3600±
		Wolfcamp		1000-7500±
Pennsylvanian			Black shale	0-200±
		Strawn		0-1100±
		Atoka		0-1100±
		Morrow		0-1200±
Mississippian		Chester Kinderhook		0-3100±
Devonian-Silurian			Cherty limestone (Miss.?)	0-500±
			Hunton Group	0-1800±
Ordovician		Upper	Montoya Formation	0-600±
		Middle	Simpson Formation	100-2250±
		Lower	Ellenburger Formation	500-1600±
Ordovician-Cambrian			—?—————?— Bliss Formation	0-150±
Precambrian				
			Total maximum thickness	33,050

[a] From Cohee, 1960.

Note: Single lines across column of stratigraphic units represent probable regional unconformities.

Table 2. Classification of the formations in the Delaware basin as used in this report. (Modified from P. B. King, 1948, p. 12.)

Series: King (1948)	Series: Cohee (1960)	Stratigraphic units	
Ochoa	Upper		Dewey Lake Redbeds
Ochoa	Upper		Rustler Formation
Ochoa	Upper		Salado Formation: Upper Salado unit Middle Salado unit Lower Salado unit
Ochoa	Upper		Castile Formation: Anhydrite V Anhydrite IV Anhydrite III Halite II Anhydrite II Halite I Anhydrite I
Guadalupe	Upper	Delaware Mountain Group	Bell Canyon Formation: Unnamed clastic unit Lamar Limestone Member Unnamed clastic unit McCombs Limestone Member Unnamed clastic unit Rader Limestone Member Unnamed clastic unit Pinery Limestone Member Unnamed clastic unit Hegler Limestone Member
Guadalupe	Lower	Delaware Mountain Group	Cherry Canyon Formation: Unnamed clastic unit Manzanita Limestone Member Unnamed clastic unit South Wells Limestone Member Unnamed clastic unit Getaway Limestone Member Unnamed clastic unit
Guadalupe	Lower	Delaware Mountain Group	Brushy Canyon Formation
Leonard	Lower		Bone Spring Limestone

Guadalupe Series

Lithology

P. B. King (1948) subdivided the Guadalupe Series into three units: Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. These three formations make up the Delaware Mountain Group in the Delaware basin. The Guadalupe Series unconformably overlies Leonard Series. The Ochoa Series, or Upper Permian evaporite sequence, conformably overlies the Guadalupe Series.

In the Delaware Mountains, the Delaware Mountain Group is about 2,700 to 3,500 feet thick, with each formation about one-third the thickness of the whole section. The Brushy Canyon Formation consists of massive, yellow or brown sandstone, coarser grained than the other units, and making up ledges or forming caps of flat-topped mesas. Generally buff, fine-grained, thin-bedded and locally shaly sandstone crops out on slopes between the massive sandstone units (King, 1948, p. 28-29). In places there are thin, interbedded layers of black, hard, platy, shaly sandstone. Some lenticular beds within the massive sandstones contain fusulinid tests and, less commonly, abraded crinoid stems and brachiopod shells with little sandstone matrix.

The Cherry Canyon Formation is made up of sandstone with interbedded limestone. The sandstones of the Cherry Canyon occur as beds a few inches thick, with some thicker layers and layers of hard, platy, shaly sandstone (King, 1948, p. 34). The limestone beds in most of the formation are lenticular, consisting in places of solid limestone units 100 feet or more thick, and in places of thin limestone beds, interbedded with thicker layers of sandstone. The limestone exhibits considerable variety in lithologic character from place to place (King, 1948, p. 34). Three limestone members were distinguished by King (1948): the lower Getaway Limestone Member, the middle South Wells Limestone Member, and the upper, more persistent Manzanita Limestone Member. The Getaway and South Wells Limestone Members are both described as being in the lower part of the formation. Of some note are characteristic volcanic ash beds that are intercalated with limestones in the Manzanita Limestone Member. These beds are altered volcanic ash appearing generally as pale apple-green siliceous shales or cherts, and in places are waxy, green, bentonitic clays. The volcanic ash beds have been identified in numerous wells drilled in the Delaware basin area down the dip to the east of the outcrops described (King, 1948, p. 37).

The Bell Canyon Formation contains buff-colored and extremely fine-grained sandstone beds like those of the Cherry Canyon. Five limestone members are distinguished in the Bell Canyon Formation. The Hegler, Pinery, and Rader Members are closely spaced in the lower fourth of the unit and are separated by several hundred feet of sandstone from the Lamar Member which is near the top of the Bell Canyon Formation. The McCombs Member is about halfway between the Rader and the Lamar and is the "flaggy limestone bed" of King (1948, p. 54-57). The limestones are thinner, but more persistent, than those in the Cherry Canyon Formation and are separated by sandstones containing a few calcareous beds. The Rader Limestone Member consists of several layers of gray, fossiliferous, granular limestone as much as three feet thick, containing numerous rounded pebbles; of interbedded, thinner, dark-gray limestone; and of an apple-green, silicified, volcanic ash bed in places as much as two feet thick. The other limestone members are generally gray or dark-gray, fine-grained, thin-bedded limestone with interbedded shaly or platy sandstone.

Hull (1955) studied the sandstones of the Delaware Mountain Group and noted an arkosic nature of the Delaware Mountain sandstone, although several samples of Guadalupian sandstone in a narrow belt several miles behind the reef zone in the Guadalupe Mountains contained practically no feldspar.

Ochoa Series

General Statement

The Upper Permian evaporite sequence consists of the Castile Formation, the Salado Formation, and the Rustler Formation. Dewey Lake Redbeds overlying the Rustler Formation are the uppermost unit of the Ochoa Series in the Delaware basin.

The evaporite sequence is made up of anhydrite, gypsum, halite, limestone, and dolomite, with minor amounts of potash minerals and clastics. The total evaporite sequence ranges in thickness from about 2,000 feet in the outcrop area in southern Eddy County, New Mexico, and in eastern Culberson and western Reeves Counties, Texas, to more than 4,600 feet in the subsurface east of the outcrop area (Fig. 11). The sequence maintains a thickness greater than 3,000 feet within a long, relatively narrow area parallel to the north and east limits of the Delaware basin from south-central Eddy County, New Mexico, to southeast Reeves and west Pecos Counties, Texas (the Ochoa basin of Kroenlein, 1939). This feature, the Ochoa trough, is about 28 miles wide in the northern part of the basin, becomes constricted to about 15 miles in southwestern Ward County, Texas, and then broadens to about 40 miles in the southern part of the basin along the Reeves-Pecos county line. The thickest sections are found in a north-south trend, 8 to 20 miles west of the edge of the Central Basin platform.

Stratigraphic relations and basin configuration are illustrated in north-south and east-west cross sections (Figs. 7, 8, 9, and 10, in pocket) and thickness maps (Figs. 11 and 14 to 24, in pocket).

Regional Correlation

Rapid lateral changes in rock types at the margins of the Delaware basin make it difficult to correlate the Upper Permian evaporites with equivalent strata at the basin margin and outside the basin. Anhydrite and salt are generally eroded in critical areas. Relative amount of structural relief in the Guadalupe Mountains due to later tectonic flexing versus the amount due to initial dip of the strata has not yet been conclusively determined. Subsurface correlations depend, in part, upon density of well control and are interpreted on the basis of lithology alone, inasmuch as few fossils have been reported from the evaporite rocks. Fusulines, the major index fossils from subsurface samples, are not known in Ochoa rocks within the Delaware basin (R. V. Hollingsworth, personal communication, March, 1965).

The study of physico-chemical changes in sea water leading to evaporite deposition and its relationship to "reef" growth may lead to revision of previous correlations. Interpretation as to the lateral equivalence of limestone and dolomite with anhydrite and halite has been inhibited by the fact that growth of limestone and dolomite reefs or shoals has been assumed to cease at the beginning of anhydrite deposition. For example, Grabau (1924, p. 434) and Kroenlein (1939, p. 1684), among others, previously attributed "reef death" to concentration of brines within a restricted basin; Grabau for the bryozoan reefs of the Zechstein in Germany, and Kroenlein for the Capitan reef of the Delaware basin.

Striking similarities exist between the Upper Silurian Cayugan evaporites in the Michigan and Ohio basins and adjacent areas as described by Alling and Briggs (1961) and the evaporites of the west Texas region. The Michigan and Ohio basins lay side by side with a thicker sequence of evaporites containing a greater amount of halite in the Michigan basin than in the Ohio basin. This is somewhat analogous to the setting of the Delaware and Midland basins. The Michigan and Ohio basins were essentially surrounded by carbonate reef complexes similar to the Delaware and Midland basins; the lithologies in both areas are carbonate-evaporite rocks. They postulated that reef growth may have been in part controlled by "positive" tectonic elements similar to the situation in the west Texas region. Major passes through the reef platform were identified by Alling and Briggs as "inlets". Similar inlets have been found between the Delaware basin and the Carlsbad shelf and linking the Delaware basin and the Midland basin.

Alling and Briggs (1961, p. 539-540) illustrated contemporaneity of reef growth and salt deposition and concluded: "The stratigraphic relations also substantiate the concept that the evaporites were deposited in reef-ringed basins surrounded by normal marine seas." The importance of this analogous situation is that reef growth may have occurred with evaporite deposition in the Delaware basin. Moore (1959), by tracing key beds, observed that "gypsum rock of the Castile formation of Permian age in the Delaware basin may be correlative with the upper part of the Capitan limestone at the margin of the basin." Future paleosalinity studies should resolve the question of favorable versus inhibiting conditions for reef growth of the Capitan limestone due to associated salinity changes in the Delaware basin. Relying on Moore's observation, it may be assumed that reef growth was contemporaneous with Castile deposition.

Correlations of the evaporite sequence with units outside the Delaware basin are shown in Figure 12. Hall (1960, p. 85-88) has summarized Upper Permian correlations prior to 1960 and has suggested revision based upon regional rather than local inference. He stated:

> "an integral part of the writer's suggestion is that the build-up of Capitan carbonates, on parts of the shelf-margin of the Delaware basin, influenced the environment locally rather than regionally. The cross section [his figure 4] is an attempt to illustrate this concept with the aid of well data. In particular, it shows the abrupt change to evaporitic sedimentation in post Grayburg-Bell Canyon time everywhere except at the shelf-margin where the local influence of the Capitan may have influenced the temporary continuance of carbonate sedimentation to form the Carlsbad formation. In this connection, it may be that the large fusuline Polydiexodina is present in the Carlsbad because it survived locally a little longer in the favorable shelf-margin environment, and also because some of the lower Carlsbad may have originated as Capitan detritus of post-Capitan age."

An alternative suggestion for the presence of Polydiexodina in the Capitan and Carlsbad rocks is that this fusuline is an environmental indicator of increased salinity. The similarity in change of Parafusulina in the Cherry Canyon Formation to Polydiexodina in the Bell Canyon Formation and younger strata with the change of Parafusulina and Neoschwagerina in the Rotliegende strata to Polydiexodina in the Zechstein evaporites in Germany (Brinkmann, 1960) certainly bears investigation.

As noted previously, King defined environmental facies with basin, basin margin, shelf, and platform structural areas. In the Delaware basin rocks of the Delaware Mountain

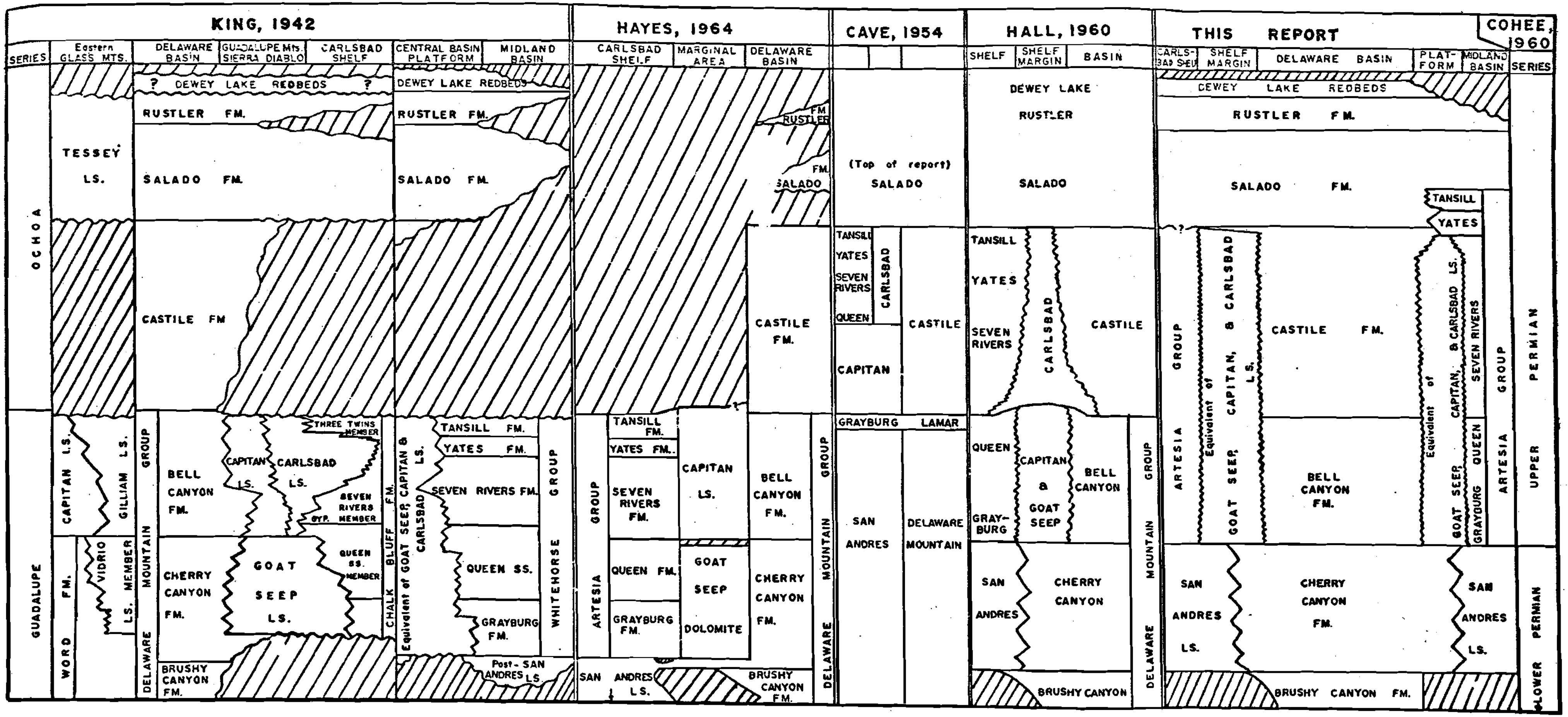

FIGURE 12. UPPER PERMIAN CORRELATIONS IN WEST TEXAS AND SOUTHEAST NEW MEXICO.

Group were defined by King (1948) as Guadalupe Series equivalents. Adams and others (1939) defined the Castile (Lower Castile), Salado (Upper Castile), Rustler, and Dewey Lake as Ochoa Series in the Delaware basin.

At the basin margin, massive limestones and dolomites of the Guadalupe Series have been divided into the Goat Seep below and Capitan Limestone above, comprising the reef zone (King, 1942 and 1948). Back-reef flaggy or bedded limestones equivalent to Capitan were originally mapped as Carlsbad Limestone (see King, 1942, Fig. 12). Flaggy or bedded limestone and dolomite overlying Capitan Limestone in the Guadalupe Mountains and massive units in subsurface were called Carlsbad in later studies. Current usage generally ascribes back-reef bedded limestone at the same stratigraphic level of the massive Capitan as equivalent to Capitan. Beds of the Carlsbad are stratigraphically higher, although some flaggy limestone of the Carlsbad may drape over the Capitan reef and, therefore, seem stratigraphically equivalent to Capitan (see Hall, 1960, Fig. 12).

Upper Guadalupe Series rocks of the shelf area consist of carbonate, evaporite, and clastic rocks of the Artesia Group (Tait and others, 1962). The Artesia Group sequence from youngest to oldest includes the Tansill, Yates, Seven Rivers, Queen, and Grayburg Formations (see Hayes, 1964, Fig. 12).

Tracing of marker beds in well logs from Reeves County within the Delaware basin to Pecos County in the Central

Basin platform area led this investigator to a tentative correlation of the Castile with the Seven Rivers (El Capitan) and lower Yates (Fig. 10, Reeves-89 to Pecos-74). The Salado of the Delaware basin may be correlative with the upper Yates, Tansill, and Salado of the Midland basin. Sections in Reeves County wells were correlated from representative sections of the Castile and Salado to the north (Fig. 7). Formation depths in well number Pecos-74, Pure Oil, W. C. Tyrrell No. 1 from the Gomez Field, Pecos County (in Brooks, 1964, p. B-85 - B-86), have been described in Midland basin or Central Basin platform terminology as: Rustler 1652 ft, Yates 2988 ft, El Capitan 3386 ft, Delaware sand 4845 ft, Bone Springs 7130 ft. Whether the noted Delaware sand is equivalent to Queen, Cherry Canyon, or Brushy Canyon sand is not known. This writer has chosen the Queen, relying on Hall's (1960) correlation. In addition, the consistently low gamma-ray counts in well logs and the sequence of evaporites of the Seven Rivers Formation as shown by Tait and others (1962) are similar to Castile characteristics. However, the correlations used in this report (Fig. 12) are emphasized as being tentative.

Castile Formation

General Statement. The Castile Formation was named by Richardson (1904, p. 43) for Castile Spring, in the east-central part of Block 61, T-2, T & P, Culberson County, Texas. Lang (1935, 1939) subdivided the evaporites in subsurface into the Castile Formation, the lower part containing more

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General Statement. The Castile Formation was named by Richardson (1904, p. 43) for Castile Spring, in the east-central part of Block 61, T-2, T & P, Culberson County, Texas. Lang (1935, 1939) subdivided the evaporites in subsurface into the Castile Formation, the lower part containing more anhydrite than halite, and the Salado Formation, the upper part containing more halite than anhydrite and notable amounts of polyhalite. The Castile Formation crops out within the Delaware basin in southern Eddy County, New Mexico, and Culberson County, Texas. Representative well logs are shown in Figure 4 (in pocket).

The Castile Formation is characterized by laminated calcareous anhydrite interrupted by halite in the northern and eastern parts of the Delaware basin. Lower halite beds are traceable from western Eddy County, New Mexico, to southern Reeves County, Texas, a distance of about 150 miles. Between and within the halite beds are laminated anhydrite units. The lowest unit that can be correlated over the Delaware basin is Anhydrite I. Above Anhydrite I is a relatively pure halite bed, Halite I. The next higher unit, Anhydrite II, is remarkably constant in thickness. Above Anhydrite II is a halite bed, Halite II, with five distinct but thin anhydrite markers. A thick unit of anhydrite, Anhydrite III, and a sequence of anhydrite and halite beds showing a characteristic cyclic repetition, Anhydrite IV, are above Halite II. The uppermost unit of the Castile, Anhydrite V, consists of anhydrite and halite and also shows a characteristic cyclic repetition in the eastern and southeastern parts of the Delaware basin.

These units were chosen to show the large-scale cyclic pattern as described by Adams (1944) and Baker (1929). In addition to the cyclic nature of these units, the distribution and thickness trends of anhydrite and halite can be used to interpret basin development and associated tectonic patterns during Upper Permian time.

Contact of the Castile Formation with the Salado Formation in this study was taken as the top of the anhydrite sequence above halite in Anhydrite IV in wells near Pinal Dome Oil, Means well No. 1, Loving County, Texas (Fig. 4). After correlating anhydrite marker beds over the Delaware basin, the contact of this report was found to coincide with the top of the Fletcher Anhydrite Member of Adams (1944) in the northern parts of the Delaware basin. This is a desirable contact between the two formations for the following reasons:

1. The top of the Fletcher Anhydrite Member is traceable over most of the Delaware basin;

2. Lang (1939, p. 1572) noted that either the top or bottom of the member would be at a useful stratigraphic position;

3. Moore (1960) suggested and used the top of the Fletcher as the Castile-Salado contact; and

4. The Stratigraphic Research Committee of the Roswell Geological Society (1958) has adopted the top of the Fletcher as the Castile-Salado boundary (see North-South stratigraphic cross section, Delaware basin--Northwest shelf, 1958, in Sweeney and others, 1960).

Comparison was made between Continental Oil, Bell Lake Unit well No. 6 (Lea-25), the most northeasterly well of

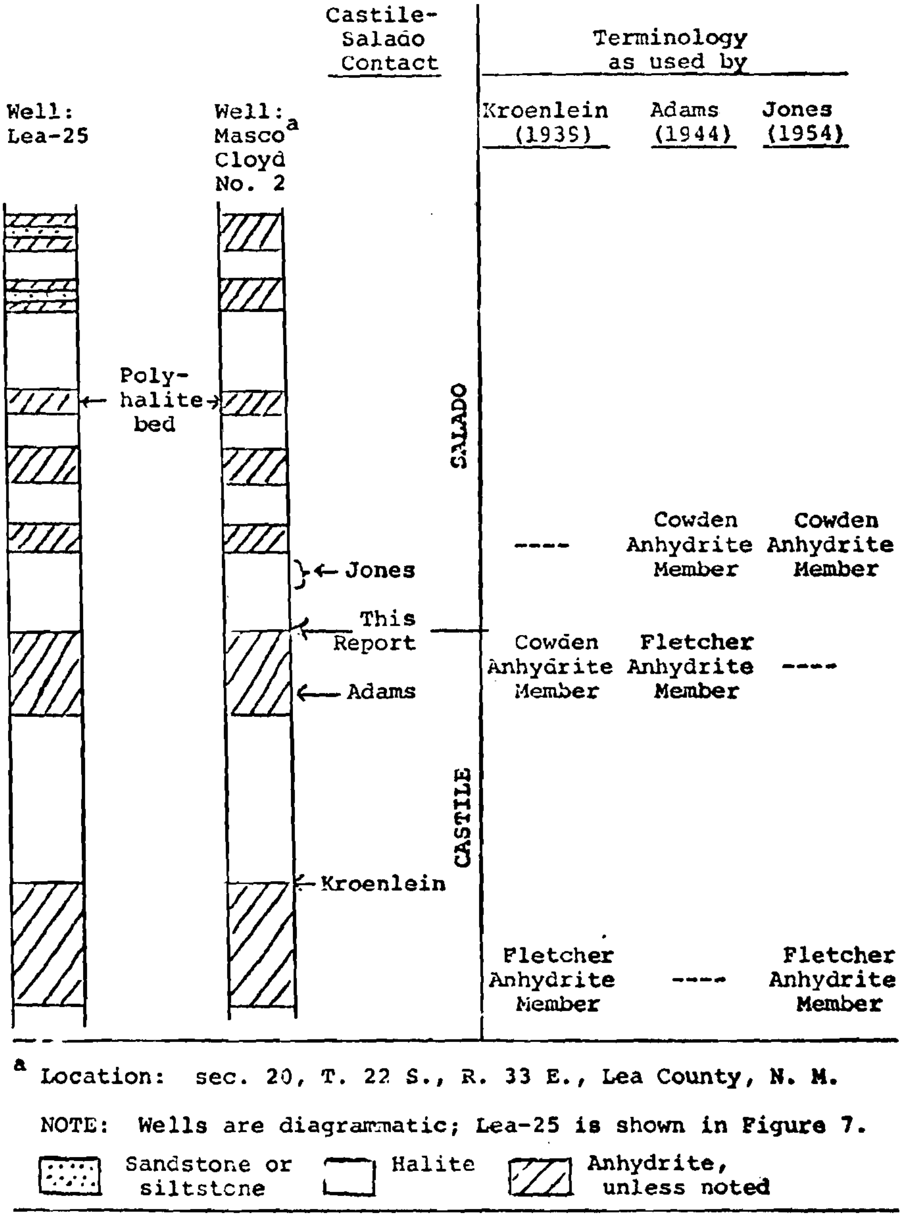

Figure 13. Comparison of correlations of anhydrite beds in northeastern part of the Delaware basin, Lea County, New Mexico.

this study in the Delaware basin, and the Masco, Cloyd well No. 2, approximately $\frac{1}{4}$ to $\frac{1}{2}$ mile northeast of Lea-25, which was used by Adams (1944) and Kroenlein (1939) in their studies. Figure 13 shows the different postulated Castile-Salado contacts as well as the apparent correlations of the anhydrite beds as interpreted from published cross sections.

The thickness of the Castile Formation ranges from 1,250 feet in the western part of the Delaware basin to more than 2,000 feet in the east-central part and in the extreme northeastern part of the Delaware basin (Fig. 14, in pocket). A net footage map of halite in the Castile Formation (Fig. 15, in pocket) shows the range of thickness from no halite in the western, southern, and southeastern parts of the Delaware basin to more than 650 feet in east-central and northeastern parts. A net footage map of non-halite strata, primarily laminated anhydrite (Fig. 16, in pocket) shows a range of thickness from 1,000 to 1,500 feet over most of the basin. Thicknesses of non-halite greater than 1,500 feet are generally found along the basin margin to the east and to the south.

Lithology. The Castile Formation consists largely of laminated anhydrite, halite, and limestone with minor amounts of clastics. Udden (1924, p. 350) described the laminated anhydrite as consisting of lighter layers of pure anhydrite making up the bulk of material and thinner, darker layers of microscopic crystals of calcite with "microscopic thin films of a brownish material from which a small amount of bitumen or oil may be distilled." The bituminous material and calcite, in most cases, make up less than one-fourth of the thickness of each lamination. Adams (1944, p. 1604) studied the laminations and noted:

> "A residue of deep brown bituminous flakes remains to mark the parting when the calcite is digested in acid. Even where the calcite is missing, brown organic bands are present along the bedding planes of the anhydrite. The bituminous material, however, is nowhere mixed with the white anhydrite as it is with the calcite."

King (1942, p. 611; 1948, p. 89) and Hayes (1964, p. 14) noted that the calcareous content increases downward with the basal few feet of the Castile being laminated brownish-gray limestone. A chemical analysis of a sample from the basal beds of the Castile east of the southern Guadalupe Mountains showed 96.63 percent by weight of $CaCO_3$, 1.17 percent by weight of $MgCO_3$, 0.47 percent by weight of $CaSO_4$, with insoluble residue and oxides 1.57 percent by weight, a total of 99.84 percent by weight (King, 1948). Comparison of analyses with Guadalupe Series limestones shows the Castile sample to have similar ranges of constituents as the Rader and Lamar Limestone Members, with the exception of the Castile containing $CaSO_4$.

The most intensive study of the lithology of the Castile Formation was made by Adams (1944, p. 1603-1608). He noted the following:

> "The Castile, the basal formation of the Ochoa series, is composed of anhydrite, calcite-banded anhydrite, salt, limestone, minor amounts of other evaporites, and minute quantities of very fine clastics. No potash salts have been reported. . . .

. . . . Calcite-banded anhydrite, the main constituent of the Castile section, is made up of alternating bands or laminae of calcite and anhydrite. . . .

There are almost unlimited variations in the character of the banding. Where evenly developed, the laminae resemble chemical varves with the anhydrite layers two or three times as thick as the calcite. . . . Individual carbonate partings range from scattered calcite crystals on the anhydrite bedding planes to beds of thinly laminated limestone several feet thick. The limestones are not dolomitic. The average thickness of the calcite laminae appear to be about 1/20 inch. Thin sections show that the thinnest laminae are made up of one layer of coarsely crystalline calcite, and that the thicker beds are coarsely granular limestone.

Irregularly distributed through the normal banded zones are beds of unlaminated anhydrite, ranging from 1/2 inch to several feet in thickness, and are separated by banded zones that vary even more widely. There is a tendency for secondary calcite crystals to develop in fractures and in wavy ghostlike bands or even sprinkled about at irregular intervals, through these thicker anhydrites. The secondary calcite is almost everywhere lighter-colored than that of the normal laminae.

A thick calcite band is to be expected immediately above each thick anhydrite member. However, it seems that the anhydrite bed has to be three or four times as thick as the regular anhydrite laminae before any corresponding calcite cap develops. The sequence is not invariable. Some over-thickened anhydrites seem to have no corresponding cap, and even where the cap is exceptionally thick it may be separated from the thick anhydrite zone by one more or less normal, but commonly paper-thin, calcite lamina. The arrangement is sufficiently constant, however, to be used in orienting random cores and surface blocks. In the rare instances where the calcite cap of one thick anhydrite is followed immediately by another thick unbanded anhydrite zone, the gradation is less sharp at the top of the cap than at the base. Everywhere that thick carbonate caps have been noted, they are made up of thin calcite laminae rather than of massive or thick-bedded limestone layers. A one-foot limestone may have four or five hundred of these almost microscopic laminae. From present limited information we cannot be certain that these unbanded, thick anhydrite beds and their thick calcite caps are of basin-wide distribution. Some individual calcite-cap zones have been followed for more than a mile along the outcrop only to be lost where the beds pass under a cover of soil. Since there are thick unbanded zones in the south as well as in the north end of the basin, it is assumed that the beds are continuous.

. . . . The thickness and prominence of the calcite laminae also vary across the basin. The thickest limestone beds appear to be at or near the base of the formation in the southern and western areas, but some central basin wells show as much as 25-30 per cent calcite in cuttings and cores through hundreds of feet of section. Near the top of the banded zone the calcite partings decrease in number and thickness, but the change from prominently laminated to unbanded anhydrite is gradual and may occupy hundreds of feet. Wells in the northeast part of the basin show relatively lean banding throughout the entire laminated zone.

On the outcrops in the Delaware Mountains, the thin calcite laminae of the northern exposures appear to thicken southward, and along Paint Horse Draw, in central Culberson County, those of the basal Castile coalesce to form beds of granular gray limestone. Interspersed through these granular beds are zones of thinly laminated, bituminous calcite, similar in appearance to the calcite caps of the more northern areas. Only a little interstitial gypsum is present. Wedges of the limestone, separated by beds of more normal calcite-banded gypsum, make up the lower 300-400 feet of the formation. The so-called "petroliferous Castile" of the Lone-man Mountain area is a tongue of banded calcite extending northeast from this area of Castile limestones. Apparently the bituminous material, the source of the strong petroliferous odor, was deposited with the calcite and was not derived from the underlying beds. A careful search of the limestones failed to show any microscopic fossils. Small quantities of chert are found along some of the bedding planes of the limestone, and in a few places concretionary masses several inches across had developed. Thin sections show a few dust-size quartz grains along some of the partings.

The bedded Castile limestones of the southern Delaware Mountains are relatively soft and should erode almost as fast as the enclosing gypsums. . . . If the liming-up of the section was as rapid in the eroded part of the formation as it is in the present outcrops, the Castile may have been an almost solid limestone along the west margin of the basin. Unfortunately the few wells in the extreme south part of the Delaware basin do not show whether the Castile limed up in that area. Certainly the basal beds in the intermediate San Martine area, of southeastern Culberson County, do not appear as limy as equivalent beds an equal distance from the Apache reef front farther west.

In addition to the primary variations in the calcite-banded anhydrite of the Castile formation, there are many secondary irregularities. Calcite laminae disappear in nodular masses of anhydrite. Concretionary anhydrite lenses grow between the partings and disrupt them. Bands of crinkled laminae appear to writhe about between flat beds, and in some transverse zones all evidence of bedding is lost. More important still is the faulting, fracturing, and slipping that characterize most of the cores and outcrops. Since most of the variations occur both at the surface and at depths of thousands of feet, it is assumed that most of them were produced by early diagenetic processes.

Interlaminated dolomite and anhydrite were present in several places in the evaporites in the southern Permian basin, but calcite-anhydrite banding of the type here described has not been noted anywhere in the Permian section outside of the Delaware basin."

The laminated anhydrite sequence is interrupted in the northern and eastern parts of the Delaware basin by halite beds, the principal markers in the Castile Formation. Adams (1944, p. 1607) described the salt beds as composed of practically pure sodium chloride with impurities of laminated calcite and anhydrite in the form of blebs and crystals. Figure 15 (in pocket) shows the net footage and extent of halite in the Castile Formation. The halite units are described in more detail later in this work. The stratigraphic position of the salt units is shown in Table 2. Figure 16 (in pocket) shows the thickness of the non-halite strata, mainly laminated calcareous anhydrite.

Minor amounts of chert and clastics are also found in the Castile Formation. Adams (1944, p. 1607) described the chert as follows:

> "Chert deposits in the Castile Formation appear to be limited to the banded limestones and to the calcareous parts of the castiles[2] in the southwestern Delaware Mountains. Even here the chert is a very minor constituent of the rock. A careful hand-lens examination showed no organic structures."

Adams (1944, p. 1608) reported fine quartz grains scattered through the calcite laminae in thin sections examined petrographically, suggestive of atmospheric dust. Udden (1924, p. 348) recorded some shale and shaly brecciated anhydrite within the section containing laminated anhydrite from the David Flood, Gresham and McAlpine well, Culberson County, Texas. In 18 sample logs from wells in Culberson County, only 1 log showed sand in the Castile. In Continental Oil, J. H. Fisher well No. 1-A (Culberson-32), sand was recorded at 600 feet and 550 feet above the base of the Castile. Some sand was recorded by Dr. R. Y. Anderson (personal communication, 1965) at about 180 feet above the base of the Castile in Culberson County. In zones at about 180 and 270 feet above the base of the Castile, massive anhydrite was also

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[2] "Present in the massive gypsum and the underlying laminated part of the Castile Formation in the Yeso Hills are several low isolated mounds of brown locally laminated limestone. Similar, but usually more prominent, features present in the Castile Formation to the south in Texas were described by Adams (1944, p. 1606, 1622), who termed them 'castiles.' Most of these castiles contain considerable limestone breccia in addition to the rather massive and laminated limestone." (Hayes, 1964, p. 14-15).

encountered. In each of the cases above, sand or massive anhydrite is at the stratigraphic level of the salt beds found in the deeper parts of the basin.

Anhydrite I. Anhydrite I is the basal unit of the Castile Formation. It is about 170 feet thick in eastern Culberson and west-central Reeves Counties, Texas, and generally thickens to about 350 feet in the east and northeast (Fig. 17, in pocket). Anhydrite I becomes more calcareous in the southwestern part of the Delaware basin, especially in the vicinity of the Apache and Delaware Mountains (Adams, 1944). The total unit, however, thickens radially to the north and east from this area.

Along the basin margin, especially west of the Central Basin platform, thicknesses of 410 to 518 feet were found in several wells. The general configuration around these wells indicates possible localization of deposition due to influx of material from outside the Delaware basin proper. The configuration of the contours suggests a fan-like or deltaic deposit. The following features suggest that the local thickenings are truly submarine "fans" rather than thickenings due to local subsidence with accumulation of sediments from within the Delaware basin.

Halite I and Halite II do not show excessive thickening in the regions of Anhydrite I thickening and in some instances show excess thinning ranging to complete pinchout, suggesting that local subsidence was not a factor. Anhydrite II shows the same general thickening trends as

Anhydrite I, especially in the "fan" areas. This is also reflected in the thickness of total non-halite strata in the Castile Formation (Fig. 16, in pocket).

Anhydrite accumulations along the edge of the Central Basin platform appear to have been controlled by influx of sediment from the east side of the "reef front" in addition to regional thickening within the Delaware basin. Evaporite deposition may have occurred contemporaneously outside as well as within the basin, or older deposits outside the basin may have been eroded and transported into the basin. The localization suggests that deposition of anhydrite was controlled by channels through the surrounding reef; probably, therefore, the basin was fringed by a barrier breached in several places, rather than by a continuous barrier reef. At least ten channels are suggested along the basin margin near the Central Basin platform (Fig. 17, in pocket).

The accumulation of anhydrite in fans was probably always submarine. It seems unlikely that sea level was low enough for subaerial accumulation to have taken place, since continuous sequences of chemical precipitates are found throughout the Delaware basin. Disturbance of the laminations in the Castile anhydrite seems to have occurred only during halite deposition. In any case, the submarine "fans" of anhydrite were of sufficient relief that they influenced the distribution of later halite deposits. Halite is extremely thin or absent in areas where fans accumulated, compared to halite accumulation in adjacent areas.

A comparison of the thickness maps for the non-halite units indicates that the channels or breaches in the barrier around the Delaware basin probably maintained the same position throughout much of Castile time. Currents coming through the channels or breaches would be expected to influence sedimentation by mixing of back-reef and basin water, by redistributing sediments near the channel entrances, and by distribution of allochthonous sediments brought in by currents.

Halite I. For convenience in describing the geographic distribution of halite strata, the term Ochoa trough is used here for the area about 30 to 35 miles wide, parallel to the Capitan reef front in the northern and eastern parts of the Delaware basin (Fig. 1). The area to the west of the Ochoa trough is designated as the intrabasin shelf. The relationship of the Ochoa trough and the intrabasin shelf to tectonics will be discussed later.

Halite I is the most widespread salt unit of the Castile Formation. This unit generally defines the western limit of salt distribution in the northern and central parts of the Ochoa trough (Figs. 15 and 18, in pocket); however, halite of the overlying units overlaps Halite I to the south. Halite I thickens from the south to the north in the Ochoa trough, a trend almost perpendicular to thickness trends of underlying Anhydrite I and overlying Anhydrite II. In the central and northern parts of the Ochoa trough, Halite I generally has a thickness of 50 to 350 feet, thickening to the north. On the intrabasin shelf, a zone about 20 to 30 feet thick consisting of massive anhydrite, contorted laminated anhydrite, and some sand is generally found at the stratigraphic position of Halite I.

A salt lens or local deposit just north of the Apache Mountains noted by Adams (1944) was encountered in only one well log in the area. Since this salt lens is at about the stratigraphic position of Halite I, it is assumed as equivalent to Halite I and correlated with the salt unit in well Reeves-81 (Fig. 18, in pocket). This local salt deposit is located in southeastern Culberson and southwestern Reeves Counties, Texas, at the southwestern end of a northeast-southwest linear trend (Fig. 14, in pocket). This linear feature may have been a local accessway for dense saline water influx to this area from the Ochoa trough during Halite I deposition.

Well logs from Eddy, Lea, and northeastern Culberson Counties showed some sections of Halite I with significantly greater or lesser thickness than would be expected from sedimentational trends. Since the halite has been reported as remarkably pure (Adams, 1944) and no marker beds are present in Halite I, salt movement can be interpreted only from analysis of the general distribution of salt, regional thickness trends of the salt unit itself, regional thickness trends of the underlying and overlying beds, variations in thickness of salt between closely spaced wells, and the tectonic setting of the areas that might have had salt movement. The writer believes that salt flow after deposition and consolidation is indicated from analysis of the above factors. Such an analysis is given in detail in the section on Salt Movement.

Anhydrite II. Anhydrite II is a remarkably consistent unit ranging in thickness from about 90 feet in eastern Culberson and western Reeves Counties to about 150 feet just west of the Central Basin platform (Fig. 19, in pocket). The thickness distribution of Anhydrite II is very similar to that of the Anhydrite I (Fig. 17, in pocket). The geometric configuration of thickening of anhydrite near the eastern basin margin is interpreted as influx of material from east of the Delaware basin distributed as fans or deltas by channel currents through breaches in the barrier zone, similar to conditions postulated for Anhydrite I.

Halite II. Halite II consists of a lower halite unit and an upper unit of interbedded halite and anhydrite. There are usually five anhydrite beds, each from 2 to 5 feet in thickness. The lowest anhydrite marker is encountered at about the middle of the unit (Figs. 3 and 4). In the central and northern parts of the Ochoa trough, Halite II has a thickness of 50 to 225 feet, thickening to the north (Fig. 20, in pocket). On the intrabasin shelf, a disturbed, non-laminated anhydrite zone about 15 to 20 feet thick, similar to Halite I zone, is found at the stratigraphic level of Halite II. Thickness trends of Halite II are similar to those of Halite I in this area. Generally Halite II is thicker than Halite I in the southern part of the Ochoa trough, where Halite II overlaps Halite I by about six miles.

Anhydrite III. Anhydrite III is a continuous sequence of anhydrite overlying Halite II. This anhydrite unit is generally 280 to 350 feet thick, thickening from southwest to northeast in the Ochoa trough. The lowest halite bed of Anhydrite IV marks the top of Anhydrite III. Since this halite bed is absent over areas outside of the Ochoa trough, thickness trends could not be distinguished throughout the basin. If the thickness trend of Anhydrite III is similar to the trends of Anhydrite I and Anhydrite II, Anhydrite III is probably about 250 feet thick in the western part of the Delaware basin.

Anhydrite IV. Overlying Anhydrite III, Anhydrite IV consists of interbedded anhydrite and halite and shows a distinct cyclic pattern in the Ochoa trough (Fig. 4, in pocket). Anhydrite IV ranges from 200 to 400 feet in thickness in the Ochoa trough. Anhydrite IV has five anhydrite beds, designated a, b, c, d, and e, separated by halite beds (see Loving-43, Fig. 4, in pocket).

The halite beds in Anhydrite IV are thin at the base of the unit with one relatively thick bed occurring between anhydrite beds d and e. The thinner halite beds pinch out locally, and it is difficult to distinguish between anhydrite beds b and c. In addition, when the lower halites pinch out, anhydrite beds a, b, and c form a continuous sequence with Anhydrite III. The uppermost halite bed separating anhydrite bed e of Anhydrite IV from the overlying anhydrite of Anhydrite V pinches out locally. The top of Anhydrite IV is then taken as the top of the halite. The thickness of halite in Anhydrite IV is shown in Figure 21.

Halite beds in Anhydrite IV are continuous in the central and southern parts and are found locally in the northern part of the Ochoa trough. Total halite thickness in Anhydrite IV ranges from 100 to 300 feet, the thickest amounts being in the north-central part of the Ochoa trough in southern Lea and northern Loving Counties.

In the Ochoa trough total anhydrite of Anhydrite IV generally ranges from 110 to 150 feet in thickness, with anhydrite bed a ranging from 8 to 12 feet in thickness, bed b 45 to 60 feet, bed c 25 to 35 feet, bed d 10 to 20 feet, and bed e 10 to 20 feet. The anhydrite beds are generally thickest in Loving and eastern Reeves-western Pecos Counties areas. Between these areas, in western Ward County, all of the anhydrite beds thin. Anhydrite IV is probably represented on the intrabasin shelf by a thickness of anhydrite of about 150 feet.

Some sands found in Culberson County wells are probably equivalent to halite beds in the Ochoa trough.

Anhydrite V. Anhydrite V is the uppermost unit of the Castile Formation. Anhydrite V is the most variable in thickness, ranging from less than 300 feet in northern and central areas to more than 1,000 feet in the southern part of the Ochoa trough. The intrabasin shelf non-halite strata, mainly laminated calcareous anhydrite equivalent to Anhydrite V, have a thickness of about 600 to 700 feet.

Halite in Anhydrite V is found only within the Ochoa trough parallel to the Central Basin platform. Some sands found in Culberson County wells are probably equivalent to halite beds of Anhydrite V in the Ochoa trough. Total halite thickness in Anhydrite V ranges from less than 100 feet to more than 300 feet (Fig. 22, in pocket). Areas with halite thickness greater than 300 feet are found in two areas: one in Lea County, New Mexico, the other in southern Loving, western Ward, and eastern Reeves Counties, Texas. A narrow area containing halite less than 100 feet in thickness is present in north-central Loving County.

Volumes and Weights of Castile Units. Volumes for halite were determined by planimetrically measuring the areas between contours, multiplying these areas by the average thickness between contours, and adding these "averaged" volumes for the total thickness of halite per unit. The areas between contours were planimetered at least twice and checked against a reference square of known dimensions. Planimetered areas all had less than 5 percent difference between measurements. The average thickness of the halite depends upon the individual thickness measurements from logs and contouring of the maps. Probably the thickness measurements had no more than 10 percent error and less than 5 percent in thicknesses greater than 100 feet. Although contouring of the data is subjective, it is probably compensatory; no error was estimated for this factor.

An average thickness for each anhydrite unit was estimated from thickness maps and data since the Castile is eroded in the western part of the Delaware basin. Net footage of non-halite strata, mainly anhydrite, and total Castile thicknesses were also estimated in this way. Average thickness was multiplied by the area of the Delaware basin to obtain the volume of each anhydrite unit. Anhydrite equivalent to lower Castile halite units was computed by averaging the thickness over the intrabasin shelf and multiplying this average by one-half the area of the basin.

To convert volume to weight for anhydrite, a factor of 10.9 cubic feet per ton was used, for halite, a factor of 14.5 cubic feet per ton was used; for calcite, a factor of 11.7 cubic feet per ton was used. Area of the Delaware basin was estimated at 10,000 square miles or 283×10^9 square feet.

Volumes and weights are tabulated in Table 3. Total anhydrite was corrected for major amounts of calcite and bituminous material. Udden (1924, p. 350) noted that calcite and bituminous material generally made up less than one-fourth of the thickness of each lamination. Castile anhydrite volume and weight were corrected assuming one-fourth

Table 3. Volumes and weights of units of the Castile Formation.

Unit	Average thickness, feet	Halite		Anhydrite, uncorrected		Anhydrite[a] corrected		Ratio of[a] $CaSO_4:NaCl$	
		Volume, cu ft x 10^{12}	Weight, tons x 10^{11}	Volume, cu ft x 10^{12}	Weight, tons x 10^{11}	Volume, cu ft x 10^{12}	Weight, tons x 10^{11}	Volume	Weight
Anhydrite I	210	----	----	59	54	----	----	----	----
Halite I	(30)[b]	27.7	19	4	3.7	3	2.8	1:9	1:7
Anhydrite II	105	----	----	30	28	----	----	----	----
Halite II	(15)[b]	17.3	12	2	1.8	1.5	1.4	1:12	1:9
Anhydrite III	350	----	----	100	92	----	----	----	----
Anhydrite IV	150	11.5	8	42	39	----	----	----	----
Anhydrite V	550	13.2	9	156	143	----	----	----	----
Total Castile	1410	69.7	48	393	362	295	270	4.2:1	5.6:1
Total[c] Castile Anhydrite	1350	----	----	378	347	284	260	4.1:1	5.4:1
Castile (from R. H. King)	1250	----	----	350	325	262	240	3.7:1	5.0:1

[a] Anhydrite corrected to 3/4 measured volume.
[b] Volume of anhydrite computed from average thickness multiplied by one-half the area of the basin.
[c] Estimated from net footage map of non-halite strata, mainly anhydrite (Fig. 16).

of the volume of total anhydrite is calcite and other material. $CaSO_4$:NaCl ratio for the Castile Formation using corrected anhydrite is about 4:1 by volume and 5.5:1 by weight. In the lower part of the Castile, halite units, including laterally equivalent anhydrite on the intrabasin shelf, have a $CaSO_4$:NaCl ratio of about 1:10 by volume and 1:8 by weight.

Salado Formation

General Statement. The Salado Formation consists of halite, anhydrite, and dolomite with minor amounts of clastic rocks, gypsum, magnesite, and potassium minerals. The Salado Formation was named by Lang (1935, 1939) from a subsurface section of the Pinal Dome Oil, Means well No. 1, Loving County, Texas, at a depth from 920 feet to about 3,300 feet.

The Castile-Salado contact of this report is at an approximate depth of 3,000 feet in the Pinal Dome well. Figure 4 shows a sonic-gamma-ray log from Wilson Exploration Company, Brunson well No. 1, Loving County, Texas (well: Loving-43), about one mile southeast of the Pinal Dome well and a sample log of the Pinal Dome well (from Hoots, 1925).

Lang (1942, p. 63-79) named three members within the Salado (depths 890-1,380 feet) from Fletcher No. 1 Potash Core well, sec. 1, T. 21 S., R. 28 E., Eddy County, New Mexico:

1. Cowden Anhydrite Member, 1,145-1,163 feet;
2. La Huerta Silt Member, 1,296-1,301 feet; and
3. Fletcher Anhydrite Member, 1,311-1,379 feet.

Adams (1944, p. 1610) proposed the Vaca Triste Sand Member, a ten-foot bed of fine red sand, about 670 feet below the top of the Salado from Continental, King well No. 1, sec. 26, T. 25 S., R. 32 E., Lea County, New Mexico.

Lithology. Lang (1935, p. 266) described the Salado as "dominantly composed of rock salt with massive anhydrite beds, redbeds, shaly sands, and prominent beds and lenses of polyhalite that are characteristic only of this formation." In 1939 (p. 1570) he noted that the halite grades into massive anhydrite in southern Reeves and northwestern Pecos Counties, Texas.

Moore (1960, p. 123) estimated the proportions of lithologic types in the Salado Formation near the northern margin of the Delaware basin as:

	Percent
Chloride rocks (halite rock, sylvite rock, etc.)	84
Sulfate rocks (anhydrite rock, gypsum rock, and polyhalite rock)	12
Clastic rocks (quartz sandstone, siltstone, and claystone)	4
Carbonate rocks (limestone and dolomite rock)	0.

In order to show north-south variations in the Ochoa trough of sulfate and carbonate rocks in the Salado, net footages of sulfate and carbonate were compiled from wells in north-south cross section, Figure 7 (Table 4). The wells denoted in Figure 7 are not directly along the maximum thickness trend in the Ochoa trough; however, from the well data (Lea-25 to Reeves-95), the sulfate-carbonate rocks are easily recognized as thickening about $4\frac{1}{2}$ times from north to south. The percentage increase, however, is only about three-fold because halite thickens at a greater rate than the sulfate-carbonate.

Schaller and Henderson (1932, p. vii) concluded from intensive petrologic and mineralogic studies that the potash minerals are, for the most part, replacement minerals or reaction products from "preexisting saline minerals with liquors rich in potash." They also noted the following mineral associations and characteristics in Salado rocks (1932, p. 9):

Sulfate group	Chloride group
Banded structure	No banded structure
Fine grained	Coarse grained
Mineralogically simple	Mineralogically complex
Essentially insoluble	Essentially soluble
Minerals:	Minerals:
Anhydrite	Halite
Polyhalite	Halite & sylvite
Anhydrite & polyhalite	Halite & polyhalite
Anhydrite & halite	Halite & anhydrite
Polyhalite & halite	Halite & carnallite
Anhydrite, polyhalite & halite	Kainite
Kieserite	Langbeinite
Magnesite	Leonite
Glauberite	Lueneburgite
Lueneburgite (?)	Sylvite
Clay, generally in layers or wavy bands.	Clay, more commonly as irregular masses than in layers.

Table 4. Net footage of sulfate-carbonate rocks in Salado Formation showing north-south variations in the Ochoa trough.

N	Lea-25	Lea-33	Lea-32	Lea-41	Lea-53	Loving-39	Loving-43	Loving-47	Loving-49	Ward-7	Ward-15	Ward-17	Reeves-73	Reeves-78	Reeves-95	S
Total Salado Thickness (feet)	1325	1830	1950	2030	2465	2120	2120	2190	2050	2015	2040	2150	1915	2220	750	
Sulfate and Carbonate Net Footage (feet)	150	200	240	240	300	350	390	460	500	510	455	670	650	670	710	
Percentage Sulfate and Carbonate	11.3	10.9	12.3	11.8	12.2	16.5	18.4	21.0	24.4	25.4	22.3	31.2	34.0	30.2	94.6	

Adams (1944, p. 1609) reported the following characteristics in the abundant salt beds:

> "Many of the salt beds, especially the upper ones, in and around the north end of the Delaware basin, contain potash and other bittern minerals. Polyhalite is the most widespread of the potash-bearing minerals. The base of the polyhalite deposits transgresses upward across the salt section toward the southwest. None is found in the salts south and west of the Pecos River. Many of the potash-free salts of the formation are also red, due to the presence of red clastics and iron oxides . . . . In addition to the potash, clastics, and common red coloration, the Salado salts contain blebby anhydrite inclusions and mats of coarse, interlocking anhydrite crystals as well as the fine granular masses of anhydrite which characterize the salts of the Castile. Salado salts in the south-central part of the Delaware basin are much cleaner than those in the areas near the north rim."

C. L. Jones (1954, p. 109) divided the halite into two distinct types: one type without clastic impurities; the other type with clastics, principally clay- and silt-size particles of quartz and silicate minerals.

Adams (1944, p. 1609, 1611) reported the common Salado carbonates as dolomite and magnesite with thin beds of dark brown, calcite-banded anhydrite separated by thick beds of salt found in southern Reeves and western Pecos Counties. He noted the following:

> "The dolomite and magnesite are present as stringers or as diffused grains in most of the anhydrite members at the north end of the Delaware basin. Near the Texas line the carbonates, especially in the upper part of the section, are concentrated into beds. Outside of the salt areas dolomite becomes more prominent."

Adams further observed that the proportion of dolomite increases southward, making up approximately 20 percent of the Salado Formation in the southern part of the Delaware basin.

Adams (1944, p. 1610-1611) described the anhydrite of the southern and western Salado areas as rather featureless, thin-bedded, and blue-white in color. In the main salt section of the northeastern Delaware basin, he divided the anhydrite into two groups: discontinuous lenses and wide-spread members which serve as markers. He noted:

> "The anhydrite marker members almost everywhere contain inclusions of salt, and thin stringers of silt and magnesite or dolomite."

Clastics in the Salado were noted by Adams (1944, p. 1609-1611) as follows:

> "Sands and silts are encountered in many parts of the Salado section. The sands are coarser than most of the Permian sands but they are not characterized by the frosted quartz grains so common in the Yates and Dewey Lake formations. Both red and gray sands are present. . . .
>
> Silts and shales are less conspicuous but more generally distributed than sands in the Salado section. Colors include brown, green, blue, gray, red, pink, violet, and black."

Adams (1944, p. 1611) further stated:

> "No chert was noted in any of the Salado samples, but a few small euhedral quartz crystals . . . are scattered through the salt. Here and there grains of pyrite are found in the dolomite."

Regional Aspects. The Salado Formation ranges in thickness from 500 feet in the western Delaware basin to more than 2,000 feet in the Ochoa trough parallel to the Central Basin platform, with a maximum thickness of 2,530 feet in well Pecos-7 (Fig. 23, in pocket). The Salado Formation was subdivided in the Loving County area into three units designated lower, middle, and upper Salado. The middle-upper Salado boundary was taken at the base of an anhydrite marker bed approximately 240 feet below the Vaca Triste Sand Member or 925 feet below the Rustler-Salado contact in Loving-43 (Fig. 4, in pocket). The lower-middle boundary was placed at the top of an anhydrite marker 670 feet below the middle-upper contact in Loving-43. These contacts were readily traced throughout most of the Ochoa trough (Fig. 7, in pocket). The general thickness of the lower, middle, and upper units is shown in Figure 29 and in cross sections (Figs. 7, 8, 9, and 10, in pocket).

The extent of Salado halite from the data of this report generally agrees with the extent of Salado "evaporite" as postulated by Kroenlein (1939, fig. 1). Salado anhydrite and carbonate, however, are found in western and southern parts of the Delaware basin. Kroenlein's "west shoreline of the Delaware Lake" coincides with the postulated intrabasin shelf margin of this report (Fig. 1). Kroenlein apparently interpreted the non-laminated Salado anhydrite as Castile equivalent.

Stewart (1954) compared the Permian evaporites in northern England with the evaporites of the Salado. He noted that British deposits were broadly comparable to those of the Salado mineralogically. In both areas, lateral zoning is prominent. Stewart (1954, p. 223) reported for British deposits that "there is, then, in each evaporite bed, a broad lateral zoning from more to less soluble salts as the shore line is approached." For the Texas-New Mexico evaporites, he (1954, p. 223-224) stated: "there is a well-developed lateral change from less to more soluble salts from the seaward connection to the inner parts of the depositional areas."

Rustler Formation

General Statement. The Rustler Formation is the youngest unit in the evaporite sequence. Rustler consists of dolomite, anhydrite, gypsum, clastics, and some halite. The Rustler Formation was named by Richardson (1904, p. 44) for Rustler Springs, Culberson County, Texas. Type sections of the Rustler Formation have been described by Lang (1935 and 1938 *in* Adams, 1944) (Table 5). Figure 4 shows representative logs of the Rustler Formation.

A total thickness map of the Rustler was made for analysis of basin development (Fig. 24, in pocket). The Rustler, however, was not studied in detail.

Lithology. The Rustler Formation consists of dolomite, anhydrite, gypsum, clastics, and halite. Adams (1944, p. 1612-1615) noted:

> "the oldest deposit of the Rustler formation, in its western outcrops, is a clastic member . . . . Toward the east the conglomerates grade into sandstones.
>
> Where the basal sandstones of the Rustler rest on the beveled surfaces of the Salado, as in the area south and east of Carlsbad, they are characterized by abrupt irregularities in thickness. . . . Above the basal clastic phase, the Rustler is largely an evaporite formation and marks the final stage of evaporite deposition in the southern Permian basin.
>
> In the subsurface where the complete Rustler section is preserved, it can be divided into two

main parts, an upper 150 to 175-foot bed of anhydrite or gypsum; and a lower group of dolomite, anhydrite, sand, and shale members. Along the southwest limits of the Rustler area the anhydrites of the lower group grade into dolomites and the dolomites into limestones. Toward the north and east the dolomite stringers, in turn, decrease in prominence, and at the northeast edge of the Delaware basin part of the upper anhydrite and the anhydrite of the lower group grade into salt."

C. L. Jones (1954, p. 110) described the Rustler at the northern margin of the Delaware basin as follows:

"Anhydrite and halite are the principal constituents of the Rustler formation. . . anhydrite is the dominant constituent of the strata. . . . The Rustler formation contains two dolomite members and several siltstone and sandstone members that form remarkably persistent stratigraphic markers. The halite is intercalated within the anhydrite and clastic members. The highest halite member lies about 30 feet below the top of the formation; and the lowest halite member, about 10 to 15 feet above the base. The other halite members form a medial zone within the formation. Within the area of the Delaware Basin, the halite members represent about half the total thickness of the Rustler formation. The halite members thin reefward and pinch out on the shelf area."

Regional Aspects. The Rustler Formation generally ranges from 250 feet to 600 feet in thickness in the northern, central, and eastern parts of the Delaware basin (Fig. 24, in pocket). It varies considerably in thickness in local areas with a tendency to thicken toward the southern part of the basin. Kroenlein (1939, p. 1692) believed that the Rustler is conformable with the Salado "in the deep part of the Delaware basin" but laps across underlying beds toward the margin of the basin. King (1942, 1948) and Adams (1944) postulated a slight angular unconformity in the western part of the Delaware basin. Moore (1960), however,

Table 5. Type sections of Rustler Formation

East of Pecos River between Laguna Grande de La Sal and Pierce Canyon, Eddy County, N. M. (from Lang, 1938, in Adams, 1944).

Unit Number	Lithology	Thickness (feet)
1.	Gypsum	30
2.	Gypsiferous dolomite (Magenta Member)	30
3.	Gypsum	100
4.	Redbeds	30
5.	Gypsum	20
6.	Dolomite (Culebra Member)	35
7.	Redbeds	30
8.	Gray sandstone	70
9.	Redbeds	35
10.	Gypsum	130
11.	Redbeds	5
	Total thickness	515

Eldridge Core: Section [illegible]3, Block C-26, P.S.L. Loving County, Texas. Offset well to Pinal Dome Oil, Means No. 1. (from Lang, 1935).

Unit	Lithology	Thickness (feet)
	Anhydrite	30
Upper Anhydrite Member	Anhydrite with sandy, gypsiferous, and redbed breaks	120
	Red shale with brecciated gypsum and anhydrite	51
Upper Limestone Member	Limestone, magnesian and cellular	31
	Redbeds	21
	Anhydrite	17
	Sandstone, gray, very fine grained, finely laminated and cross-bedded	80
Lower Limestone Member	Limestone, magnesian and cellular	11
	Basal redbeds, fine sandy to earthy, with anhydrite breaks and showing of halite crystals	9
	Total thickness	370

believed that the Rustler conformably overlies the Salado Formation. The Rustler is overlain by clastics of the Upper Permian Dewey Lake Redbeds.

Cyclic Aspects and Conditions of Deposition

Laminated Sediments

The earliest indication of varve-like[3] deposition in Lower Permian strata in and near the Delaware basin is found in the black limestone beds of the Bone Spring Group, Leonard Series (King, 1948, p. 14 and plate 10, A).

King noted:

> "The black limestone in most exposures shows no stratification between the bedding planes, but in some exposures it is marked by finer laminations. Limestones marked by closely spaced, light and dark laminae similar to varves are common lower down in the formation. . .; they have been observed on the promontory of the Delaware Mountains 18 miles south of El Capitan, in the Sierra Diablo, and in the cores from the Updike well [N. B. Updike, Williams No. 1, drilled in 1921 and 1922, 3 miles south of El Capitan]."

From his petrologic and chemical studies, Marshall (1954) stated that the Bone Spring Limestone shows strong indication of being annual in nature.

The next younger indication of varve-like properties is found in the sandstone beds of the Brushy Canyon Formation. King (1948, p. 28-29) described many of the layers of the massive sandstone beds as having "widely spaced, parallel laminae." He further noted:

---

[3] Varve: an assumed annual couplet usually made up of a light and dark layer.

"The thin-bedded sandstones that lie between the massive beds are generally buff and fine-grained, and are marked by closely set, light and dark laminations, suggestive of varves."

Beds of the Cherry Canyon Formation show a marked development in varve-like characteristics. King (1948, p. 34-35) noted the following:

"The sandstones of the Cherry Canyon formation lie in beds a few inches thick, with occasional thicker layers and layers of hard, platy, shaly sandstone. The thinner beds are all marked by light and dark laminae, possibly varves, of which there are commonly 10 or 20 to the inch; there are occasional zones where they are more closely or more widely spaced."

King did not note any varve-like laminations in the limestone beds of the Cherry Canyon, although he did describe the Getaway Limestone Member as being thinly laminated or platy in some places. He noted also that a black limestone facies of the South Wells Limestone Member was "reminiscent of the black limestones of the Bone Spring" (King, 1948, p. 46).

Continuation of varve-like lamination in the Bell Canyon was described by King (1948, p. 54) as follows:

"The sandstone beds of the Bell Canyon formation, like those of the Cherry Canyon, are buff colored and extremely fine grained. . . .

. . . . Some of the sandstones are in layers a few inches thick, some are thinner bedded or even platy, and some are thicker bedded or massive. Most of the beds show faint, closely spaced, light and dark laminations, but these laminations are absent in some of the massive beds."

The Lamar Limestone Member (King, 1948, p. 57) consists of 15 to 30 feet of gray, dark gray, or black, fine-grained limestone generally made up of beds a few inches thick with some of the rock being thinly laminated. The Lamar Limestone Member grades directly into the lower beds of the Castile Formation within most of the Delaware basin. King (1948, p. 58) reported, however, that:

> ". . . within several miles of the Reef Escarpment, the Lamar member is separated from the Castile formation by a small thickness of younger Bell Canyon beds. . . . these beds consist of 20 feet of very fine grained sandstone. . . . The rock is thinly laminated, its bedding surfaces are flat and smooth, and it breaks out in thin, flat plates."

A specimen from this sandstone unit showed finer grains in some laminae than others, with the platy layering due to an increase in the amount of clay in the same laminae (King, 1948, p. 54).

The recurrence throughout the descriptions of Guadalupe Series rocks of the varve-like laminations in clastic as well as limestone beds should stimulate interest in the duration of time necessary for such units to accumulate. The most logical assumption would be that each lamination consisting of one light and one dark layer was deposited in one year, the difference in light and dark layering being seasonal features. If we tentatively assume annual deposition for each varve-like lamination, we have a means to measure relative time of deposition, a calibration unit for cyclic studies, and correlatable strata usable as time planes.

Analogous situations have been interpreted as annual deposits. A parallel example exists in the upper Jurassic Todilto Formation in northwestern New Mexico (Anderson and Kirkland, 1960). At the base of the Todilto in a transition zone from the underlying Entrada Sandstone, a two-fold cycle of clastic and organic layers is overlain by a three-fold cycle of clastic, organic, and limestone laminae. The three-fold cycle, in turn, is overlain by a four-fold cycle of clastic, organic, limestone, and gypsum laminae. These changes are equivalent to the change from "Delaware sand" (two-fold cycle) to the Lamar Limestone Member (three-fold cycle) to the basal beds of the Castile Formation (four-fold cycle).

Another almost identical example is found in the Upper Permian Zechstein of Germany. The sequence of rocks at the base of the Zechstein is: Kupferschiefer (shales, 0.2-.5 meters); Zechstein Limestone (5-12 meters); and anhydrite or anhydrite with marl partings (30-100 meters) (Borchert and Muir, 1964, table 2 and p. 53). The rocks of the Zechstein are considered to be varved deposits (Borchert and Muir, 1964, p. 37-42).

The Castile laminated anhydrite has generally been accepted as a varved deposit since Udden's (1924) postulation of annual deposition. Udden (1924, p. 350) noted the range in thickness of the layers from 0.2 to 7.0 mm with the most common variations between 0.5 and 2.0 mm. In about 36 feet of core measured, the average thickness of 6,436 varves was 1.63 mm per varve (Table 6, p. 72).

Udden (1924, p. 350) described the layering as made up of two elements, one element consisting of bituminous material and calcite, the other of anhydrite. He stated "It is evident that each layer composed of these two elements represents a cycle of precipitation and sedimentation in the water in which the anhydrite was laid down." Udden's analysis (1924, p. 351-352) of the layering was as follows:

> "That each layer should represent the sediment of a single day seems hardly probable. If the precipitation of the material in each layer was due to daily evaporation, this evaporation would be in great excess over any known conditions in the present seas. If, on the other hand, a single layer should represent the accumulation during a year, the quantity of water evaporated would seem small. But I believe that this would be nearer to our common-sense estimate of the amount of materials that might accumulate annually in a basin of water where calcium sulphate has reached the point of saturation, and where water thus saturated is constantly supplied."

Adams (1944, p. 1619) further suggested that the calcite was deposited during part of the summer while "further evaporation and concentration would cause the precipitation of gypsum." Lang (1950) ascribed the lamination to annual climatic variation and gave the following types of seasonal rhythms for the Castile Formation:

$$\frac{C,\ Ca}{C,\ Ca'},\quad \frac{Ca}{C,\ Ca'},\quad \frac{A}{C,\ Ca'},\quad \frac{A}{Ca,\ A'},\quad \frac{A}{A}\qquad \frac{\text{Summer}}{\text{Winter}}$$

where C = organic material, Ca = calcite, and A = anhydrite. The series in the overlying Salado Formation is represented by the succession:

$$\frac{A}{A'},\quad \frac{A}{M'},\quad \frac{A}{M,\ G'},\quad \frac{H}{M,\ G'},\quad \frac{H}{H'},\quad \frac{H}{S}\qquad \frac{\text{Summer}}{\text{Winter}}$$

in which A = anhydrite, M = magnesite, G = gypsum, H = halite, and S = sylvite.

Laminated Salado rocks are well illustrated in Schaller and Henderson's work (1932, pls. 1-4, 7-8, 10, 16, 24, 26-27, 29-30). "Banded structure" was noted as a characteristic of sulfate group minerals.

Schaller and Henderson (1932, p. 14-15) described the banding of anhydrite as:

"Nearly all the cores composed essentially of anhydrite, $CaSO_4$ (CaO, 41.2; SO_3, 58.8 per cent), are banded, as shown in Plates 1, 2, and 3. Thin sections show that most of these bands are caused by layers of magnesite. Other bands in the anhydrite rock are due essentially to clay, which, however, was found to contain magnesite whenever tested.

. . . .

The bands or laminations in anhydrite here described are not nearly so perfect or abundant as those shown by Udden in an anhydrite from the Gresham & McAlpine farm, in section 42, block 54, State school land, Culberson County, Tex. (about 22 miles west-northeast of Toyah), at a depth of 2,118 feet, and illustrated in his Plate 7, Figure 1. In thin sections the bands from the Eldridge and Government cores somewhat resemble those shown by Udden in his Plate 10, although the individual crystals forming the bands are not so coarse and consist of magnesite rather than calcite or dolomite."

They further noted that banding in much of the polyhalite is similar to the banded anhydrite and "may have genetic significance." In almost all cases, banding in Salado rocks was disturbed, as shown by crinkling, folding, partial disruption of magnesite layers (in anhydrite-magnesite layers), lensing, and solution with recrystallization.

Lang (1935, p. 268-269) noted:

"Although these bands or 'varves' are most conspicuous in the Castile, they are by no means confined to it. On the contrary, rhythmical deposition is expressed in all of the sediments of the Delaware Basin, although it is sometimes difficult to detect. Even uniform, fine-grained, dense polyhalite that has been produced by the alteration of anhydrite will, on careful inspection, invariably

> disclose 'varves' of approximately 5 mm. thickness . . . . Partially disrupted bands in polyhalite from the top of the Salado in the Edgridge core test are 10 to 12 mm. thick."

Measurements of "unusually well banded anhydrite rock" from Schaller and Henderson (1932, plate 2) were recorded by this writer as:

			Average thickness of pairs of dark and light layers, inches	Number of pairs measured
A.	Anhydrite-magnesite layers. Govt. hole #11. Depth 1,428 ft. 4 in. to 1,428 ft. 8 in.	Top part of figure	0.07	10
		Middle	0.08	10
		Bottom	0.08	10
B.	Anhydrite-magnesite 1,428 ft. 8 in. to 1,429 ft.	Top	0.05	21
		Bottom	0.07	11
C.	Anhydrite-magnesite, usually crinkled, however. Bands are nearly parallel with little lensing shown. 1,532 ft. 1 in. to 1,532 ft. 5 in.		0.10	30

These measurements probably represent the closest approximation to original thickness since the anhydrite-magnesite pair shows the least amount of disturbance, contortion of laminations, and solution and recrystallization of all the rocks illustrated. The average thickness of an anhydrite-magnesite "varve" from the data above is about 0.08 inches, or 156 varves per foot.

No distinct laminated properties have been reported for Rustler Formation rocks.

Table 6. Average thickness of some layers in the laminated Castile anhydrite and correlation of stratigraphic units with Udden's study well.

Length of[a] cores, cm	No. of[a] layers in each core	Average[a] thickness of layers, mm	Estimated[a, b] average thickness for each 100 feet, mm	Depth of[a] cores below surface, feet	Stratigraphic correlation	Estimated[c] average thickness per unit, mm
20.3	108	1.87	1.87	1,122		
20.4	110	1.85	1.85	1,258		
43.6	206	2.11	....	1,307	Anhydrite V	2.01
22.4	167	1.34	....	1,363		
26.7	190	1.40	1.61	1,394		
19.0	70	2.71	2.71	1,449		
17.7	218	.81	.81	1,530	Anhydrite IV	.81
21.0	184	1.14	....	1,620		
28.5	195	1.46	....	1,623		
7.5	70	1.07	....	1,626	Anhydrite III	1.71
24.0	113	2.12	1.44	1,679		
17.4	103	1.69	1.69	1,734		
345.5	1,737	1.98	....	1,809		
19.5	167	1.16	1.57	1,850	Halite II	1.16
95.2	480	1.98	....	1,945		
41.2	197	2.09	....	1,953	Anhydrite II	2.01
116.0	591	1.96	....	1,954		
26.0	296	.87	1.72	1,970	Halite I	.87
9.0	72	1.25	....	2,023		
18.0	125	1.44	....	2,027		
16.5	156	1.05	....	2,093		
13.0	122	1.06	1.20	2,097		
15.0	102	1.47	....	2,111	Anhydrite I	1.35
20.5	120	1.70	....	2,114		
13.0	90	1.44	....	2,117		
41.5	234	1.77	....	2,118		
18.0	182	.98	....	2,131		
21.7	131	1.65	1.50	2,143		
1,098.1	6,436				Totals	
Average thickness of measured layers.						1.63

[a]Data from Udden (1924, p. 353). Cores from David Flood, Grisham and McAlpine well, Culberson County, Texas (Culberson-U).

[b]"The averages for each hundred feet are based on one or several cores of stated lengths and depths," Udden (1924).

[c]Estimated average thickness of layers for each unit based on Udden's estimated 100-foot average (i.e., Anhydrites I and V) unless directly correlated with individual core data (i.e., Halites I and II and Anhydrite IV). For Anhydrite II, average of individual cores was used; for Anhydrite III, average of 100-foot data (1.44 and 1.69) and individual core data (1.98) was used.

Rates of Deposition

Rates of deposition and duration of time were estimated for the Cherry Canyon, Bell Canyon, Castile, and Salado Formations, using the hypothesis that the laminations described (see Laminated Sediments) are annual in nature (Table 7). Based on King's estimate of 10 to 20 varves per inch, the rate of deposition of Cherry Canyon strata is not greatly different than the rates of deposition of Recent sediments in deep basins near land (Shepard, 1948) and are of the same order of magnitude as the rate of deposition of the Castile laminated anhydrite. In the data from Shepard, one should note that no correction was made for further compaction to a "solid rock state." This correction would increase the years per centimeter but probably would not more than double the figures given. Even with a doubling of Shepard's figures, the thicknesses are comparable.

The Bell Canyon Formation has been described by King (1948) as similar to Cherry Canyon. One sample from southeast of Guadalupe Peak, measured by this author, showed 30 laminations per inch for 3 inches, a slower rate of deposition than the Cherry Canyon Formation, but still comparable to Castile and Recent sediments. From these data a tentative and probably maximum duration for Bell Canyon time is 360,000 years for 1,000 feet of section. The Brushy Canyon Formation, approximately 1,000 feet thick in the Delaware basin, is assumed to have taken about the same amount of time for accumulation as Cherry Canyon Formation, 120,000-240,000 years,

Table 7. Estimated rates of deposition of Permian rocks in the Delaware basin, European Permian evaporites, and Recent sediments in deep basins near land.

Rock Units, thickness in feet	Time, years	Rate of deposition: No. yrs. for 1 ft	No. yrs. for 1 cm
Delaware basin			
Total Permian section	50 million[a]	2,500	82
(20,000)	20-30 million[b]	1,000-1,500	41 ave.
Bone Spring Limestone[c]	600,000	270	7.5
(2,250)	800,000	360	10
Cherry Canyon Formation[d]	120,000	120	3.9
(1,000)	240,000	240	7.8
Bell Canyon Formation[e]			
(1,000)	360,000	360	10
Castile Formation			
(1,300-1,400)[e]	250,000-280,000[e]	191[f]	
(2,000 in Ochoa trough)[e]	same	125-135[e]	
(1,600)[f]	306,000[f]	191[f]	6.3[f]
Salado Formation			
(700-750)	110,000-150,000	156-200	5-6
(2,000 in Ochoa trough)	same	55-75	
European Permian evaporites			
Zechstein (total section)[b]			
(4,000-6,000)	500,000	83-125	
Lower Evaporite Series (Germany)[b]			
(1,650, mostly halite)	6,000-8,000	ave. 4.5	
Fordon anhydrite[g]		80	
Middle cycle of Lower Evaporite Series at Fordon (Northern England)[g]			
(500)	22,300	45	
Recent sediments in deep basins near land[h]			
Dutch East Indies	uncorrected		15
	corrected for sample loss		9
Gulf of California	uncorrected		10
(some varves)	corrected for sample loss		6
Basins off California	no correction needed		33
Black Sea	uncorrected		50
(deep part varved)	corrected for sample loss		25

[a] From Dunbar (1960)
[b] From Borchert and Muir (1964)
[c] From Marshall (1954)
[d] From data of King [10-20 varves per inch] (1948, p. 34-35)
[e] Data from this report
[f] From Udden (1924) [Thickness includes part of Salado]
[g] From Stewart (1963b)
[h] From Shepard (1948)

since lithologies and paleoenvironments are apparently similar. This gives approximately 600,000-800,000 years required for deposition of the Delaware Mountain Group in the Delaware basin.

Castile Formation rate of deposition is based upon Udden's (1924) average, 191 years per foot. Duration of Castile time would be 250,000-280,000 years for 1,300-1,400 feet of laminated calcareous anhydrite. Udden's estimate of 1,600 feet of Castile section probably includes about 300 feet of Salado of this report. A 2,000-foot section in the Ochoa trough would show a rate of deposition of 125-135 years per foot resulting from the faster deposition of halite in the trough than equivalent anhydrite on the intrabasin shelf. This rate compares remarkably well with the Zechstein rate of deposition of 83-125 years per foot.

Salado Formation laminations of anhydrite-magnesite layers are about 160 laminations per foot (see Laminated Sediments). In southern Reeves County, in a Salado section that contains a minimum of halite, the anhydrite measures approximately 700-750 feet. If continual deposition occured with the rate of deposition of 160 years per foot, total Salado time would be about 110,000-120,000 years.

Since the anhydrite has been reported as massive (Adams, 1944), the rate of deposition attributed to magnesite-anhydrite may not be applicable to this section. The absence of magnesite may be compensated for in two ways. First, if carbonate makes up one-fourth of the thickness of a layer as in the Castile laminations, a reconstructed section would be 875 to 930 feet thick, adding 175 to 180 feet of magnesite for the missing magnesite in this section. This would give a maximum duration of Salado time of 150,000 years at the rate of deposition of 160 years per foot. The 750 feet of anhydrite then would have been deposited at the rate of 200 years per foot.

From another viewpoint, if the magnesite made up one-fourth of the section but accounts for one-half of deposition time, magnesite accounts for 80 years per 0.25 feet, while anhydrite accounts for 80 years per 0.75 feet. Since magnesite is missing on the intrabasin shelf, massive anhydrite would account for 160 years per 0.75 feet or 200 years per foot, the same rate determined for this section from the first analysis.

Based upon the range of 110,000 to 150,000 years for Salado deposition, a 2,000-foot section in the Ochoa trough, containing mostly halite, would have been deposited at a rate of 55 to 75 years per foot, a rate about three times faster than on the intrabasin shelf.

Comparison of Salado data from this report with data of Permian evaporites from northern England from Stewart (1963b) shows remarkable resemblences in rates of deposition. Salado rocks in the Ochoa trough were probably deposited at a rate of 55 to 75 years per foot, rocks of Lower Evaporite Series at Fordon, northern England, at 45 years per foot. A clearer parallel is shown by comparing the duration of time for deposition of 500 feet of evaporites. British evaporites took 22,300 years; an average of Salado shows 27,500 to 37,500 years. The rate of deposition for the Fordon anhydrite of 80 years per foot, however, is in contrast to 200 years per foot for the massive Salado anhydrite.

Estimates of duration for deposition of the Zechstein of Germany (Borchert and Muir, 1964) and of the Upper Permian evaporites of west Texas exhibit an extraordinary similarity. Zechstein deposition lasted 500,000 years. Lang (1950) approximated 500,000 years for the Castile and Salado. Udden (1924) noted 306,000 years for 1,600 feet of anhydrite. A 2,000-foot section would represent about 380,000 years for Castile and Salado. From the data of this report, total Castile and Salado time lasted from 360,000 to 415,000 years. If the rate of Rustler deposition was about the same as Salado, 200 years per foot, 500 feet of Rustler would represent another 100,000 years; and the duration of Upper Permian evaporite deposition would be 460,000 to 515,000 years. Although duration of time necessary for Dewey Lake deposition cannot be established at this time, the duration of evaporite deposition probably represents a minimum of 500,000 years, a duration comparable to Zechstein estimates.

Large-scale Cycles

The Guadalupe Series was considered by King (1948, p. 28) in its entirety as expressing "more or less perfectly the gradual changes in sedimentation and faunas that took place, by virtue of the passage of time, within a single cycle of sedimentation." The first large cyclical units noted by King (1948, p. 31) are found in the Brushy Canyon Formation. A typical unit consists of a massive sandstone generally resting on a channeled surface succeeded by thin-bedded, fine-grained sandstone with varve-like laminae (Fig. 25). Toward the top of each cycle are intercalations of dark shaly sandstone, probably with a considerable bituminous content. Each cycle is brought to an end by another period of channeling and deposition of coarser sandstone. King noted that these are rude cyclical units which cannot be traced far along the outcrops and are probably local in extent.

In the Cherry Canyon Formation, King (1948, p. 34) noted:

> "In some exposures, as on the south side of Getaway Gap, the various rock types appear in rude cyclical order through intervals of 10 or 20 feet of beds. Shaly sandstones below are followed by thin-bedded sandstones, and then by limestone lenses or nodules, after which the succession is repeated. . . ." (section 40, Fig. 25, this report).

King (1948, p. 52) described further development of cyclical order in parts of the Cherry Canyon Formation as follows:

> "The repetition of the cycle of shaly sandstone, sandstone, and nodular limestone below the Getaway member at one locality has already been noted [section 40, Fig. 25, this report]. Higher up, each limestone bed or member is commonly underlain by massive sandstone and is succeeded by thin-bedded sandstone; this succession is repeated several times upward in the section." (section 42b, Fig. 25, this report).

Bell Canyon sandstones and limestones also tend to be repeated in cyclical order. King (1948, p. 85) described

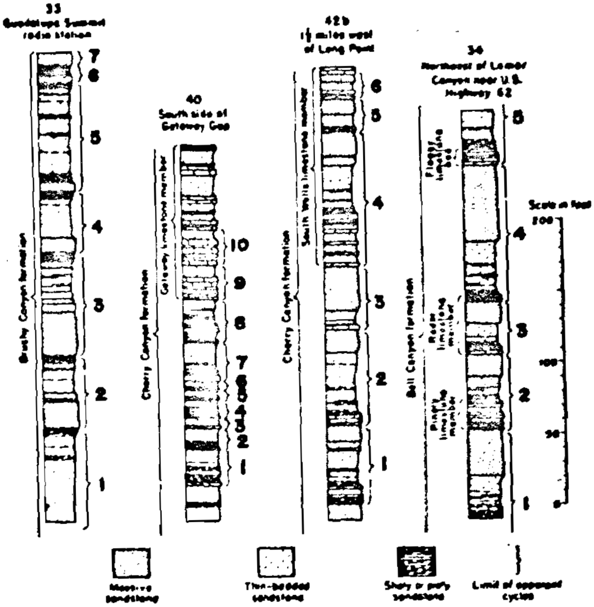


Figure 25. Sections showing cyclical deposition in Brushy Canyon, Cherry Canyon, and Bell Canyon Formations of the Delaware Mountain Group. From King (1948, p. 32). [Numbers of sections at top of columns correspond to sections shown on plate 6 in King, 1948.]

this ordering as follows:

> "The cycles resemble those in the upper part of the Cherry Canyon formation. . . . Limestone members are generally underlain by massive sandstones and overlain by thin-bedded sandstones [section 34, Fig. 25, this report]. In the section near United States Highway No. 62. . ., there are 5 such cycles in the 670-foot thickness of the [Bell Canyon] formation."

Figure 25 (from King, 1948, p. 32) shows 28 cycles as interpreted by King. In the Brushy Canyon section, 7 cycles are represented in about 340 feet of rock, an average of 48 feet per cycle. In 480 feet of Cherry Canyon there are 16 cycles, an average of 30 feet per cycle. If the rates of deposition (Table 7) are correct, the Brushy Canyon and Cherry Canyon cycles range from 5,000 to 8,000 years per cycle using the average rate of 180 years per foot. It is emphasized that these averages are based upon comparatively few data and are only intended to show the order of magnitude.

Another striking repetition in Delaware Mountain Group rocks is a consistent recurrence of thick cyclic units (Fig. 25: section 33, nos. 1-5; sec. 42b, nos. 1-4; and sec. 34, nos. 2-4) that generally contain a thick massive sandstone unit at the base as in Brushy Canyon or at the top as in Cherry Canyon and Bell Canyon. The thickness of these units averages 64 feet per cycle, representing about 15,000 years per cycle assuming a rate of deposition of 240 years per foot. In the cycles mentioned to this point, regularity in time is not implied.

The next larger cycle in the Delaware Mountain Group consists of the alternation of major limestone and clastic units such as the Pinery, Rader, McComb, and Lamar limestones and the unnamed clastic units. There are nine such major alternations in the Cherry Canyon and Bell Canyon Formations (Table 2). Using the tentative estimate of about 600,000 years for Cherry Canyon and Bell Canyon time, each alternation took an average of about 70,000 years.

Data from the Castile Formation are better grounded since they are based upon detailed counts throughout the Castile section. Udden (1924, p. 351) noted short-period cycles made up of 5 to 19 varves with "an excess of cycles that comprise six or seven and twelve or thirteen laminations." He also mentioned many cycles that measure 8, 9, and 16 layers. Particular emphasis was placed on the periodic recurrence in one short part of the core of much bituminous material near every seventh and thirteenth layer. Udden suggested the frequency of the numbers twelve and thirteen as possible evidence of sun-spot cycles.

Udden further noted larger scale cycles of 330 to 420 laminations containing "a fairly regular recurrence of one maximum and one minimum" with maxima about twice as thick as minima. This recurrence was found by averaging measurements in groups of thirty layers and noting that eleven to fourteen of these groups contained one maximum and one minimum. These cycles were noted in a section containing 1,737 laminations, from about 1,810 to 1,820 feet below the surface, and in several cores below this section (well Culberson-U).

A comparison was made between duration of time for major Castile stratigraphic units based upon an average varve thickness of 1.63 mm per varve, and duration of deposition based upon Udden's detailed estimates of varve thickness (Table 8). Castile unit thicknesses were obtained from unit thickness maps and data of this report in the vicinity of Udden's reference well. The stratigraphic section was correlated with Udden's described section (Table 6). Rates of deposition were determined from estimated average thicknesses per unit.

Duration of time for individual units of the Castile are of the same order of magnitude using the above methods and are remarkably consistent for some units, such as Anhydrite I through Anhydrite III. Anhydrite IV shows a discrepancy; however, the duration from both methods of computation is still of the same order of magnitude.

Baker (1929, p. 35) based cyclic succession on anhydrite-halite alternations from samples of wells. His data on the number of halite-anhydrite alternations for the Castile-Salado-Rustler sequence are:

Number of Cycles	Situation
3 (some eroded)	Near Carlsbad, New Mexico
1 (solid anhydrite, 1,164 ft. thick)	Eastern Culberson and western Reeves Counties, Texas
6	Reeves-Pecos County line, Texas
5 (some eroded)	Northwestern Reeves County, Texas
22	Southern Ward County, Texas
26	Loving County, Texas.

The 26 cycles noted from Loving County can be counted in the Pinal Dome Oil, Means well No. 1 (see Loving-M, Fig. 4).

Table 8. Duration of time for Castile units using average varve thickness compared with duration using varve thickness estimates for individual units. Data for varve thicknesses from Udden, 1924.

Castile Units	Unit thickness, feet	Duration of time, in years, from average varve thickness, 1.63 mm[a]	Correlated varve thickness, mm (see Table 6)	Rate of deposition, years per foot	Duration of time from detailed data, years
Anhydrite I	170	34,000	1.35	223	37,910
Halite I	20-30	5,000	.87	380	7,600
Anhydrite II	90	17,000	2.01	155	13,950
Halite II	15-20	3,000	1.16	270	4,000
Anhydrite III	300	57,000	1.71	176	52,800
Anhydrite IV	100-150	20,000-30,000	.81	380	38,000-57,000
Anhydrite V	600-700	114,000-133,000	2.01	155	93,000-108,000
Castile time		250,000-279,000			247,260-281,760

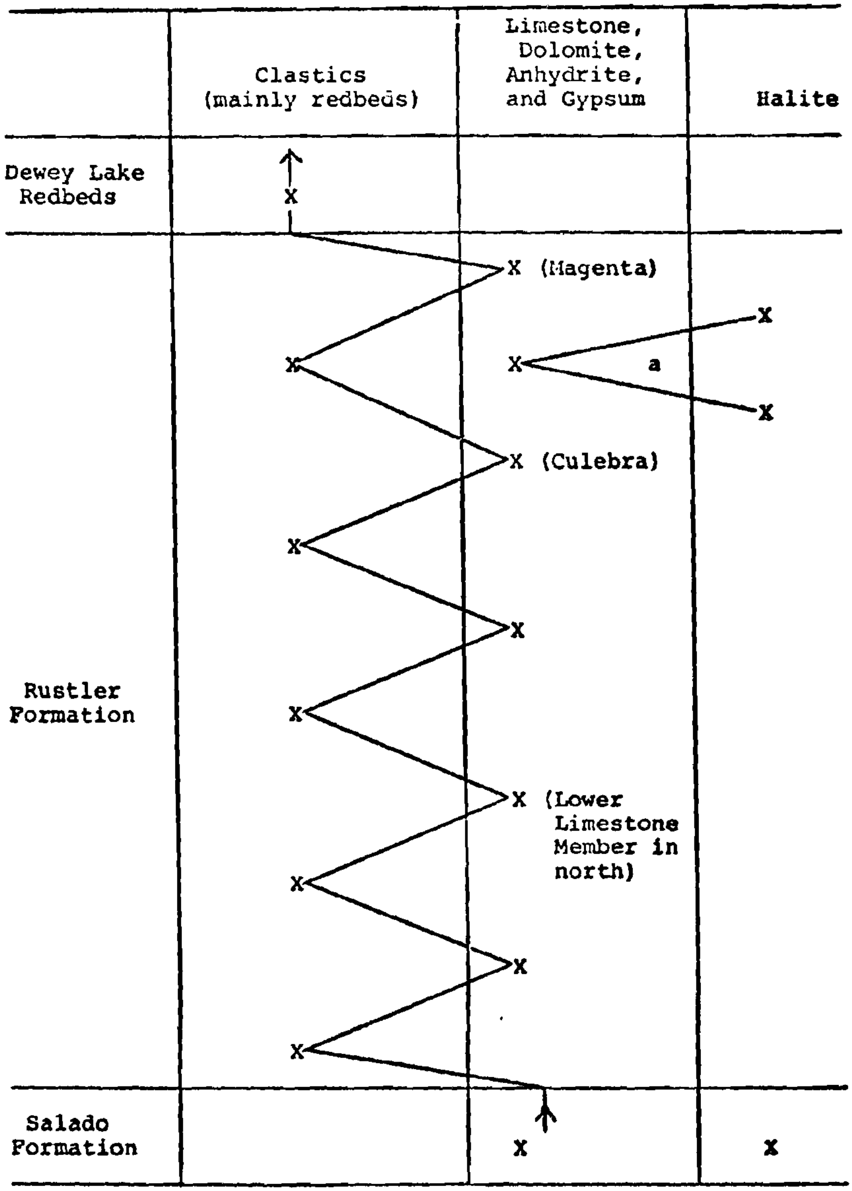
[a]Rate of deposition approximately 190 years per foot.

Eleven of these cycles can be attributed to the Castile of this report. These large-scale cycles would average about 20,000 to 25,000 years each in the Castile and about 8,000 to 11,000 years each in the Salado.

From the sonic-gamma-ray log of well Loving-43, at least 5 more cycles are seen in Halite II and 5 more in Anhydrite IV. This would give a minimum of 21 alternations for the Castile in Loving County. Kroenlein (1939) noted 44 anhydrite beds in the Salado Formation in the Pinal Dome well. In Loving County, therefore, the minimum number of cycles would be about 65 anhydrite-halite alternations for the Castile and Salado. The average duration for Castile alternations would be from 12,000 to 13,500 years; for the Salado alternations; 2,500 to 3,000 years. This suggests cycle length tends to decrease with time.

In the Rustler Formation, anhydrite, dolomite, and redbeds are widespread throughout the Delaware basin. Lithologic fluctuations found in the Rustler show five trends from clastic to anhydrite and dolomite deposition (Fig. 26). If Rustler deposition lasted 100,000 years, the average duration per alternation was 20,000 years.

In general, cycle lengths can be postulated from 2,500 to 70,000 years, with cycle length appearing to decrease with younger age. Probably a variety of cycle lengths occurred throughout the Guadalupe and Ochoa; however, alternations of less than about 2,500 years could not be resolved from sonic logs with certainty. Duration of time for some



a. Near reef zone in south-central Lea County, New Mexico.

Figure 26. Generalized cyclic trends in Rustler Formation. Data compiled from Lang (1935, 1938) and from Adams (1944).

Table 9. Duration of time for some stratigraphic and cyclic units in Permian of Delaware basin.

	Duration per series, years	Duration per formation, years	Estimated duration for limestone-clastic alternations, anhydrite-halite alternations, and some Castile stratigraphic units, years.			
OCHOA SERIES	500,000+					
Dewey Lake Redbeds		?				
Rustler Fm.		100,000?			20,000?	
Salado Fm.		110,000- 150,000			8,000- 11,000	2,500- 3,000
Castile Fm.		250,000- 280,000	A III,[a] 53,000- 57,000	A I - H I 40,000- 45,000	12,000- 13,500	H II 3,000- 4,000
			A IV 38,000- 57,000	A II-H II 17,000- 21,000		H I 5,000- 8,000
GUADALUPE SERIES	600,000- 800,000					
Bell Canyon Fm.		360,000?	60,000- 70,000			
Cherry Canyon Fm.		240,000?			15,000	5,000- 8,000
Brushy Canyon Fm.		120,000?				
LEONARD SERIES	600,000- 800,000					
Bone Spring Limestone						

NOTE: Data show order of magnitude; regularity throughout time is not implied.

[a]A = Anhydrite unit, H = Halite unit, Roman numeral designates unit number; see Table 2.

stratigraphic and cyclic units is summarized in Table 9.

Long cycles lasting from 30,000 to 70,000 years consist of major limestone-clastic alternations in the Cherry Canyon and Bell Canyon and major anhydrite-halite alternations in the Castile. Many of the thicker clastic units of the Delaware Mountain Group have an intermediate length of about 15,000 years duration. The average cycle length for Castile anhydrite-halite alternations in Loving County also has an intermediate value of 12,000 to 13,500 years. The most distinct example in the Castile is shown by Anhydrite II-Halite II, lasting from 17,000 to 21,000 years. The clastic-limestone and anhydrite alternations in the Rustler may also be of intermediate length. Major Salado sulfate-chloride alternations lasted 8,000 to 11,000 years.

Shorter cycles lasting from less than 2,500 to 8,000 years are found in the clastics of the Brushy Canyon, in the limestone-clastics of the Cherry Canyon, and in the sulfate-chloride alternations of the Salado.

Relative Changes in Water Depth

The recurrence of cyclic changes of similar duration throughout Guadalupe and Ochoa rocks, both clastics and evaporites, suggests that the same depositional control or mechanism may be responsible. King's work (1942, 1948) and evidence in this report from the Castile Formation suggest that changes in water depth within the basin are related to the major cycles. Weller (1960, p. 368-369) stated:

> "Symmetrical marine cycles can be explained simply as resulting from rather regular fluctuations of depth of water in the depositional basin, or amount and kind of sediment supplied to it, although more complicated interactions of factors may have occurred. In such a succession as sandstone, shale, limestone, shale, and sandstone, for example, regular transgression and regression of the strand line is suggested with attendant deepening and shallowing of water in offshore areas."

Transgression and regression accompanied by deepening and shallowing of water in the basin may be expressed in the limestone-clastic alternations in the Delaware Mountain Group, the clastic-limestone and anhydrite alternations in the Rustler Formation, and by the anhydrite-halite alternations in the Castile and Salado Formations.

King (1948, p. 31) postulated a shallowing of water in the Delaware basin at the beginning of Guadalupe time. A concurrent change in lithology within the basin took place with this regression of the sea. Limestone of the Bone Spring is overlain by Brushy Canyon sandstone, in part moderately coarse grained.

Transgression of the sea with associated deepening of water in the basin during Cherry Canyon deposition was described by King (1948, p. 50) as follows:

> "During middle Guadalupe time, deposits were laid down not only in the Delaware Basin, but also in the shelf area beyond. As compared with lower Guadalupe time, the area of deposition was greatly increased. . . . The deposits both in and beyond the Delaware Basin were of marine origin. If the region outside the basin was land during lower Guadalupe time, there was a readvance of the sea during middle Guadalupe time."

Hull (1955, p. 65) in his study of the Delaware Mountain Group, concluded that "Deposition of basin and shelf sediments was controlled by submarine topography and by cyclic changes in the relative position of sea level."

Changes between agitated and quiet water conditions may reflect deepening and shallowing of water. Describing the change from deeper to shallower water at the beginning of Guadalupe time, King (1948, p. 31) noted:

> "The preceding deposits in the Delaware Basin (black limestone facies) show evidence of having been deposited in quiet. . . water, whereas many beds of the succeeding Brushy Canyon formation in the same area were laid down in agitated water, and the whole formation is probably a shallow-water deposit."

For middle Guadalupe time King (1948, p. 52) reported agitated water conditions to be most common in the lower part of the Cherry Canyon and quiet water in the upper part. King proposed a progressive deepening of the water to account for the change in water conditions. King (1948, p. 82-85) further noted that the sandstone and limestone of the Bell Canyon were deposited in quiet water.

Another factor involved in the change from agitated to quiet water conditions is the growth of reefs on the basin margin. Reef growth started in about middle Cherry Canyon time and continued into Castile time. These reefs, now the Goat Seep and Capitan Limestones, may have acted as a physical barrier between the sea in the Delaware basin and water between the reef and landward areas. Relatively little deepening combined with this physical barrier may have effectively produced quiet water conditions within the Delaware basin.

The gradation of Lamar Limestone Member of the Bell Canyon Formation into the basal laminated limestone of the Castile Formation suggests little change in depositional conditions at the beginning of Ochoa time. The laminated characteristics suggestive of quiet-water conditions continue from limestone into the laminated anhydrite of Anhydrite I.

Several zones of massive anhydrite, brecciated laminated anhydrite, and sand are found within the thick section of laminated anhydrite of the Castile. These zones are found on the intrabasin shelf and are characteristically at the stratigraphic level of halite in the Ochoa trough. Some sands are widespread over the intrabasin shelf, especially at the stratigraphic levels of Halite I and halite in Anhydrites IV and V. Laminated characteristics of anhydrite are often lost in these zones of rock on the intrabasin shelf, possibly by mixing of constituents by agitated waters. An alternative explanation for the loss of lamination is that laminated sediment could have been "weathered" either on the basin floor contemporaneously with deposition (halmyrolysis) or by later movement of water through sand layers acting as aquifers. Decrease in average thickness of laminations is also a feature of these zones (Tables 6 and 8).

Salado rocks have characteristics similar to the rocks of the disturbed zones found in the Castile. Massive anhydrite and sands are abundant on the intrabasin shelf, while chlorides and sulfates make up most of the section in the Ochoa trough. Previously, Kroenlein (1939, p. 1688) interpreted Salado rocks as having been laid down under lacustrine conditions. Massive anhydrite, limestone, dolomite, and sand of the Rustler Formation were probably laid down under conditions similar to those in the Salado.

It is concluded that the laminated sediments of the Guadalupe and Ochoa Series were laid down under relatively deeper water than the sediments of the Brushy Canyon, lower part of the Cherry Canyon, and non-laminated zones of the Castile, Salado, and Rustler Formations.

Deep-water deposition of upper Guadalupe and lower Ochoa Series rocks has been postulated by several writers. Kroenlein (1939, p. 1684) interpreted the depth of water of the basin floor at the end of Guadalupe time as approximately 1,800 to 2,000 feet below the top of the reef. King (1942, p. 637-639, 770) postulated the depth as 1,000 feet or more. Adams (1944, p. 1598) hypothesized "an unfilled, geosynclinal bowl averaging approximately 1,700 feet in depth and encircled by steep-faced, cliff-like reefs between 1,200 and 2,000 feet high." Kroenlein (1939, p. 1688) further defined the depth of the basin during Salado time at approximately 700 feet below the top of the reef. Hypothesis for these depths is generally based upon present relief between the Tansill Formation atop the Guadalupe Mountains and the Lamar Limestone Member of the Bell Canyon Formation in the Delaware basin, assuming Tansill-Lamar equivalence. Since the Tansill overlies the Capitan Limestone in the Guadalupe Mountains and Moore (1959) noted the equivalence of part of the Castile with the upper part of the Capitan Limestone, the equivalence of Tansill and Lamar is subject to question. In addition, part of the present relief is most certainly due to post-Permian uplift. A factor of the amount of subsidence contemporaneous with deposition also was not taken into account by Kroenlein, King, or Adams. The above figures of Kroenlein, King, and Adams, therefore, are maximum values and may be several times greater than the original depth of the basin floor.

Source of Salts in the Castile Formation

Baker (1929, p. 33) observed that the total amount of evaporation greater than total water supply, a more or less constant long-continued supply of water from the ocean, and a basin of sedimentation are the only requisites to account satisfactorily for the volume of "saline residues" in the Permian basin.

A qualitative discussion of models explaining the source of salts is feasible, but two factors prohibit quantitative analysis: 1. the unknown extent of the "Castile sea" and 2. the debatable depth of water in the Delaware basin and in back-reef areas. Extent of the sea affecting deposition within the Delaware basin is based upon subsurface correlations and regional inference (see Ochoa Series, Regional Correlation). Cave (1954), Hall (1960), and this writer believe that the sea extended over the Delaware basin, Central Basin platform, and back-reef areas. Hills (1942), Adams (1944), and R. H. King (1947), however, described the

"Castile sea" as restricted to the Delaware basin. Ramifications of the assumption of limited versus regional extent of the sea are evident in the text.

Depth of water in the Delaware basin during Castile deposition can be interpreted as shallow or deep, the only limitation being a minimum depth (unknown also) below sill points of the barrier reef surrounding the Delaware basin. This minimum depth is necessary to account for the preserved laminations in the Castile; however, if a shallow depth is assumed, subsidence must have kept pace with the rate of deposition. Depths of the basin floor have been proposed as much as 2,000 feet below a "reef top", as previously noted. Estimates of the volume of water within the Delaware basin and limiting values on the volume and rate of transport of water in and out of the basin depend upon depth figures and, therefore, are also debatable. Depth of water and volume of water in back-reef areas is also an important factor when considering the Delaware basin as a small area within a widespread marine sea (for example, see area of Delaware basin within Grayburg-Marlow sea, Hills, 1942, figure 9). Consequences related to existence of back-reef waters during Castile deposition are evident, and the existence of such a condition is a matter of interpretation.

The simplest model has been proposed by Baker (1929), described previously. Modification of this model may be necessary, however, to explain rapid thickening of anhydrite along the eastern basin margin parallel to the reef front

(Figs. 16, 17, and 19, in pocket).

Thickening along the basin margin may be due to mechanical or chemical phenomena. Physical transport of sediment into the Delaware basin through passes in the barrier reef has been suggested previously to account for interpreted fans or deltas (see Castile Formation, Anhydrite I). Adams (1944), R. H. King (1947), Scruton (1953), and others have stated that the amount of anhydrite in the Castile is much too high with respect to the amount of halite. Relative sulfate enrichment, or chloride depletion, or both, may have occurred and, interestingly, each interpretation leads to different models for the Delaware basin.

Sulfate enrichment of water in the Delaware basin can be explained by several mechanisms. The possible case of "normal sea water" of different composition during Permian time should be kept in mind. If sea water concentration were approximately equivalent to that found today, sulfate enrichment of water may have been necessary and could have taken place prior to entering the Delaware basin. Borchert and Muir (1964, p. 46-47, figure 5.1) described the situation of several sub-basins within one marginal marine basin. The marginal basin has restricted connection with the open sea, while sub-basins develop due to swells or bar zones within the marginal basin itself. In their simplified model, three sub-basins are described: sub-basin A nearest to the open sea, an intermediate sub-basin B, and sub-basin C nearest to land. Thick successions of bedded calcareous dolomite,

dolomite-anhydrite, and clay-anhydrite-halite characterize sediments found in sub-basins A, B, and C, respectively. Brine concentration increases from sub-basins A to B to C. In the west Texas region, back-reef conditions appear to be similar to those in sub-basin C; Delaware basin conditions appear similar to those in sub-basin B. The presence of a sub-basin seaward from the Delaware basin, possibly in the Marfa basin area, would fulfill necessary requirements for sulfate enrichment of sea water prior to entering the Delaware basin. If previously present, Castile-equivalent strata to the south and west of the Delaware basin have been completely eroded; therefore, this model remains debatable.

Sulfate enrichment could also have taken place in back-reef waters prior to movement into the Delaware basin. Evaporation would enrich back-reef water in sulfate and chloride. Sulfate-rich runoff from land surrounding the back-reef area, however, could have caused enrichment of sulfate alone. Older sulfate deposits in areas surrounding the Delaware basin and back-reef areas could have been subject to erosion and solution, thereby enriching runoff. Presence of older Permian sulfate deposits is well known (Hills, 1942; Baker, 1929; and Hayes, 1964).

Movement of sulfate-enriched waters from back-reef areas into the Delaware basin could have been accomplished in at least four ways.

1. Water could have moved through major channels linking back-reef areas to the Delaware basin, such as the

Sheffield channel between the Midland basin and the Delaware basin (King, 1942).

2. Water could have moved through passes in the reef, such as those interpreted in this report.

3. Water could have percolated through the reef itself.

4. The dense, hypersaline brine of the back-reef area may have moved over the reef (see Reflux model below).

To accomplish depletion of chloride from waters in the Delaware basin, R. H. King (1947) postulated a "reflux" model for the Delaware basin. Scruton (1953) described King's model of the Delaware basin as follows:

> "the deep Permian Delaware basin of Texas and New Mexico, an arid region where evaporation exceeded precipitation plus runoff, was connected to the open sea by a restricted channel on the southwest. The water within this basin below what he inferred to be average wave base consisted of a uniform brine formed by the excess of evaporation. Normal marine water flowing into the basin through the restricted channel, replaced that lost by the excessive evaporation, moved over the uniform brine toward the distal end of the basin, and was concentrated by evaporation until it became similar in density to the brine below. It then mingled with the brine and sank. To compensate for the volume of sinking brine at the basin's upper end, he suggested that a continuous seaward flow of dense hypersaline water, a 'reflux' from the basin, took place in the bottom of the channel below average wave base."

After studying "the flow characteristics and distribution of properties in estuaries, inlets, and other bodies of water partly restricted from the open sea," Scruton (1953, p. 2498) modified King's model as follows:

> "Surface currents flow from regions of low salinity to regions of higher salinity in response to hydrostatic head and are accompanied at depth

> by oppositely directed currents flowing from high to low salinity regions because of density distribution. Salts are deposited in restricted estuaries where evaporation exceeds precipitation plus runoff. The necessary restrictions of the estuary or basin are in part dynamic and in part static. Dynamic restriction is caused by the hydrostatic head and by frictional stresses between the oppositely directed surface and bottom currents, and between the bottom current and the channel floor. Static restriction is produced by topographic confinement.
>
> When high concentrations are developed, a strong horizontal salinity gradient exists which produces lateral segregation of different salts during precipitation. The escaping deep current returns to the sea those salts which have not been precipitated. Fluctuations in equilibrium caused principally by changes in excess of evaporation or in degree of channel closure cause migrations of the horizontal salinity gradient along the longitudinal axis of the basin which produce vertical differentiation of salts."

Within the Delaware basin, certain geologic evidence is at variance with the King-Scruton model. Although Anhydrites I and II follow their model by thickening from the southwest or channel area to the northeast or distal end of the basin, Halites I and II thicken from south to north in the Ochoa trough. Halite trends place the longitudinal axis of the basin parallel to the Central Basin platform and within the Ochoa trough. The entrance from the open sea would, therefore, be in the southern or southeastern part of the Delaware basin, as proposed by Hills (1942, figure 11).

If one assumes that anhydrite and halite thickness increase is related to salinity increase, then Scruton's model must account for the almost perpendicular trends of anhydrite thickness with respect to halite thickness. This could conceivably be done by changing salinity gradient patterns during different modes of deposition. Alternatively, individual mechanisms of anhydrite and halite deposition can be proposed, but if this is so, Scruton's model applies only during halite deposition or only during anhydrite deposition.

A further complicating factor is that of topographic influence on salinity distribution. During Castile deposition, the intrabasin shelf to the south and west of the Ochoa trough is interpreted as a relatively positive tectonic area. Inference from this interpretation would suggest that there was some relief between the intrabasin shelf and the Ochoa trough. With the introduction of topographic influence, Scruton's model, as well as any other, must take into consideration the amount of relief, the position of the channel with respect to the ocean, the distribution of the salinity gradients, and the possibility of sulfate-concentrated waters entering the Delaware basin from back-reef areas. Further analysis would undoubtedly add more complexities to the basic factors that influenced sea water composition and distribution of salt. It appears most reasonable to assume only that sulfate was deposited during Castile time by evaporation of marine surface water moving into the Delaware basin. However, sulfate preconcentration, especially in back-reef areas, and reflux probably modified this basic sedimentational mechanism; physical transport of sediment into the Delaware basin through passes in the reef further modified local sedimentation near the reef front.

Rates of Evaporation During Castile Time

Briggs (1957, p. 117-119) noted the relationship of weight or thickness of evaporite minerals precipitated, rate of evaporation of brine, and density of brine by stating: "None of these is independent of the other two." Since rate of evaporation and density of the original brine are unknown and dependent factors, no unique solution for these factors can be evaluated. Certain limiting values, however, may be inferred from geological and meteorological data.

Assuming that recent meteorological data give the correct order of magnitude of past evaporation rates, net or effective evaporation rates in the Delaware basin of about 60 inches per year may be considered reasonable. Recently computed and measured net rates of evaporation on sea surfaces generally range from 31 to 60 inches per year in 15° to 30° north latitudes, the zone of maximum evaporation in the northern hemisphere (von Arx, 1962, p. 187-189). Two areas in the northern hemisphere show a maximum net rate of evaporation of about 133 inches per year, one area over open sea in the Pacific Ocean and the other over the northern part of South America (von Arx, 1962, figure 7-5).

Briggs (1957, p. 119) estimated evaporation for the climatic setting for evaporite basins as follows:

> "The maximum evaporation rate from the oceans is 52± 6 inches per year in the lower equatorial latitudes. . . . The average of six semi-arid and arid reservoir evaporation rates, ranging from 51 to 123 inches per year, is 88 inches. . .; thus, a value of 70 inches (185 centimeters), a mean of oceanic and reservoir evaporations, is considered

> the most reasonable for ancient evaporite basins envisaged as semi-marine bodies of water in a region of arid climate. A further factor affecting evaporation is that brines of high density do not evaporate as readily as those of low density, owing to a change in heats of solution. . . . An additional correction factor of 0.90 in the density range above 1.21 might be applied where an evaporite sequence composed largely of halite and potash salts is being considered. Rainfall and terrestrial runoff might further reduce the effective evaporation rate to about 60 inches (152 centimeters) per year."

Richter-Bernburg (1964, p. 510-519) stated that a $CaSO_4$-saturated brine should deposit 1 mm per year $CaSO_4$ if the evaporation rate of the area is 2 meters of water (about 79 inches). The net evaporation rate over the Delaware basin during Castile time has also been estimated by R. H. King (1947), who arrived at a higher estimate of 116 inches per year.

Assuming a net evaporation rate of about 60 inches or 152 centimeters per year, Briggs (1957, p. 115-123) calculated a reasonable estimate of sulfate-carbonate thickness, 0.711 mm, compared with average Castile layer thickness of 1.63 mm determined by Udden (1924) and of 1.5 to 1.6 mm determined by Anderson and Kirkland (in press). Since Briggs' calculations are based upon solubility data of gypsum rather than anhydrite, consideration should be given to the differences obtained if anhydrite was the originally precipitated material.

Deer, Howie, and Zussman (1962, p. 205-211, 221-22), in their review of the chemistry of anhydrite and gypsum, noted:

1. Anhydrite is soluble in acids but in water its solubility is slight.

2. Anhydrite solubility decreases with increasing temperature.

3. Increased salinity decreases the temperature of anhydrite-gypsum dehydration.

4. Pressure also affects gypsum-anhydrite equilibrium; however, for this study precipitation is tacitly assumed to occur at the surface of the sea. Pressure probably had a negligible effect on Castile sulfate precipitation.

In general, relatively high temperature with increased salinity due to evaporation of sea water would tend to increase the amount of precipitated material in Briggs' calculations. This increase would bring his results closer to the data determined by Udden, and Anderson and Kirkland.

INTRABASIN TECTONICS

Concepts and Framework

In order to analyze tectonics associated with the Upper Permian evaporite complex, several stratigraphic and tectonic concepts must be utilized. Weller (1960, p. 580) noted:

> "All tectonic evidence is indirect. It is derived mainly from interpretations based on stratigraphic and sedimentologic features and relations. Thus thickening or thinning of stratigraphic units commonly records variable degrees of subsidence. . . . The occurrence of other types of sediments. . . and the progressive structural developments in successive stratigraphic zones all aid in the recognition of tectonic activity, its character, distribution, and relative importance."

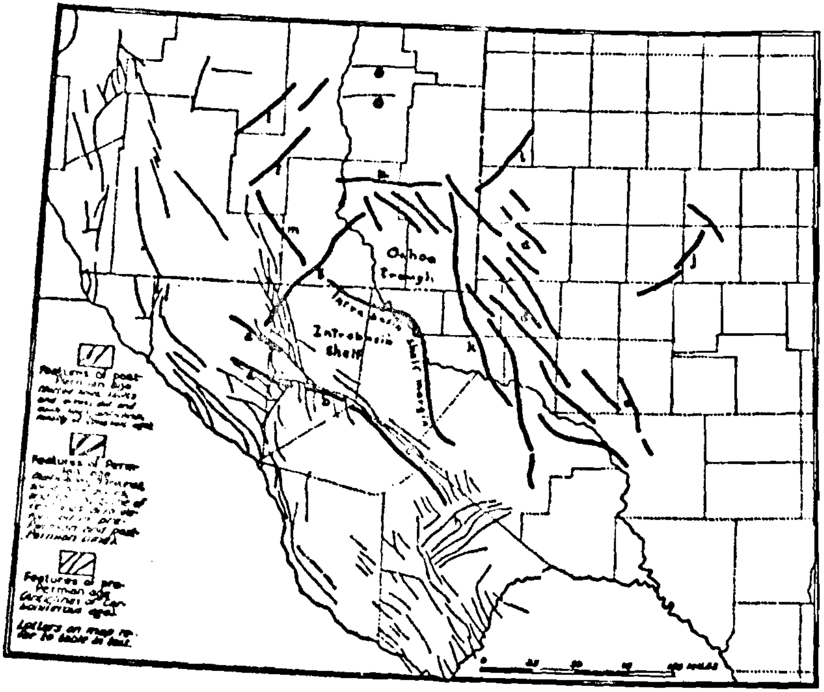
King (1942, p. 726) stated:

> "the theory was developed that the provinces of Permian time in the Guadalupe Mountains region were primarily tectonic features, and that depositional and erosional features seen on them are secondary. Similar conclusions seem justified elsewhere in the West Texas region."

Within the Delaware basin the relationship of tectonic elements to depositional features can be well illustrated. King (1942, p. 724-726) described tectonic features in which linear elements are predominant (Fig. 27). Depositional features in the Upper Permian evaporite complex within the Delaware basin that show a distinct relationship to King's tectonic linear elements are:

1. The Ochoa trough parallel to the west edge of the Central Basin platform (north-northwest trend);

2. Intrabasin shelf margin, a continuation of the



TEXT

Systems and Features	Rocks Involved
1. Northwest-trending system	
a. Babb and Victorio flexures	Permian
b. Reef zone in Apache Mountains	Permian
c. Hovey anticline and related folds	Permian to Tertiary
d. Folds on east flank of Central Basin platform	Permian
e. Anticlines of Big Lake, Powell, and Todd fields	Permian and older
2. Northeast-trending system	
f. Y O and other faults	Permian
g. Reef zone in Guadalupe Mountains	Permian
h. Pre-Wolfcamp folds and faults of Marathon basin	Pennsylvanian to Cambrian
i. Flexure of Wasson field	Permian
j. Anticlines of Chalk and Westbrook fields	Permian
3. North northwest-trending system	
k. West edge of Central Basin platform	Permian
l. Faults on west side of Guadalupe and Delaware mountains	Cenozoic age
m. Huapache flexure	Permian
4. East-west-trending system	
n. Anticlines of Artesia, Maljamar, and related fields	Permian
o. Dikes northeast of Roswell	Tertiary

DELAWARE BASIN

Figure 27. Map of west Texas region showing trends of tectonic features in which linear elements dominate. Modified from King (1942).

Huapache flexure in the northwestern part of the basin (north-northwest trend);

3. Northwest-trending dome (see Fig. 14, in pocket);

4. Northeast trend of halite in Anhydrite V in Reeves County; and

5. The general east-west trend of maximum halite thickness in Halite I and II.

Northeast-, northwest-, and north-northwest-trending systems can also be found in Salado and Rustler Formation thickness variations.

The tectonic framework of the west Texas region reflects many of the forces that have influenced stratigraphic units in the Delaware basin. Pre-Permian tectonism is not discussed inasmuch as the Permian tectonic history of the west Texas-southeast New Mexico area has been generally accepted as being quite different from that of pre-Permian time (King, 1942; Galley, 1958; and Hills, 1963).

Galley (1958, p. 423) described the end of the Pennsylvanian period as follows:

> "At the close of the Pennsylvanian Period occurred the principal uplift of two subparallel features which had been intermittently but moderately positive throughout earlier Paleozoic time, the Central Basin platform and the Diablo platform . . . . The intervening Delaware basin was thereby accentuated in negative relief, and the Midland basin for the first time became clearly evident; the Delaware basin, however, remained the center of further subsidence."

King (1942, p. 721-729) described the regional tectonic features of the Permian as follows:

"Following the pre-Wolfcamp deformation, and throughout Permian time, the West Texas region was divided into a number of large units or provinces, which received contrasting sets of deposits and probably had unlike tectonic behaviors. These are the basins, platforms, and shelves [see Fig. 1 of this report].

The basins were dominantly negative areas, each 100 miles or more across. They are dispersed along the north margin of the Marathon folded belt, and are partly connected near the belt and at their south ends by narrow passageways or channels. Strata in the basins lie at much lower altitudes than equivalent beds in the platforms and shelves . . . . Moreover, the basins received greater thicknesses of Permian sediments than the other areas, and in some places nearly twice as much.

. . . .

The basins, platforms, and shelves of Permian time are closely related in plan to the tectonic features formed during the pre-Wolfcamp orogeny. Representation of these features. . . is not entirely objective, but enough is known to suggest that beneath each platform is an uplift in the pre-Wolfcamp rocks, whereas beneath the basins the pre-Wolfcamp rocks may be little disturbed. Moreover, the basins and their connecting channels are dispersed along the front of the pre-Wolfcamp Marathon folded belt, as though there were some relation between them."

Hills (1963) referred to Permian tectonic history as "limited to epeirogenic uplift of broad areas." In his paleogeologic map and diagram of tectonic elements at the beginning of Permian time, a major tectonic feature, the Toyah uplift, was defined as extending from the southern margin of the Delaware basin northeastward as far as southern Loving County within the Delaware basin (Figs. 28A and 28B).

Harrington (1963) noted that two distinctly different sets of folds and faults affect the Central Basin platform

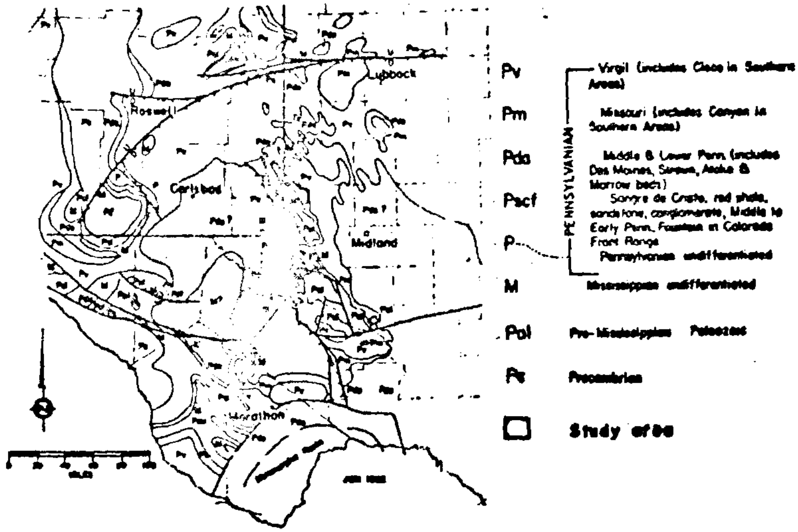


Figure 28A. Paleogeologic map of west Texas and southeast New Mexico area at beginning of Permian time. From Hills (1963).

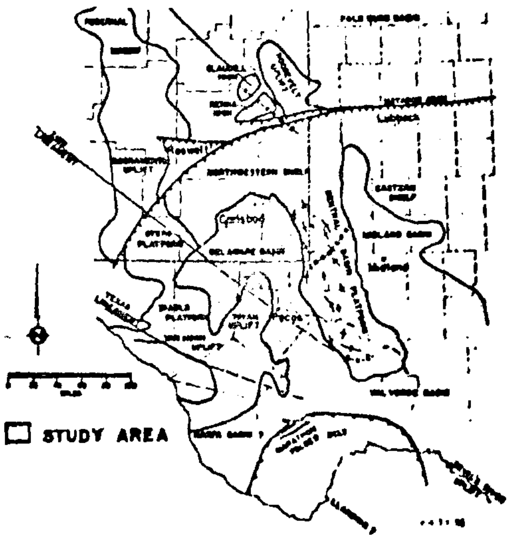


Figure 28B. Tectonic elements of west Texas and southeast New Mexico area at beginning of Permian time. Based on information developed on Figure 28A. From Hills (1963).

and surrounding areas. He observed:

> "The folding in the Central Basin platform area occurred in two distinctly different ways. The first type of movement took place in pre-Atoka time on the 4,000-6,000 feet of sediment between the basement and the Barnett shale. This thin skin orogeny appears as a series of thrust-faulted anticlines and is believed, by comparison with a demonstration experiment, to have been imposed over right-handed strike-slip basement faults. Power came from the Marathon-Ouachita orogeny on the south. Following the early deformation the platform was essentially a geanticline subject to a beveling erosion that truncated some of the folds completely to the basement.
>
> The second type of movement was part of the development of the Pennsylvanian and Permian autogeosynclinal complex on top of the older rocks and folds. Subsidence was concentrated on normal faults with differential movement between blocks. Supratenuous folds were formed in the younger beds as they were deposited."

Structure contour maps near the top of the Guadalupe Series have been made by King (1942, fig. 21), Galley (1958, fig. 2), and Sellards and Hendricks (1946), among others. The general configuration of the Delaware basin, when contoured on horizons near the top of the Guadalupe Series, is an elongate, asymmetrical basin with a nearly north-south basin axis about 20 miles west of the basin margin at the west flank of the Central Basin platform. The Ochoa trough trends parallel to the Central Basin platform and gently plunges from the northeast and southeast parts of the Delaware basin toward the lowest area in the basin, about 10 miles southwest of the Reeves-Pecos-Ward Counties intersection. Beds on the intrabasin shelf dip eastward toward the Ochoa trough. Structure contours west of the Central Basin platform rise from lower than -2,500 feet mean sea level to about 0 feet mean sea level on the Central Basin platform.

Intrabasin Tectonic Elements

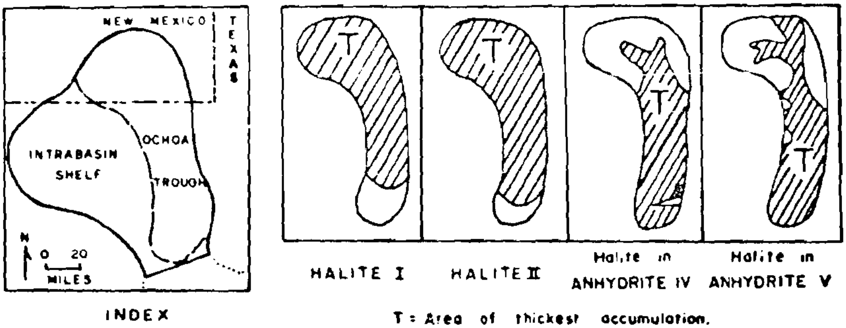
Thickness and distribution of stratigraphic units were studied to analyze tectonic elements. The Delaware basin can be divided into two distinctly different tectonic areas, an intrabasin shelf and the Ochoa trough (Figs. 1, 27, and 29). A traverse across these features shows the following thicknesses (west to east):

	Intrabasin Shelf ft	Intrabasin Shelf Margin ft	Ochoa Trough ft	Basin Margin ft
Rustler Formation	350-400	400-500	500-600	200-500
Salado Formation	500-750	750-1,750	1,750-2,500	1,000-1,750
Castile Formation	1,250-1,500	1,500-1,750	1,750-2,185	1,750-2,000
Total Evaporite Complex	2,300-2,700	2,750-3,750	3,750-4,500	3,000-3,750.

The intrabasin shelf extends from ~~the~~ Toyah uplift northwestward toward the Guadalupe Mountains. This shelf may be an extension of the Otero or Diablo platforms (Fig. 28B). The intrabasin shelf margin may be an extension of the Huapache flexure in the northwestern part of the Delaware basin; however, it extends along the eastern flank of the Toyah uplift in the east-central and southeastern parts of the basin. The Ochoa trough roughly parallels the Central Basin platform in the eastern part of the basin and parallels the "reef front" in the northern part.

On the intrabasin shelf an elongate dome was interpreted from the thickness variations in the Castile Formation (Fig. 14) and the net footage of non-halite strata (Fig. 16). On both thickness maps the Castile section is thinner in this domal area than in surrounding areas. The thickness of the total Upper Permian evaporite complex is slightly less than 2,500 feet in the domal area (Fig. 11). The dome is approximately 28 miles long by 18 miles wide, with the longer axis trending northwest in west-central Reeves County. The dome coincides with the central part of the Toyah uplift of Hills (1963) (see Fig. 28B). The shape of this dome appears to be modified by a northeasterly trending depression. A slight increase in total Salado thickness in the same local area also shows this northeasterly depression (Fig. 23).

Castile rocks on the intrabasin shelf are mainly anhydrite and limestone. Salado rocks on the intrabasin shelf are mainly anhydrite and dolomite. The greatest influence of tectonism is reflected in the distribution of halite in the Castile Formation. Little to no halite accumulated on the intrabasin shelf, while thick halite beds accumulated in the Ochoa trough. Lower and middle Salado halite also may have been restricted to the Ochoa trough. Upper Salado halite, however, overlapped the Central Basin platform and covered areas to the north and east of the Delaware basin.



Generalized extent of halite in Castile Formation units in the Ochoa trough.

	Thickness of unit in Ochoa trough		
	Northern Part (feet)	Central Part (feet)	Southern Part (feet)
RUSTLER FORMATION	350-500	450-500	450-600
SALADO FORMATION			
Upper Salado	400-900	500-980	300-700
Middle Salado	400-600	500-890	400-900
Lower Salado	250-700	200-700	450-1200
CASTILE FORMATION			
Anhydrite V	560 max.	255-900	500-1007
Anhydrite IV	200	400	200
Anhydrite III	350	300	280
Halite II	225		30
Anhydrite II	120	105	110
Halite I	320		10
Anhydrite I	350	300	180

TREND OF MAXIMUM THICKNESS

Figure 29. Diagrams showing change in halite distribution in Castile Formation and trend of maximum thickness of evaporite units of the Castile, Salado, and Rustler Formations in the Ochoa trough. Thickness of units Anhydrite I through Anhydrite IV are estimated average values; thickness range is given for Anhydrite V through Rustler Formation.

Basin Development

The intrabasin shelf, when considered during total evaporite depositional time, consisted of central, south-central, and western parts of the Delaware basin. Total Castile, Salado, and Rustler thickness in this area ranges from 2,300 to 2,750 feet (Fig. 11). Figure 29 shows the trend of maximum thickness of evaporite units of the Castile, Salado, and Rustler Formations and generalized extent of halite in the Castile Formation in the Ochoa trough. The intrabasin shelf and Ochoa trough can first be delineated from distribution of Halite I (Fig. 18). The shelf covered southwestern, south-central, and southern areas of the Delaware basin, while the Ochoa trough was located in the northern and northeastern parts. Halite I thickens from 0 to 200 feet in about 4 miles across the intrabasin shelf margin in northeastern Culberson County. Halite II distribution shows the same general trends as Halite I (Fig. 20). The largest accumulation of Halite II was still confined to the northern and northeastern areas. Halite II, in addition, overlapped Halite I to the south in the Ochoa trough by about 6 miles. Halite in Anhydrite IV shows a pronounced restriction within the Ochoa trough parallel to the Central Basin platform (Fig. 21). The thickest accumulation of halite in Anhydrite IV is near the Lea-Loving County line. Halite in Anhydrite IV overlapped Halite II to the south in the Ochoa trough by several miles. The intrabasin shelf covered most of the western two-thirds of the

Delaware basin during Anhydrite IV deposition.

Halite in Anhydrite V shows a further restriction in geographic distribution (Fig. 22). The thickest halite accumulations are in eastern Reeves County, along the Loving-Ward County line, and in the northeastern part of the basin in Lea County. The Lea County accumulation, however, may have been affected by later salt flowage. Halite in Anhydrite V also overlapped halite in Anhydrite IV to the south.

The generalized extent of Castile halite in the Ochoa trough suggests original basin relief was greatest in the north and northeastern parts with differential subsidence toward the south during Castile time. Changes in maximum thickness of evaporite units during Castile and lower Salado deposition also suggests this southerly "tilting" (Fig. 29). During middle and upper Salado time, this trend seems to have reversed.

Southerly movement of similar environmental conditions within the basin could also account for halite and anhydrite distribution. Noted previously, however, the thickness trends of Halites I and II cross almost perpendicular to regional thickness patterns of Anhydrites I and II. This distribution suggests somewhat independent depositional mechanisms for anhydrite and halite.

The above discussion assumes that halite was deposited in the deeper part of the then existing basin--an assumption that may be justified since the sands and loss of lamination in correlative anhydrite suggest a lowering of sea level coincident with halite deposition.

Salt Movement

Local Structures

Local deformation may be readily expected in the Castile Formation since the mineralogy mainly consists of anhydrite and halite. De Sitter (1956, p. 79) noted that salt and gypsum are among the most incompetent of rocks. Borchert and Muir (1964, p. 237) have stated:

> "Evaporites deform more readily than any other consolidated sediments. Because of their exceedingly incompetent character, they often exhibit complex folding and piercement structures in areas where the adjacent clastic sediments or limestones remain almost completely undisturbed. Flowage may easily occur either because stress has been applied, or because some water has been introduced or produced by geothermal heating."

Areas of local salt movement were identified by assuming that regional thickness closely approximates original thickness of halite. Imposed upon regional trends are localized areas with anomalous thicknesses of halite.

Examples of halite and anhydrite movements in Castile units were found in Eddy, Lea, Reeves, and Culberson Counties. Repetition of "salines" cannot be defined in Halite I since this unit has no marker beds; however, Halite II contains five distinct anhydrite markers (Figs. 3, and 4, in pocket). A repeated section of Halite II was found in Reeves County in TXL Oil, State Northrup et al. well No. 1 (Reeves-15). This repetition of Halite II, although the only example found in the Delaware basin, confirms that salt movement took place, perhaps due to faulting. The area in which the repeated section occurs is shown in Figure 28B (location A). The well site is on the northwest edge of the Toyah uplift.

Without dense well control or geophysical information, regional salt movements can be postulated only from general distribution of salt, regional thickness trends of salt, regional thickness of units above and below the salt, and consideration of the tectonic setting of areas that might have salt movement. An example of the relationship between salt movement and tectonic setting is shown by the Reeves County repeated section.

In southern Eddy County about six miles north-northwest of the Eddy-Culberson-Reeves County intersection, the following thicknesses of Castile units were found:

Wells	Distance between wells, miles	Thickness of units, feet			
		Anhydrite I	Halite I	Anhydrite II	Halite II
	North				
Eddy-41		235	323	92	180
	2.0				
Eddy-H		220	195	95	156
	1.5				
Eddy-J		200	300	95	167
	1.5				
Eddy-58A		186	225	195	50
	2.5				
Eddy-58		184	109	31	109.
	South				

Cross section A-A', Figure 30, shows halite and anhydrite units and interpreted apparent directions of movement for these well data. Halite I is thinner than expected from regional trends in well Eddy-58 and thickens to well Eddy-J.

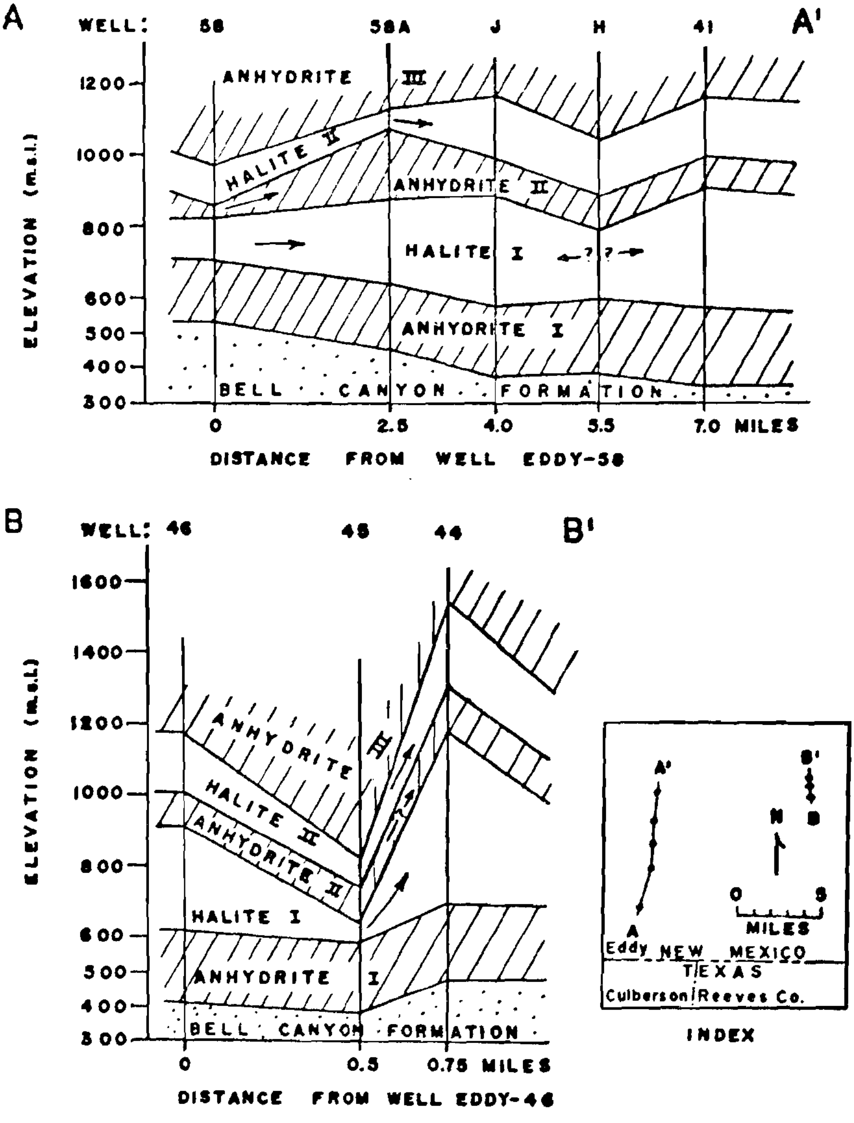


Figure 30. Diagrammatic cross sections showing halite and anhydrite movement in the lower part of the Castile Formation in Eddy County, New Mexico. Arrows indicate apparent direction of movement.

Halite I in Eddy-H is also thinner than expected and thickens both south in well Eddy-J and north in well Eddy-41. Halite II is thinner than regional trends in well Eddy-58A and appears to thicken northward in well Eddy-J.

Anhydrite II is excessively thin in well Eddy-58 and excessively thick in well Eddy-58A. Movement of interbedded anhydrite related to halite movement is a well-known phenomenon and should be expected in the Castile sequence. The relationship of Anhydrite II thinning and thickening to movement of Halites I and II appears conclusive in cross section A-A', Figure 30.

In another area in Eddy County about 12 miles north-northeast of the Eddy-Culberson-Reeves County intersection, the following was found:

Wells	Distance between wells, miles	Thickness of units, feet			
		Anhydrite I	Halite I	Anhydrite II	Halite II
	North				
Eddy-44		203	486	109	242
	0.25				
Eddy-45		203	51	85	56
	0.5				
Eddy-46		203	300	95	160
	South				
Average thickness of units in area		200	300	95	175

Cross section B-B', Figure 30, shows halite and anhydrite units and interpreted apparent directions of movement for these well data. Thicknesses for units north of well Eddy-44 were estimated from unit thickness maps. Halites I and II appear to have formed salt anticlines or domes north of well

Eddy-45. In this case, an upward flexing or anticlinal structure below the area near well Eddy-44 is suggested as the control for possible gravity flow of Halites I and II. The slight thinning of Anhydrite II in well Eddy-45 may be due to original depositional thinning or to post-depositional anhydrite movement. The apparent thickening of Anhydrite II in well Eddy-44 compensates for the thinning in well Eddy-45.

In northeast Culberson and northwest Reeves Counties, salt movement is suggested from a study of several wells. Figure 31, in pocket, shows structure contour maps at the top of the Guadalupe Series and at the top of Anhydrite I, and thickness maps of Anhydrites I and II and Halites I and II of the Castile Formation. Two asymmetrical noses were interpreted from the structure contour maps. The axis of nose A to the south of wells Culberson-17 to -21 plunges to the northwest. The axis of nose B to the north of these wells plunges to the north-northwest. Along the axis of nose A, Anhydrite I tends to be thinner than on the flanks. Halite I thickens along the southern part of nose A and along the northern part of nose B. Anhydrite II thins along the axis and south flank of nose A. No distinct control is shown by nose B. Halite II thins along the southern part of nose A, suggesting a squeezing out of Halite II due to a possible salt anticline in Halite I in this area. No distinct effect upon Halite II can be determined along the axis of nose B.

It is concluded that in the northeast Culberson-northwest Reeves Counties area local tectonic movements have caused salt flowage in Halite I. Tectonic uplift may have controlled depositional thinning of Anhydrite II, although Anhydrite II could have been thinned by post-depositional movement. Upward movement of Halite I appears to have squeezed out Halite II laterally.

Regional Structures

In the northeast part of the Delaware basin in Lea County, T. 22 - 23 S., R. 32 - 34 E., halite may have accumulated as a series of "salt pillows" or "salt stocks" similar to those described by Trusheim (1960) in German evaporite deposits. Figure 32, in pocket, shows structure contour maps at the top of the Guadalupe Series and at the top of Anhydrite I, and thickness maps of Anhydrites I and II and Halites I and II of the Castile Formation, and thickness maps of the Salado and Rustler Formations.

Thicknesses of Halite I in excess of regional thickness, about 375 feet in this area, were found in at least two wells (Lea-7 with 925 feet and Lea-J with 696 feet). In two other wells in this area (Lea-8 and Lea-25), Anhydrite II may be missing, giving rise to continuous halite sequences of 510 feet in each well. In wells Lea-9 and Lea-24, Halite I is excessively thin (29 feet in Lea-9, 192 feet in Lea-24). Castile Formation in this area, however, shows a regional thickness range from 1,750 feet to slightly more than 2,000 feet. Salado Formation overlying this Lea County area has a fairly constant thickness of 1,500 to 1,750 feet. Rustler

Formation, however, shows a distinct thinning over the 2,000-foot contour of the Castile Formation, with a distinct thickening just to the south. In Figure 7, in pocket, the upper Salado also thins from well Lea-33 in the south to well Lea-25 in the north.

A lens of halite in Anhydrite V, 200 to 385 feet thick, is also found in this Lea County area. Of the 925 feet of halite of the Castile in well Lea-25, 895 feet are found in two salt sections, halite in lower Castile of 510 feet with no Anhydrite II and halite in Anhydrite V of 385 feet (Fig. 7, in pocket).

Recent salt domes and anticlines affecting Salado, Rustler, and post-Permian rocks have been reported in Eddy County by Vine (1960) and Reddy (1961). These structures overlie the general area in which local salt structures in the Castile were found. The relationship between these structures and underlying Castile salt structures has not been determined.

Analysis

Several models can be proposed to account for Castile salt movement. Four models are analyzed here to account for the anomalous salt section in the Delaware basin. Movement contemporaneous with deposition has been termed "down building" by Barton (in Russell, 1955, p. 209-210). Russell stated this theory as follows: "the top of the salt domes stayed near the surface as the greater thickness of sediments accumulated on the source salt layer." Figure 33, top, shows

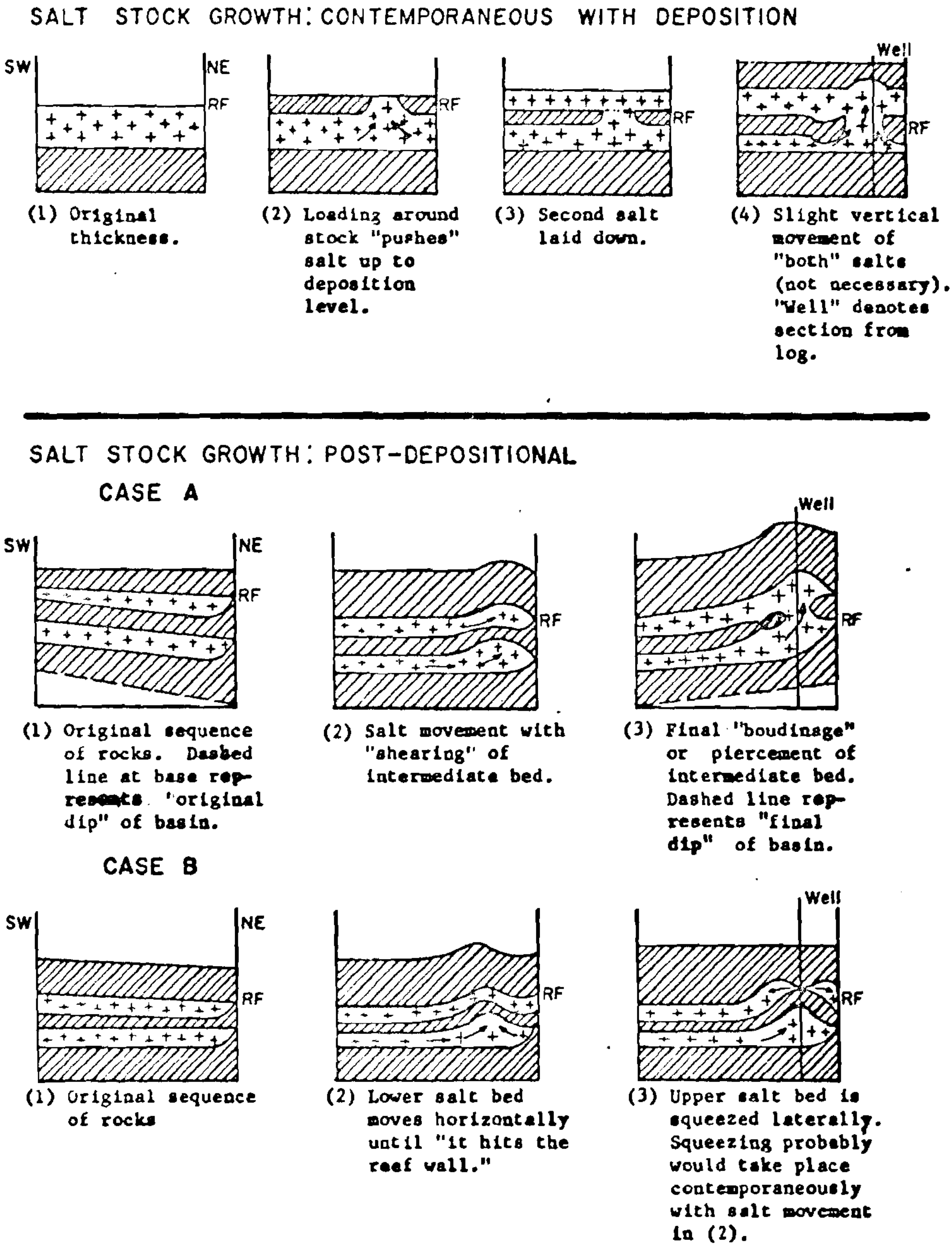


Figure 33.--Diagrammatic sketches showing different salt movement interpretations. RF denotes reef front. "Well" denotes section found in wells Lea-8 and Lea-25.

diagrammatic sketches of "down building." In the Delaware basin two well sections were found similar to the example in this sketch, well Lea-8 (not shown) and well Lea-25 (Figs. 32 and 7, both in pocket). Well Lea-8 has one continuous halite bed 510 feet thick in the lower Castile with several thin anhydrite beds at the top of the halite. These anhydrite beds resemble the anhydrite markers of Halite II.

Post-depositional movement can also be postulated for halite in areas near wells Lea-8 and Lea-25. Figure 33, bottom, case A, shows sketches of halite movement with concurrent piercement or "boudinage" of Anhydrite II. Evidence for boudinage, or at least anhydrite movement, is well illustrated in Eddy County in cross section A-A', Figure 30, wells Eddy-58 to Eddy-58A. Borchert and Muir (1964, p. 248) stated that boudinage structures, joints, and faults tend to develop in more competent beds between less competent beds, especially in interbedded anhydrite and halite. They further stated that halite usually deforms plastically into various types of folds, diapirs, and salt domes. In this case a diapirism of Halite I piercing Anhydrite II to form a continuous Halite I-Halite II section is suggested. The cause of the salt movement, interpreted in case A as due to "tilting", is not a necessary condition and is discussed later.

Case B, bottom of Figure 33, is an alternate explanation for post-depositional salt movement. Evidence for this type of movement is illustrated in several areas in the northern part of the Delaware basin. Analysis of data in the northern Culberson-Reeves County area indicates upwelling of Halite I over a nose with lateral squeezing out of overlying Halite II (Fig. 31). Further examples in Eddy County are inferred from two patterns anomalous to regional thicknesses of Halites I and II. Generally, in Eddy County the Halite II to Halite I thickness ratio is about 2:3. One pattern shows a higher Halite I thickness than expected as in well Eddy-24 where Halite II to Halite I is about 2:4+, and in well Eddy-28 with a ratio of 2:3.3. The opposite pattern, where Halite II is thicker than Halite I, suggests the areas peripheral to the Halite I rises. Such could be the case in well Eddy-K about 1.8 miles north of Eddy-28, where the Halite II to Halite I ratio is 2:1.4, and in Eddy-53 with a ratio of 2:1.

The fourth model to be considered is the "anticline on anticline" found in localized structures in Eddy County (cross section B-B', Fig. 30). In this case gravity or tectonic "triggering" of Halite I movement appears to have influenced movement of Halite II. In well Eddy-56 about 19 miles southwest of the described localized structure, both Halites I and II are thinner than expected regionally. This section resembles well Eddy-45, cross section B-B', Figure 30.

In general, the rule of Trusheim (1960, p. 1535) that "each salt stock has its own history, and closely adjoining structures may have developed quite differently" applies to the salt structures in the Delaware basin. As an example, the salt stocks of Halite I in Lea County appear to have individual histories (Fig. 32, in pocket). Salt stocks A and B have influenced the thickness of overlying units to different degrees. The thickest sections of Halite I in these stocks are in well Lea-7 with 925 feet in stock A and well Lea-J with 696 feet in stock B. Anhydrite II is thicker in well Lea-7 than in well Lea-J. Halite II, however, is thinner in well Lea-7 than in well Lea-J. Salado Formation thins over Lea-7 but is not affected over Lea-J. In stock B, well Lea-25 southeast of Lea-J appears to have effectively thinned Salado rocks above. The thinnest section of Rustler rocks in the Lea County area is found above well Lea-J, stock B. Rustler Formation thickness does not appear to have been affected by stock A.

Although the first cause initiating salt movement is beyond the range of observation, Trusheim (1960, p. 1523) outlined several possible initial impulses to be sought. These impulses are:

1. Inhomogeneities, either in the basement under the salt, in the salt itself, or in the roof of the salt layer;

2. Stresses already present converted into initial movement by a tectonic event or an earthquake;

3. The presence of a sufficiently deep sedimentation trough, in the shape of a shallow saucer; and

4. Requisite instabilities so small as to be undefined with certainty.

A condition postulated as necessary for salt movement by Russell (1955, p. 211) is that "the source salt must have a certain minimum thickness." Trusheim (1960, p. 1523) further explained this condition as follows:

> "Salt can begin to flow only when it has been buried under sufficient load to cross the boundary between the elastic and the plastic condition. The lateral fluid-like plastic flow is faciliated if the basement dips at an angle of more than 1°, and if the salt layer possesses a certain thickness and is not too strongly mixed by competent intercalations. Experiences with the German Zechstein basins showed that an overburden of about 1,000 m. . . . and a thickness of at least 300 m. of salt were necessary to initiate the process of flowing."

In the lower part of the Castile, however, halite movement appears to have occurred in beds as thin as 150 to 300 feet, approximately 50 to 100 meters.

Russell (1955, p. 207) and Trusheim (1960, p. 1519) noted two operational processes to account for salt movement; gravity flow (geostatic, halo-kinetic) and tangential compressive pressure (lateral pressure, halo-tectonic). Trusheim further stated: "Every conceivable transition between the two types is to be found in the world." The majority of salt structures in northern Germany were directly or indirectly attributed to "essentially gravity phenomena" or "halo-kinesis" by Trusheim (1960). Because of the limited thickness of Castile halite beds, tectonic "triggering" may be the cause of halite movement in the Delaware basin. Gravity flow due to loading of overlying rocks of the Salado must also be considered as a cause of Castile halite movement.

The tectonic relationship to halite movement can be inferred from well data in Eddy County (Fig. 30). In both cross sections Halite I appears to be influenced by a relative change in regional dip. An anticlinal structure, terrace, or monoclinal flexure can be interpreted below Halite I in the area of halite movement. The true structure itself cannot be determined since regional dip may have been established prior to or superimposed upon these subtle structures. As another example, Figure 31 shows structure contours on the top of Anhydrite I in the Eddy-Culberson-Reeves Counties area. Two noses are present. If the regional northeastward dip in this area is "taken out", these noses could be reconstructed into anticlines. The time of development of these structures is not known, however, and they may have been superimposed upon the regional dip.

The data from wells in Lea County also give an interesting structure contour pattern on the top of Anhydrite I which shows a relationship to halite movement (Fig. 32, in pocket). In stock A, well Lea-7 with the thickest Halite I is at the synclinal bend of a local monocline between wells Lea-7 and Lea-8 to the northeast. The major areal extent of stock A is parallel to the regional dip and may be on a terrace. Anhydrite II is absent in well Lea-8 on the anticlinal bend. In stock B, well Lea-J with the thickest Halite I section is at the base of a local rise. This well can be described as at the synclinal bend of a monocline if only the area from well Lea-J to well Lea-8 is considered. Stock B is perpendicular to the regional dip. Well Lea-25 is also apparently at the anticlinal bend of a monocline or, at least, on the southeastern flank of a syncline. Anhydrite II is absent in well Lea-25.

The thick lens of halite in Anhydrite V in the Lea County area, previously mentioned, also may have been tectonically controlled. In this case tangential compressive forces may have resulted from recurrent uplift of the Capitan Reef. If the halite originally was deposited over the reef top, recurrent movement may have squeezed out Castile halite into this halite lens. If the halite was restricted to the basin, compressive forces from vertical movement of the "reef zone" could still account for localized movement of halite south of the reef. Post-depositional movement in this area is inferred from the upward flexing of the Salado and Rustler Formations over the Masco, Cloyd well No. 2 (see Moore, 1960, fig. 23). Irregularities in the surfaces of potash strata above the reef zone, shown in plate 1 of Jones (1954), also suggest vertical movement of the "reef zone" after Salado and Rustler deposition.

A further cause for halite movement in the Lea County area may have been the differential subsidence or "tilting" of the Ochoa trough during Castile deposition (see Basin Development). Assuming that the Ochoa trough did tilt southward, lithostatic pressures would be greater on the halite to the south due to the greater thickness of sediment being laid down in the central and southern parts of the Ochoa trough. Case A, bottom of Figure 33, shows the relative change of the base of the Castile during tilting. Lateral movement of halite would be enhanced due to the differential lithostatic pressure in the Ochoa trough as well as by compressive forces due to reef movement. Where the salt reached the northeastern part of the Ochoa trough, irregularities at the base of Halite I due to anhydrite fan accumulation and the physical barrier of the reef front would prevent further lateral movement, and the halite then could flow only vertically.

In addition, gravity flow due to loading should be considered for Castile halite movement. Reddy (1961) stated that a pressure of 853 psi is enough to cause salt movement. He further noted that lithostatic pressure generally increases at the rate of 1 psi per foot of rock. In the Lea County area the amount of Castile above Halites I and II can be estimated as greater than 1,000 feet. Salado overlying Castile consists of 1,500 to 1,750 feet of rock. Pressures on Halites I and II were greater than 1,000 psi at the end of Castile time and greater than 2,500 psi at the end of Salado time. Lower Castile halite movement prior to Salado and Rustler deposition appears to be reasonable from these mechanical considerations. The Rustler Formation in southern Lea County is thin over salt stocks and thickens over peripheral areas, suggesting pre-Rustler salt movement. Upper Salado thinning over salt stocks in Lea County further suggests movement prior to upper Salado deposition.

Upper Permian Unconformities

Unconformities have been postulated between Castile and Salado and between Salado and Rustler Formations. Adams (1944) described an angular unconformity between the Castile and Salado Formations along the north and east borders of the Delaware basin as "accompanied by marked changes in distribution of lithologic character." However, the postulated salt movement of Castile halite during lower Salado sedimentation might give the appearance of an angular unconformity to the north and east. Lower Salado halite beds thin in the northeastern area of the Delaware basin, and Salado anhydrite markers coalesce to form apparent single anhydrite beds. Anhydrite markers in the Salado (Fig. 7, in pocket) appear to be continuous from well Lea-25 southward with no unconformity apparent. Lensing of anhydrite in the Salado as described by Adams (1944, p. 1610) may well be due to shearing, schuppen structure, or boudinage during salt movement within the Salado Formation.

Under apparently similar circumstances, Trusheim (1960, p. 1536) has described "apparent" unconformities in the salt stock areas of northern Germany. He noted:

> "These [closely spaced wells] have proved in many places that unconformities occur only in the upper parts of salt structures, and are absent in the accompanying peripheral sinks. These unconformities were not caused by one brief orogenic event but are local ingressions continually progressing throughout long periods of time, in the course of which any stratigraphic unit of the overlying series may overlap any of the older beds."

Salado anhydrite overlies Castile on the intrabasin shelf. Lower Salado anhydrite is found in greater thickness in Reeves County than elsewhere in the basin. Salado anhydrite markers and Castile units are traceable over the entire Ochoa trough, and similar sections are found in the northern and southern parts of the basin. Although Adams (1944) postulated a greater time break in the southern areas between Castile and Salado Formations, no evidence was found to support a major unconformity between the Castile and Salado Formations in the Delaware basin.

Adams (1944, p. 1608, 1612-13) further described a major unconformity between Salado and Rustler Formations, noting: "This erosion stripped off all the western Salado and may have truncated the entire Castile formation as well." George Moore, in detailed mapping of the evaporites in outcrop in the area around Carlsbad, New Mexico, has differentiated between Salado and Castile anhydrite and shows Rustler Formation always overlying Salado (James B. Cooper, U. S. Geological Survey, personal communication, 1965).

Sections described by Hayes (1964) and Udden (1924) probably have several hundred feet of Salado anhydrite overlying Castile in southern Eddy County and east-central Culberson County. In west-central and southwestern parts of the Delaware basin, the Castile and Salado Formation ranges from 0 to about 2,000 feet in thickness. The Castile Formation probably makes up the basal 1,200 to 1,400 feet of the group in this area. For example, in southern Eddy County, Hayes (1964, p. 15) reported the following lithologies for the "Castile Formation" from the McBride Randel well No. 1 (sec. 7, T. 26 S., R. 26 E.):

	Thickness, (feet)	Lithology	Interpretation
(approx.)	125	Missing	
	120	White gypsum	Salado Formation (550 ft)
	305	White anhydrite, relatively pure	
	560	Sequence of anhydrite with limestone laminae	
	150	Halite	
	90	Laminated anhydrite	Castile Formation (1,275 ft)
	275	Halite	
	200	Interlaminated white anhydrite with gray to brown limestone. Limestone dominant in lower part.	

Total original thickness at least 1,825 ft.

The stratigraphy of the David Flood, Grisham McAlpine well, Culberson County (Culberson-U) (Udden, 1924, p. 348), is interpreted as follows:

Depth (feet)	Thickness (feet)	Interpretation
0-238	238	Rustler Formation
238-850	612	Salado Formation
850-2,150	1,300	Castile Formation

This section is shown in Figure 4, in pocket.

In sample logs from central and east-central Culberson County, lower Salado sandstone overlies Castile. From 300 to 500 feet of Salado anhydrite overlies Salado sandstone. Rustler Formation rocks lie above the Salado anhydrite. In the past, sandstone of the Salado, Salado anhydrite, and "castiles" in the Castile Formation have been correlated with the Rustler Formation.

Variations in thickness of the Rustler Formation in the northeast part of the Delaware basin in Lea County appear to be related to filling of peripheral areas around Castile salt stocks. Local re-solution of upper Salado halite during basal clastic deposition in Rustler time may account for the "unconformable aspect" between Salado and Rustler rocks. An unconformity between the Rustler and Salado Formations, if one exists, would probably be found locally rather than as a major regional phenomenon.

The Dewey Lake Redbeds appear to overlie the Rustler Formation conformably (from Adams, 1944, figs. 2 and 4).

Figure 34 is a map of the west Texas area showing the geologic units directly beneath Triassic System (from McKee and others, 1959). East and north of the Delaware basin Triassic rocks overlie Dewey Lake and Rustler rocks. At the southeastern end of the Delaware basin, Triassic rocks overlie Tessey Limestone, generally considered older than Dewey Lake. Regional uplift and erosion of Dewey Lake Red-beds prior to Triassic deposition is indicated to the north, east, and south of the Delaware basin. The eastern and southern limits of the Triassic are in areas related to an angular unconformity below the Triassic. In these areas Triassic rocks lie on Dewey Lake Redbeds in the central part of the west Texas area and on Rustler, Tessey, and older beds of the Whitehorse Group near the limits of Triassic rock outcrop.

The general western limits of the Triassic may be related to formation of the Basin and Range Province (Fig. 2). If uplift recurred in the western area, suggested throughout Permian time by the studies of King (1942, 1948) and Hayes (1964), Triassic may have been laid down on an angular unconformity in this area also. Assuming this relationship, uplift prior to Triassic deposition would have modified the area comprised of the Delaware basin, Central Basin platform, and Midland basin into a single shallow, saucer-shaped basin, the form essentially found today.

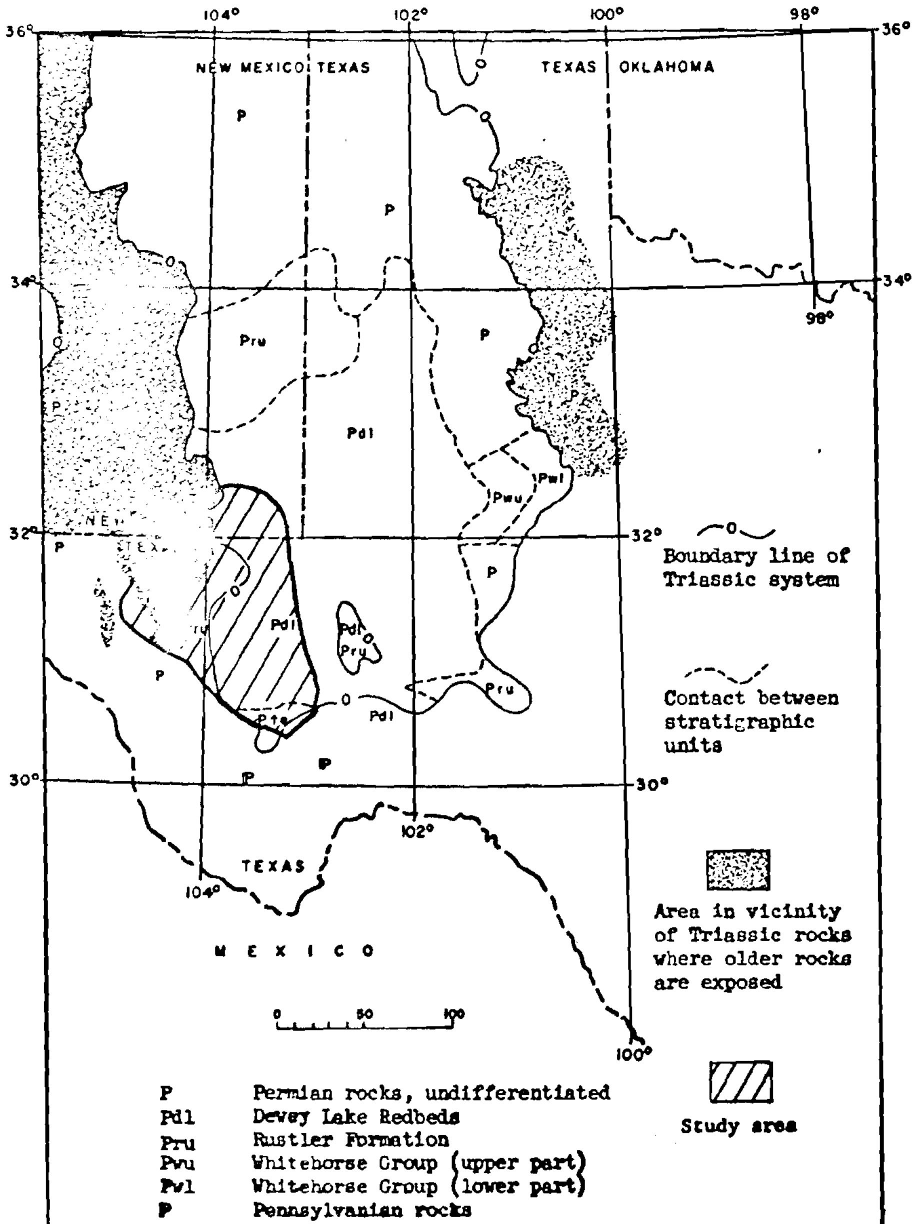


Figure 34.--Geologic units directly beneath Triassic System. Modified from McKee and others (1959).

CONCLUSIONS

The following sedimentational features are postulated from analyses of data in this report:

1. Sulfate deposition during Castile time was caused by relatively high evaporation of surface water.

2. Sulfate enrichment of water in the Delaware basin may have resulted from preconcentration of sulfate in back-reef waters and subsequent movement of the sulfate-rich, back-reef waters into the Delaware basin, a situation similar to that proposed by Mear and Yarbrough (1961) during Yates deposition. Reflux or movement of hypersaline water out of the Delaware basin into adjacent ocean water also may have affected the concentration of water in the Delaware basin.

3. Submarine fans of anhydrite or gypsum accumulated during Castile time along the eastern and northern basin margin due to influx of sediment from back-reef areas through passes in the surrounding reef. Later Castile halite deposition was affected locally by these fans.

4. Within Castile, Salado, and Rustler Formations, large-scale cyclic repetitions reflect deepening and shallowing of water in the Delaware basin during transgression and regression of seas.

5. Thickness trends of anhydrite and halite are almost perpendicular, anhydrite thickening from southwest to northeast in the Delaware basin while halite thickens from south

to north in the Ochoa trough. This change in thickness trends may be explained by different inlets from the ocean during anhydrite versus halite deposition, individual mechanisms of deposition, or by changes in current patterns within the Delaware basin affecting changes in salinity gradient patterns.

Study of sediment thickness and distribution reveals that the Delaware basin consisted of three tectonic elements:

1. An intrabasin shelf related to the Guadalupe Mountains area and the southern part of the Carlsbad shelf;

2. An intrabasin shelf margin related to the Huapache flexure and the Toyah uplift; and

3. The Ochoa trough, a relatively negative area located between the intrabasin shelf and the Central Basin platform.

Evidence for salt movement in lower Castile halite is abundant, especially in the northern part of the Delaware basin. Piercement of Anhydrite II by Halite I with resulting Halite I-Halite II section is suggested to account for anomalous halite thicknesses in wells Lea-8 and Lea-25. Squeezing of Halite II laterally due to upwelling of Halite I appears to be common. "Anticline on anticline" due to gravity flow of Halite II over an upwelling of Halite I is also proposed.

Regional salt structures apparently similar to "salt pillows" or "salt stocks" as described by Trusheim (1960) occur in southern Lea County, New Mexico. Although "down building" may have occurred, the limited thickness of halite beds with thick interbedded anhydrite and anomalous thin sections of halite in wells near salt stocks indicate post-depositional salt movement. Evidence for gravity flow of salt due to loading during lower Castile deposition is lacking. Gravity flow of halite due to lower and middle Salado rock overburden, however, can be considered as a possible cause of Castile salt movement.

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APPENDIX

Well Data

Abbreviations and symbols used in well data:

Stratigraphic units

Ru - Rustler Formation
Ca - Castile Formation
Sal- Salado Formation
BC - Bell Canyon Formation
Carlsbad - Carlsbad Limestone

Location symbols in Texas

Blk. - Block
T. - Township

Surveys:
- PSL - Public School Lands
- ULS - University Lands Survey
- T&P - Texas and Pacific Railroad
- Other railroad surveys

TC RR	GC&SF	H&GN
TM RR	GH&SA	W&NW
T&T	G&MMB&A	TT RR
T&ST.L	H&TC	

Elevation symbols

DF - Derrick floor
GL - Ground level
KB - Kelly drive bushing
RDB - Rotary drive bushing
RT - Rotary table
est. - estimated
n.a. - not available

Log symbols

EL - Electric log; includes resistivity, lateral, microlog, self potential, and other electric measurements
GR - Gamma-ray log
GRN - Gamma-ray-neutron log
SGR - Sonic-gamma-ray or acoustic-gamma-ray log
SPL - Sample log

Log reference number refers to catalog number of West Texas Electrical Log Service.

Petroleum companies

Atlantic - Atlantic Refining Company
Gulf - Gulf Oil Corporation
Humble - Humble Oil and Refining Company
Pan American P. C. - Pan American Petroleum Corporation
Shell - Shell Oil Company
Sinclair - Sinclair Oil and Gas Company

Reference number refers to well control posted on Figures 5 and 6.

Well data: Eddy County, New Mexico

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
3	30	20S	31E	Shell and Texas Crude Co.-Big Eddy Unit #1-30, W8944A SGR, est. 3588 KB Tops: Ru 630, Sal 890, Ca 2050, BC 3700?
4	17	21S	27E	J. Glen Bennett-Gulf State #1, W178L SGR, 3220 KB Tops: Spud in Sal, Ca 1150, BC 2490?
5	15	21S	27E	Humble-Cedar Hills Unit #1, W2676L SGR, 3270 KB Tops: Spud in Sal, Ca 1270, BC 2580?
6	27	21S	29E	Richardson and Bass-Federal Fidel #1, A2795C GRN and SPL, est. 3434 RT Tops: Ca 2000, BC 3260
7	20	21S	31E	Richardson and Bass-Federal Welch #1, W4773E GR-EL, 3524 DF Tops: Ru 540, Sal 800, Ca 2040, BC 3585
8	25	22S	25E	Honolulu Oil-McKittrick Canyon Unit #1, A337L GRN, 3511 KB Tops: Ca 715, BC 2190
9	7	22S	26E	Gulf-Hackberry Hills #2, W2838M SGR, 3675 KB Tops: Ca 890, BC 2388
10	21	22S	28E	W. K. Byrom-Pecos Irrigation #1, A1172K GR, est. 3077 DF Tops: Sal 320, Ca 1035, BC 2555
11	36	22S	28E	R. R. Morrison-Gulf State #1, A67L GRN, est. 3083 Control Head Tops: Sal 325, Ca 1230, BC 2805
12	6	22S	29E	W. A. and E. R. Hudson-Eddy Federal #1, W8588B GR, 3304 KB Tops: Ru 340?, Sal 490, Ca 1560, BC 2980
13	27	22S	30E	Richardson and Bass-Federal Legg #1, A2998E GRN, 3323 RDB Tops: Ru 215, Sal 530, Ca 2250, BC 3755
14	21	22S	31E	Patoil Corp.-Muse Federal #1, W2348K SGR, 3374 KB Tops: Ru 460, Sal 800, Ca 2685, BC 4230
15	11	23S	24E	Gulf-North Caverns &nit #1, W33G SGR, est. 4011 KB Tops: BC 40?

Well data: Eddy County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
16	13	23S	27E	Burk Royalty-Lovelace #1, W1398G SGR, 3101 KB Tops: Spud in Sal?, Ca 740, BC 2324
17	9	23S	28E	Harry D. Kahn-Marks Federal #1, W115L SGR, 3055 KB Tops: Ru 35?, Sal 205, Ca 920, BC 2530
18	24	23S	29E	Texaco-Remuda Basin Unit #1, W407K GR-EL, 3045 DF Tops: Spud in Sal, Ca 1780, BC 3253
19	32	23S	31E	J. A. Leonard-Continental State #1, W774L SGR, 3358 KB Tops: Ru 360, Sal 698, Ca 2560, BC 4080
20	33	23S	31E	Patoil Corp.-Wright Federal #2, W1253L SGR, 3392 KB Tops: Ru 430, Sal 818, Ca 2697, BC 4179
21	27	23S	31E	Patoil Corp.-Wright Federal #1, W1177L SGR, est. 3397 KB Tops: Ru 498, Sal 835, Ca 2734, BC 4260
22	2	23S	31E	Continental Oil-State #1-AA-2, W672G SGR, 3453 KB Tops: Ru 625, Sal 1070, Ca 2760, BC 4430
23	29	24S	26E	Gulf-Federal Estell #1-AD, W440L SGR, 3412 KB Tops: Spud in Sal?, Ca 494, BC 1634
24	27	24S	26E	Union Oil of Calif.-Crawford #2-27, W439L SGR and W8399C GR-EL, 3316 KB Tops: Spud in Ru, Sal 135?, Ca 345, BC 1850
24A	26	24S	26E	Union Oil of Calif.-Crawford #1-26, W7604A GR-EL, 3262 KB Tops: BC 1890
25	9	24S	27E	Burk Royalty-Crawford #1, W1398H SGR, 3173 KB Tops: Log starts in Sal, Ca 520, BC 2050
26	16	24S	28E	Union Oil of Calif.-Union State #1-16 W1809M SGR, 3052 KB Tops: Ru 100, Sal 350, Ca 1030, BC 2530
27	26	24S	28E	Neil H. Wills-State #1, W8196B SGR, 2964 DF Tops: Ru 160, Sal 540, Ca 1000, BC 2590

Well data: Eddy County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
28	24	24S	28E	Southern Calif. Petr. Corp.-Federal Silver #1, A2855A GRN and SPL, 2976 KB Tops: Ru 60?, Sal 195, Ca 1070, BC 2690
28A	2	24S	28E	Richardson and Bass-Beeman #1, ---- SPL, 2998 GL Tops: BC 2600
29	6	24S	29E	El Capitan-Federal Reid #1, A1995D GRN, 2984 Braden Head Tops: Ru 85?, Sal 290, Ca 990, BC 2744
30	23	24S	30E	Hill and Meeker-Shugart Federal #1-23, W902H SGR, 3413 KB Tops: Ru 455, Sal 780, Ca 2365, BC 3980
31	25	24S	30E	Hill and Meeker-Bass Federal #1-25, W1546M SGR, 3429 KB Tops: Ru 475, Sal 840, Ca 2410, BC 4105
32	7	24S	31E	Ambassador Oil-Federal #1-Y, W9286E SGR, 3535 KB Tops: Ru 600, Sal 960, Ca 2515, BC 4277
33	18	24S	31E	Charles B. Read-Ritchie Federal #1, W1188L SGR, 3514 KB Tops: Ru 577, Sal 940, Ca 2450, BC 4264
34	21	24S	31E	Hill and Meeker-Carper Federal #1-21, W2168L SGR, 3535 KB Tops: Ru 692, Sal 952, Ca 2610, BC 4395
35	11	24S	31E	Gulf-Federal Littlefield "CT" #1, W4103M SGR, 3528 KB Tops: Ru 769, Sal 1140, Ca 2770, BC 4482
36	30	25S	25E	Gulf-Federal Kelly "A" Option #1, W553M SGR, 3681 KB Tops: Spud in Ca?, BC 1326
37	11	25S	26E	Cree Drilling Co., Inc.-Gulf Federal #1, W8518A SGR, 3367 KB Tops: Spud in Sal, Ca 440, BC 1953
38	16	25S	27E	R. E. Sutton-R. E. Sutton Humble State #1, A9260D GRN, 3217 DF Tops: Spud in Sal?, Ca 570, BC 2112
38A	15	25S	27E	Aldridge and Stroud-Signal State #1, A5749B GRN, 3191 DF Tops: Ca 660, BC 2220

Well data: Eddy County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
39	28	25S	27E	Chambers, Kennedy and J. M. C. Ritchie-Snowden Federal #1, A8301C GRN, 3122 DF Tops: Spud in Ru, Sal 150?, Ca 605, BC 2149
40	35	25S	27E	Chambers, Kennedy and Ritchie-Lockwood Federal #1, A7940C GRN, 3102 DF Tops: Spud in Ru, Sal 210, Ca 680, BC 2265
41	14	25S	28E	Walter W. Krug and Tom Brown Drilling-Nada Federal #1, A8343A GRN, 2946 DF Tops: Ru 50?, Sal 490?, Ca 1020, BC 2590
42	8	25S	29E	Neil H. Wills-Superior Federal #1, W9632C SGR, 2924 KB Tops: Ru 40, Sal 260, Ca 1278, BC 2844
43	3	25S	29E	J. Glen Bennett-Superior Federal #1-3, W8159B SGR, 2985 DF Tops: Ru 125, Sal 380, Ca 1630, BC 3064
44	8	25S	30E	Fred Pool Drilling Co.-Superior State #1, W2453H SGR, est. 3200 KB Tops: Ru 580, Sal 760, Ca 1940, BC 3684
45	8	25S	30E	Ralph Lowe-Poker Lake State #3, W504L SGR, est. 3200 KB Tops: Ru 699, Sal 899, Ca 2110, BC 3588
46	17	25S	30E	Ralph Lowe-Richardson and Bass Federal "A" #1-X, W43L SGR, 3210 KB Tops: Ru 595, Sal 785, Ca 2100, BC 3612
47	4	25S	30E	Patoil Corp.-Richardson and Bass Federal #1, W753G SGR, 3273 KB Tops: Ru 848, Sal 1220, Ca 2260, BC 3785
48	21	25S	30E	Alamo Corp.-Poker Lake Unit #6-2A, W8082E SGR, 3252 DF Tops: Ru 1130, Sal 1370, Ca 2230, BC 3792
48A	22	25S	30E	El Paso Natural Gas Co.-Poker Lake Unit #3, ---- SPL, 3297 GL Tops: Ru 1130, Banded anhydrite 2640, BC 3890
49	35	25S	31E	Gold Metals and Santana Petroleum Corp.-Delaware Basin Federal #1, W2211K SGR, 3319 KB Tops: Ru 1322, Sal 1570, Ca 2648, BC 4229

Well data: Eddy County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
50	12	26S	24E	Superior Oil Co.-Government "134" #1, W485M SGR, 3879 KB Tops: Spud in Ca, BC 902
51	13	26S	24E	Universal Production Service, Inc.-Superior Federal "B" #1, A1679L GRN, 3791 GL Tops: Spud in Ca, BC 830
52	3	26S	25E	W. E. Doolin-Erickson Federal #1, A6873B GRN, 3685 DF Tops: Spud in Ca, BC 1585
53	26	26S	25E	W. E. Doolin-McKean Federal #1, A6966D GRN, 3605 DF Tops: Spud in Ca, BC 1348
54	1	26S	25E	W. E. Doolin-Milner Federal #1, A6806D GRN, 3493 DF Tops: Spud in Sal, BC 1690
54A	7	26S	26E	McBride et al-Randel #1, ---- SPL, 3541 GL Tops: Banded anhydrite 385, BC 1700
55	28	26S	26E	W. E. Doolin-Watkins Federal #1, A6851E GRN, 3433 DF Tops: Spud in Sal, BC 1757
56	17	26S	27E	El Paso Natural Gas Products Co.-Welch Unit #6, W8342D SGR, 3336 KB Tops: Ca 550?, BC 2165
56A	21	26S	27E	Stanolind Oil and Gas-Welch Unit #1, ---- SPL, 3232 GL Tops: Banded anhydrite 570, BC 2030
57	30	26S	28E	Highland Production-U. S. Smelting State #1, A1693K GRN, est. 3122 KB? Tops: Spud in Sal, Ca 840, BC 2270
58	15	26S	28E	Sun Oil Co.-State "B" #1, W8977B SGR, 3022 KB Tops: Spud in Ru, Sal 80?, Ca 1020, BC 2491
58A	3	26S	28E	Aldridge and Stroud-State of N. M. #1 (G. T. Lang and D. A. Schlachter-State #1) A5749B GRN and SPL, 2948 DF Tops: Ru 82, Banded anhydrite 1125, BC 2490

Well data: Eddy County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
59	2	26S	29E	Tom Brown Drilling Co.-State #1, W68H SGR, 3049 KB Tops: Ru 665, Sal 875, Ca 1660, BC 3202
60	24	26S	29E	Curtis Hankamer-Gulf Beaty #1, W9219E SGR, 2972 KB Tops: Ru 150, Sal 530, Ca 1560, BC 3105
61	6	26S	30E	J. Glen Bennett-Brunson Federal #1, W8972E SGR, 3059 KB Tops: Ru 815, Sal 1165, Ca 1775, BC 3324
62	18	26S	30E	Curtis Hankamer-Federal AT #1, W9219C SGR, 3059 KB Tops: Ru 685, Sal 1120, Ca 1660, BC 3273
63	3	26S	30E	Charles B. Read-Scott Federal #1, W1312M SGR, 3165 KB Tops: Ru 1305, Sal 1630, Ca 2127, BC 3660
64	12	26S	30E	Monterey Oil Co.-Monterey Blaydes #1, W8992B SGR, 3210 KB Tops: Ru 950, Sal 1295, Ca 2310, BC 3840
65	20	26S	31E	Max Wilson-Hanson Federal #1, W3189G SGR, 3187 GL Tops: Ru 925, Sal 1268, Ca 2350, BC 3860
66	1	26S	31E	Tom Brown Drilling Co.-Ruth Ross "O" #1, W748K GR, est. 3235 KB Tops: Ru 1352, Sal 1905, Ca 2750, BC 4310
66A	11	26S	31E	Ibex Co.-Bauerdorf #1, A3845A GRN and SPL, 3220 GL Tops: Ru 1280, Sal 1920, Banded anhydrite 2620 intermittent, continuous from 2990, BC 4150
67	25	26S	31E	Ibex Co.-Hanson #3, W5162C GR, 3136 KB Tops: Ru 875, Sal 1231, Ca 2480, BC 4074
A	15	21S	28E	Nix and Curtis-Muse Federal #2, ---- SPL, est. 3225 GL Tops: Samples start at 1305 in Sal, Banded anhydrite 1977, BC 2368
B	1	23S	26E	U. S. Smelting and Refining Co.-Collatt #1, A2119C GR, 3227 ? Tops: Ca 635, BC 1810

Well data: Eddy County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
C	22	23S	26E	Hanson and Yates-Cordie King, ---- SPL, 3324 GL Tops: Spud in Ru, Sal 555, Banded anhydrite 1045, BC 1695?
D	34	24S	27E	Tennessee Gas Transmission Co.-Kelly State #1, A7325E GRN, 3255 KB Tops: Ca 640?, BC 2280
E	31	24S	27E	Humble-Federal Wiggs #1, 1056C GR-EL, est. 3463 RT Tops: Ca 580?, BC 2245
F	32	25S	29E	D. B. Scully-Superior Oil Co. #1, ---- SPL, 3012 GL Tops: Samples start in Sal at 515, Banded anhydrite 1555, BC 2887
G	17	25S	28E	Aldridge and Stroud-Signal State #3, A5749A GRN, 3030 DF Tops: BC 2443
H	23	25S	28E	Aldridge and Stroud-Signal Federal #2, A5748B GRN and SPL, 2919 DF Tops: Spud in Ru, Sal 240?, Ca 1000, Banded anhydrite 1232, BC 2520
J	26	25S	28E	Aldridge and Stroud-Signal Federal (Federal Davis) #1, A5748D GRN and SPL, 2958 DF Tops: Ru 70, Sal 300, Banded anhydrite 1198, BC 2573
K	7	24S	29E	Tennessee Production Co.-Valley Land #3, W3412E GR-EL, est. 2950 RT Tops: Spud in Ru, Sal 150, Ca 1470, BC 2675
L	12	25S	30E	Richardson and Bass-J. P. Harrison Federal #1, ---- SPL, 3378 GL Tops: Ru 1160, Banded anhydrite 2830, BC 4040

Well data: Lea County, New Mexico

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
1	35	20S	33E	Helbing and Podpechan-Shell Federal #1, W1834L SGR, 3679 KB Tops: Ru 1478, Sal 1840, Carlsbad 2920
2	28	20S	34E	Carper and Sivley-Threlkeld, Carper and Sivley #1, W2605K SGR, 3693 KB Tops: Ru 1580, Sal 1960, Carlsbad 3120
3	26	21S	32E	Gulf-San Simon #1, W1849G SGR, 3798 KB Tops: Ru 1292, Sal 1780, Ca 3195
4	2	21S	34E	Ralph Lowe-Gulf New Mexico #1, W2763M SGR, 3723 KB Tops: Ru 1890, Sal 2270, Ca 3365
5	32	21S	35E	Robert G. Hanagan-Humble State #1, W2440H SGR, 3634 KB Tops: Ru 1773, Sal 2195, Ca 3305
6	18	22S	32E	John H. Trigg Co.-Federal Jennings #1-18, W954K SGR, 3696 KB Tops: Ru 900, Sal 1225, Ca 2850, BC 4700
7	13	22S	32E	Ray Smith Drilling-B&H Federal #1, W1804H SGR, 3644 KB Tops: Ru 860, Sal 1276, Ca 2730, BC 4861
8	7	22S	33E	Cabot Corp.-State #1-K, W2244L SGR, 3631 KB Tops: Ru 877, Sal 1235, Ca 2970, BC 4760
9	20	22S	33E	Davis and Collins-Conoco Federal #1, W2751G SGR, 3647 KB Tops: Ru 920, Sal 1225, Ca 2780, BC 4823
10	34	22S	33E	Charles P. Miller-Humble State #1, W4218K SGR, 3571 KB Tops: Ru 1057, Sal 1362, Ca 3010, BC 5091
11	1	22S	34E	Atlantic-State "AR" #1, W1567G SGR, 3606 KB Tops: Ru 1650, Sal 2100, Ca 3300
12	9	22S	35E	W. A. and E. R. Hudson-Humble State #1, W471G SGR, 3581 KB Tops: Ru 1810, Sal 2270, Ca 3493
13	31	23S	32E	Curtis Hamkamer-Continental Federal #1, W2424K SGR, 3551 KB Tops: Ru 862, Sal 1210, Ca 3070, BC 4588

Well data: Lea County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
14	21	23S	32E	Curtis Hankamer-Gulf Federal "A-A" #1, W3198G SGR, 3701 KB Tops: Ru 1163, Sal 1515, Ca 3222, BC 4820
15	3	23S	32E	O. B. Kiel, Jr.-Federal #1, W1474K SGR, 3727 KB Tops: Ru 1153, Sal 1580, Ca 3140, BC 4877
16	26	23S	32E	John H. Trigg-Federal #4-WL-26, W1921K SGR, 3713 KB Tops: Ru 1225, Sal 1670, Ca 3445, BC 4985
17	26	23S	32E	John H. Trigg-Federal #3-WL-26, W1857K SGR, 3698 KB Tops: Ru 1225, Sal 1680, Ca 3458, BC 5010
18	35	23S	32E	John H. Trigg-Federal #1-WL-35, W1840L SGR, 3694 KB Tops: Ru 1208, Sal 1655, Ca 3455, BC 4966
19	35	23S	32E	John H. Trigg-Federal #2-WL-35, W1845M SGR, 3692 KB Tops: Ru 1205, Sal 1650, Ca 3475, BC 4990
20	19	23S	33E	Continental Oil-Marshall #4, W1595H SGR, 3713 KB Tops: Ru 1220, Sal 1710, Ca 3380, BC 5030
21	6	23S	33E	W. A. and E. R. Hudson-Shell Federal #1-6, W1968L SGR, 3704 KB Tops: Ru 1260, Sal 1770, Ca 3365, BC 5030
22	32	23S	33E	El Cinco Production-Humble State #1-32, W487L SGR, 3683 KB Tops: Ru 1270, Sal 1770, Ca 3523, BC 5100
23	20	23S	33E	Continental Oil-Levick Federal #1, W3052L SGR, 3701 KB Tops: Ru 1280, Sal 1782, Ca 3485, BC 5148
24	4	23S	33E	Cabeen Explorations-Continental Federal #1-P, W1025H SGR, 3636 KB Tops: Ru 1160, Sal 1650, Ca 3235, BC 5112
25	6	23S	34E	Continental Oil-Bell Lake Unit #6, W49L SGR, 3485 KB Tops: Ru 1030, Sal 1375, Ca 2700, BC 4870
26	8	23S	35E	John H. Trigg-Federal #1-SR-8, W3268K SGR, 3370 KB Tops: Ru 1714, Sal 2130, Ca 3670

Well data: Lea County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
27	17	23S	35E	Murphy Corp.-State Henry #1-17, W7178B GR-EL, 3408 KB Tops: Ru 1683, Sal 2187, Ca 3710
28	36	23S	35E	Monsanto Chemical-State #1-D, W6467B GR-EL, 3491 KB Tops: Ru 1878, Sal 2380, Ca 3780, BC 5610
29	14	24S	32E	Tenneco Oil-U. S. A. Jennings #3, W2467H SGR, 3624 KB Tops: Ru 1142, Sal 1450, Ca 3335, BC 4910
30	8	24S	33E	Sunray Mid-Continent-New Mexico State #1-AG, W2348L SGR, 3617? KB Tops: Ru 1215, Sal 1700, Ca 3395, BC 5100
31	29	24S	33E	Tidewater Oil-State #1-AP, W1976M SGR, 3526 KB Tops: Ru 1146, Sal 1492, Ca 3350, BC 5018
32	21	24S	34E	Cabeen Explorations-Shell Federal "B" #1, W1030K SGR, 3539 KB Tops: Ru 1190, Sal 1749, Ca 3691, BC 5350
33	4	24S	34E	Shell-Federal #1-BE, W3595H SGR, 3567 KB Tops: Ru 1047, Sal 1540, Ca 3359, BC 5130
34	9	24S	35E	Midwest Oil-Custer Mountain Unit Federal #1, W4113G GR, 3404 KB Tops: Ru 905, Sal 1240, BC 5320
35	15	24S	35E	Gulf-Lea State #1-GB, W1289G SGR, 3371 KB Tops: Ru 1097, Sal 1529, Ca 3330, BC 5360
36	21	25S	32E	Texaco-Cotton Draw Unit #57, W1275K SGR, est. 3480 KB Tops: Ru 740, Sal 1115, Ca 2750, BC 4585
37	3	25S	32E	Texaco-Cotton Draw Unit #49, W1804K SGR, 3486 KB Tops: Ru 805, Sal 1120, Ca 3015, BC 4748
38	18	25S	33E	Sam H. Jolliffe, Jr.-Bass Federal #1, W2440L SGR, 3497 KB Tops: Ru 985, Sal 1310, Ca 3190, BC 4914
39	1	25S	33E	Perry R. Bass-Federal Muse #1, W1222K SGR, 3490 KB Tops: Ru 1200, Sal 1670, Ca 3550, BC 5200

Well data: Lea County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
40	36	25S	33E	Ashmun and Hilliard-State #1-36, W1827H SGR, 3346 KB Tops: Ru 1037, Sal 1430, Ca 3325, BC 5128
41	8	25S	34E	Hill and Meeker-Federal Muse #1, W2424H SGR, 3353 KB Tops: Ru 1010, Sal 1350, Ca 3380, BC 5321
41A	21	25S	34E	Continental Oil-Ethel Nolen Federal #1, A4917E GRN and W6249A EL, est. 3369 KB Tops: Ru 830, Sal 1250, Ca 3470, BC 5330 Sample log: Top of limy anhydrite 3970
42	22	25S	35E	Sun Oil-Elliott Federal #1, W9241A GR-EL, 3218 KB Tops: Ru 810, Sal 1115, Ca 3150, BC 5232
42A	26	25S	35E	Sun Oil-Harper Federal #1, W3791B EL and SPL, 3119 GL Tops: Ru 705, Sal 1115, Ca 3080?, BC 5040
43	26	25S	36E	Burk Royalty-Lindley #1, W1226G SGR, 3049 KB Tops: Ru 1100, Sal 1545, Carlsbad? 2910
44	14	25S	37E	Union Texas Petroleum-Langlie #1-D, W2734K SGR, 3117 KB Tops: Ru 915, Sal 1105, Carlsbad? 2245
45	31	26S	32E	Charles B. Read-Russell Federal #2, W3300H SGR, 3152 KB Tops: Ru 1100, Sal 1372, Ca 2480, BC 4156
45A	19	26S	32E	Continental Oil-Russell Federal #1-19, ---- SPL, 3191 GL Tops: Ru 1450, Banded anhydrite 2830, BC 4210
46	31	26S	32E	Charles B. Read-Russell #1, W3300K SGR, 3156 KB Tops: Ru 919, Sal 1249, Ca 2470, BC 4172
47	31	26S	32E	Charles B. Read-Russell #3, W3300G SGR, 3152 KB Tops: Ru 900, Sal 1220, Ca 2475, BC 4182
47A	29	26S	32E	Continental Oil-Wilder (Federal) #1-29, W4455D EL and SPL, 3149 GL Tops: Ru 1080, Sal 2050?, Banded anhydrite 3080, BC 4280

Well data: Lea County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
48	16	26S	32E	Robert N. Enfield-Ohio State #1, W1404L SGR, 3494 KB Tops: Ru 580, Sal 940, Ca 2582, BC 4395
48A	5	26S	32E	Hill and Meeker-Sun Federal #1, ---- SPL, est. 3150 GL Tops: Ru 1050, Sal 1350, Laminated anhydrite 2960, BC 4450
49	26	26S	32E	Continental Oil-Wilder #25, W104M SGR, 3116 KB Tops: Ru 545, Sal 940, Ca 2840, BC 4513
50	35	26S	32E	Continental Oil-Bradley #1-35, A8887A GR, 3109 KB Tops: BC 4540
50A	34	25S	32E	Ohio Oil-Federal Sunshine Royalty #1, ---- SPL, 3364 DF Tops: Ru 820, Limy anhydrite 3070, BC 4600
50B	36	25S	32E	Fullerton Oil-Bradley #1, ---- SPL, 3352 DF Tops: Banded anhydrite 3590, BC 4750
51	15	26S	33E	Coastal States Gas-Federal Continental #3, W2169G SGR, 3315 KB Tops: Ru 924, Sal 1260, Ca 3200, BC 4988
52	6	26S	34E	American Petroleum-Federal #1-K, W4044H SGR, 3338 KB Tops: Ru 800, Sal 1140, Ca 3135, BC 5255
53	20	26S	34E	Max Wilson-Leonard Federal #1, W3158L SGR, 3332 KB Tops: Ru 635, Sal 1000, Ca 3470, BC 5317
54	9	26S	34E	Max Wilson-Yates Federal #1, W3159G SGR, 3327 KB Tops: Ru 770, Sal 1145, Ca 3475, BC 5343
55	33	26S	34E	Mallard Petroleum-Elliott Federal #1, W2564L SGR, 3299 KB Tops: Ru 832, Sal 1212, Ca 3438, BC 5385
56	26	26S	34E	Kirklin Drilling-Kirklin Drilling Hondo Federal #1, W1717H SGR, 3220 KB Tops: Ru 960, Sal 1350, Ca 3480, BC 5340

Well data: Lea County, New Mexico (Cont'd)

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
57	27	26S	35E	Kirklin Drilling-Federal Boothe #1-BD, W9609C SGR, 3067 KB Tops: Ru 915, Sal 1370, Ca 3315, BC 5145
58	6	26S	36E	Cities Service Oil-Sandhills #8, W9704E SGR, 2979 KB Tops: Ru 1400, Sal 1830, Ca? 3330
59	5	26S	36E	Cities Service Oil-Sandhills Unit #9-A, W9847B SGR, 2999 KB Tops: Ru 1052, Sal 1428, Ca? 3200
60	5	26S	36E	Toreador Royalties-Sinclair Federal Sandhills Unit #4, W8301B SGR, 3010 KB Tops: Ru 1196, Sal 1580, Ca? 3300
61	17	26S	36E	Cities Service Oil-Sandhills Unit #7, A9426C GRN, 2959 KB Tops: Ru 1737, Sal 2038, Ca? 3442
62	20	26S	36E	Cities Service Oil-Sandhills Unit #6-A, W9392B SGR, 2932 KB Tops: Ru 1862, Sal 2310, Ca? 3170
63	13	26S	36E	Pan American P. C.-C. M. Farnsworth #8-A, W2836H SGR, 2956 KB Tops: Ru 1170, Sal 1450, Ca? 2760
A	21	22S	32E	Union Oil of Calif.-Gilmore Federal #1, ---- SPL, est. 3650 GL Tops: Ru 880, Ca 3300?, Banded anhydrite 3930, BC 4690
B	15	23S	34E	J. H. Snowden and U. S. Potash-Hall Federal #1, W4376E EL and SPL, 3419 KB Tops: Ru 1080?, Sal 1430, Ca 3840?, BC 5035; samples start at 4110 in banded anhydrite
C	30	23S	34E	Continental Oil-Bell Lake Unit #2, W4854A GR-EL and SPL, est. 3520 KB Tops: Ru 1250, Sal 1780, Ca 3730, BC 5127, Banded anhydrite 4000
D and E	31	23S	34E	Continental Oil-Bell Lake Unit #1 and #1-A, W4927E GR-EL and SPL, 3635 KB Tops: Ru 1230, Sal 1760, Ca 3725, BC 5143, Banded anhydrite 4050

Well data: Lea County, New Mexico (Cont'd

Ref. no.	Location Sec.	Twp.	Rge.	Operator, lease, well number, log reference number and log type, elevation
F	12	24S	35E	British American Producers-Fields #1, W4755A GR-EL and SPL, 3466 KB Tops: Ru 1725, Sal 2220, Ca 3860
G	? Near Lea-B	23S	34E	James H. Snowden-Snowden U. S. Potash Federal #1, A2909A GR, est. 3420 KB Tops: Ru 1080, Sal 1400, Ca 3550, BC 5037
H	32	22S	33E	Helbing and Podpechan-Shell State #1-B, W849G SGR, 3726 KB Tops: Ru 1212, Sal 1708, Ca 3258, BC 5010
J	33	22S	33E	R. B. Farris-Phillips State #1, W960H SGR, 3587 KB Tops: Ru 1048, Sal 1338, Ca 2955, BC 5017

Well data: Texas

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
				Brewster County, Texas
1	66	10	GH&SA	Texas-New Mexico Development Co.-State #14-66, W9237A SGR, est. 4090 KB Equivalent section? 730-2000 Ru-BC
				Jeff Davis County, Texas
1	33	57	T&P T.9S.	Gulf-W. L. Kingston et al. "A" #1, A3979C GRN, 3937 KB No correlation made; up to 4000 feet of dolomite?
2	41	57	T&P T.9S.	Sunray Mid-Continent Oil and Sinclair-Fannye Lovelady #1, W1799G SGR, 4039 KB Same as above
3	18	11	GH&SA	Continental Oil-Mrs. L. K. McCutcheon #1, A2207D GRN, 4170 RT Equivalent section? 790-4175 Ru-BC
				Culberson County, Texas
1	26	63	T&P T.1S.	Bonanza Oil Corp.-Pierson #1, W824M SGR, 4422 KB Tops: Spud in Ca, BC 275?
2	18	61	T&P T.1S.	Continental Oil-E. E. Pokorny #1, W376G SGR, 3928 KB Tops: Spud in Ca, BC 1253
3	18	60	T&P T.1S.	Cree Oil, Inc.-E. E. Pokorny "B" #1, W8447D Sonic only, 3530 KB Tops: Spud in Sal, Ca 365, BC 1540
4	8	60	T&P T.1S.	Cree Oil, Inc.-E. E. Pokorny "A" Lease #1, W8422D, 3410 KB Tops: Spud in Sal, Ca 200?, BC 1711
5	12	59	T&P T.1S.	W. D. Thorn et al.-Billie Prewit #1, W9001C SGR, n.a. Tops: Spud in Sal?, Ca 620, BC 2265
6	23	58	T&P T.1S.	Texaco-Culberson "F" Fee #1, W3067M SGR, 3012 KB Tops: Ru 55?, Sal 250, Ca 960, BC 2588
7	23	58	T&P T.1S.	Texaco-Culberson "F" Fee #3, W3988M SGR, 3020 KB Tops: Ru 258, Sal 460?, Ca 955, BC 2562

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
8	26	58	T&P T.1S.	Continental Oil-G. E. Ramsey, Jr. 26 #6, W3869L SGR, 3011 KB Tops: Ru 440?, Sal 590, Ca 870, BC 2550
9	24	64	T&P T.2S.	Socony Mobil Oil-State Cowden #1, W948L SGR, 4330 DF Tops: Spud in BC
10	8	63	T&P T.2S.	Socony Mobil Oil-State Barrett #2, W1097G SGR, n.a. Tops: Spud in BC
11	33	62	T&P T.2S.	TXL Oil-Culberson B-T Fee #1, W610M SGR, 4072 KB Tops: Spud in Ca, BC 215
12	4	61	T&P T.2S.	Utex Exploration-Pokorney #1-4, W8422E SGR, 3623 KB Tops: Spud in Ca, BC 902
13	30	60	T&P T.2S.	Bluebonnet Oil and Gas-Windham State #1, A7858D GRN and SPL, 3817 DF Tops: Spud in Sal?, Banded anhydrite 120, BC 1420
14	28	60	T&P T.2S.	L. D. Crumley, Jr.-Covington #1, W1106M SGR, 3788 KB Tops: Spud in Sal, Ca 375, BC 1541
15	40	59	T&P T.2S.	Ray Smith Drilling-Windham #1-A, W2835K SGR, n.a. Tops: Spud in Ru?, Sal 35?, Ca 650, BC 2110
16	34	59	T&P T.2S.	Ray Smith Drilling-James T. Windham et al. #1, W2859L SGR, 3461 KB Tops: Spud in Ru, Sal 175, Ca 640, BC 2163
17	4	58	T&P T.2S.	Continental Oil-Russell 4 #3, W4096H SGR, 3196 KB Tops: Ca 930, BC 2500
18	4	58	T&P T.2S.	Continental Oil-J. C. Russell "4" #2, W3663G SGR, 3204 KB Tops: Ru 170, Sal 495, Ca 1010, BC 2527
19	3	58	T&P T.2S.	Texaco-Culberson "E" Fee #2, W2436L SGR, 3158 KB Tops: Spud in Ru, Sal 250, Ca 1003, BC 2530

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
20	9	58	T&P T.2S.	Bass Brothers Enterprises-TXL 9 #4, W2972B SGR, 3236 KB Tops: Spud in Ru, Sal 200, Ca 1000, BC 2515
21	9	58	T&P T.2S.	Bass Brothers Enterprises-TXL 9 #2, W2893L SGR, 3174 KB Tops: Spud in Ru, Sal 250, Ca 930, BC 2435
22	10	58	T&P T.2S.	Continental Oil-Russell #10-2 W3680L SGR, 3186 RDB Tops: Spud in Ru, Sal 375, Ca 990, BC 2530
23	22	58	T&P T.2S.	I. W. Lovelady-Delaware Basin Properties #2, W2410H SGR, 3103 KB Tops: Spud in Ru, Sal 440, Ca 952, BC 2463
24	24	68	PSL	Humble-M. C. Sibley #1, W751M SGR, n.a. Tops: Spud in BC
25	25	115	PSL	Derecho Corp.-Montgomery #1, W2377K GR, n.a. Tops: Spud in Ca, BC 850
26	14	114	PSL	Ford Chapman-H. M. Phillips #1, W2963G GR, n.a. Tops: Spud in Sal, BC 1690
27	23	114	PSL	F. R. Robinson & Son Drilling-W. A. Scott Estate #1, W5108A EL, 3675 GL Tops: Ca 665?, BC 1835
28	15	113	PSL	Chapman and Patterson-Scott #1, W2816M GR, n.a. Tops: Spud in Ru, Sal 330, Ca 830, BC 2090
29	17	45	PSL	Bob Dean, Limited-Monroe State #1, W1653H SGR, 3140 KB Tops: Ru 35?, Sal 480, Ca 1150, BC 2400
30	16	45	PSL	Texas Co.-State of Texas AK #1, A2436E GRN, 3193 KB Tops: Ru 310, Sal 720, Ca 1260, BC 2610

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
31	28	45	PSL	Penrose Production-Bateman #1, W3554K SGR, 3243 KB Tops: Ru 420, Sal 820, Ca 1457, BC 2638
32	8	111	PSL	Continental Oil-J. H. Fisher #1-A, W8351E SGR and SPL, 3393? KB Tops: Spud in Ru, Sal 235, Ca 650, Banded anhydrite 670, BC 1968
33	17	111	PSL	Kirklin Drilling-J. H. Fisher #1, W1702L SGR and SPL, 3444 KB Tops: Spud in Ru, Sal 325, Ca 785, Banded anhydrite 810, BC 1980
34	21	111	PSL	Big Spring Exploration-J. H. Fisher #1, W8761A SGR, 3403 KB Tops: Spud in Ru, Sal 110?, Ca 914, BC 2123
35	22	108	PSL	Hunt Oil-Rounsaville #1, W4588B GR-EL, 4159 KB Tops: Spud in Ca, BC 430
36	11	103	PSL	Continental Oil-T. B. Fite #1, A5794D GRN and W6869B EL, 4073 DF Tops: BC 1190?
37	16	42	PSL	Ada Oil-H. R. Nevill #1, A4980A GR, 3785 KB Tops: Spud in Sal?, Ca 530, BC 1705
38	6	52	PSL	Kirklin Drilling-J. H. Fisher #1, W2259K EL and SPL, 3592 KB Tops: Banded anhydrite 660, BC 1937
39	18	52	PSL	Burford and Sams, Ray Smith-Cox #2, A8171E GRN, 3653 DF Tops: Spud in Ru, Sal 205, Ca 810?, BC 2130
40	5	52	PSL	Western American Oil-Fisher #1, W2194L SGR, 3552 KB Tops: Ru 180?, Sal 580?, Ca 720, BC 2080
41	40	52	PSL	I. W. Lovelady-Shelby Brooks #1, W2525G SGR, 3497 KB Tops: Ru 180, Sal 680?, Ca 1000?, BC 2233

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
42	29	53	PSL	Utex Exploration Co.-T. A. Kirk #1, W8616D SGR, n.a. Tops: Ru 340, Sal 675, Ca 1550, BC 2730
43	18	99	PSL	Gulf-Grisham #1, 1070D EL, 5688? RDB Tops: Spud in BC
44	17	100	PSL	El Paso Natural Gas-Montgomery #1 W3937E GR-EL, 4507 KB Tops: Spud in BC
45	22	97	PSL	Sinclair-K. P. Looney #1, W839M GR-EL and W840G Microlog, 4298 GL Tops: Spud in Ca, BC 285
46	13	96	PSL	Haynes and V. T. Drilling-State B #1, A9234E GRN, n.a. Tops: Spud in Ca, BC 1065
47	10	60	T&P T.5S.	M. A. Grisham-M. A. Grisham Fee #1, W2844E EL and Scout Report, 3642 DF Tops: BC 1380
48	34	60	T&P T.5S.	TXL Oil-Harry Goode #1, W915L SGR, W9397A EL and W9397B Microlog, n.a. Tops: BC 1704
49	19	54	PSL	Grisham and Hunter-M. A. Grisham State #1, A3192A GRN and W4733E EL, 3067 KB Tops: Spud in Sal, Ca 760, BC 1850
50	31	54	PSL	El Paso Natural Gas-Grisham Hunter State #1-L, W3252B GR and Scout Report, 3212 KB Tops: Spud in Ru, Sal 210, Ca 960, BC 2108
51	16	54	PSL	Gulf-Grisham Hunter #1, 592E GR, 3598 RT Tops: Spud in Ru, Sal 60?, Ca 900, BC 1985
52	22	54	PSL	Richardson and Bass-Grisham Hunter State #1, W3374D GR-EL and SPL, 3544 KB Tops: Spud in Ru, Sal 100, Ca 923, Banded anhydrite 1100, BC 2045

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
53	13	54	PSL	Tidewater Oil-Delaware Basin Properties Inc. #1, W598M SGR and SPL, 3409 KB Tops: Ru 125, Sal 470, Banded anhydrite 1030, BC 2270
54	20	91	PSL	I. W. Lovelady-Veale #1, A7938B GRN and SPL, 4588 DF Tops: Spud in Sal, Ca 490, Banded anhydrite 479, BC 2108
55	24	88	PSL	Continental Oil-J. D. Foster #1, A2208A GRN, W3438C GR-EL, 4146 RDB Tops: BC 342
56	10	89	PSL	I. W. Lovelady-J. B. Foster #1, A8151C GRN, 4131 DF Tops: Spud in Ru, Sal 300, Ca 1030, BC 2610
57	24	89	PSL	Burford and Sams-J. B. Foster #1, W1965K GR and SPL, 4049 DF Tops: Spud in Ru, Sal 250, Ca 810, Banded anhydrite 940, BC 2330
58	43	60	PSL	Central Drilling and American Liberty-Rachel Cerf #1, A8649D GRN and SPL, 3972 GL Tops: Spud in Ru, Sal 230, Ca 850, Banded anhydrite 1105, BC 2230
59	44	60	PSL	McFarland Corp.-Rachel Cerf #1-44, W3598M EL and A1759H GRN, 4096 KB Tops: Spud in Ru, Sal 340, Ca 850, BC 2300
60	28	60	PSL	Ford Chapman and Guy Patterson-Bank #1, A9526A GRN, n.a. Tops: Ru 100, Sal 440, Ca 1200, BC 2890
61	22	62	PSL	Sunray Mid-Continent Oil-J. B. Foster #1, W1598H GR, n.a. Tops: No correlations--reef zone?
62	3	61	PSL	Canter, Hamm and O'Brien-J. B. Foster #1, W798G SGR and SPL, 4017 KB Tops: Spud in Ru, Sal 260, Ca 785, Banded anhydrite 980, BC 1465
63	15	61	PSL	Ray Smith Drilling-J. B. Foster #1-15, W4353K SGR, 3938 KB Tops: Gravel 0-660?, Ca 660, BC 1620?

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
64	22	59	T&P T.7S.	Phillips Petroleum-Crews #1, W4951C GR-EL and Scout Report, 3605 KB Tops: Ru 325, Sal 650, Ca 1285, BC 2595
65	5	82	PSL	La Gloria Oil and Gas-Stansbury #1, A5182B GRN, 3844 KB Tops: No correlations--reef zone?
66	15	59	T&P T.8S.	Johnson Drilling-Cowden #1, W4299L GRN, n.a. Tops: No correlations--reef zone?
67	12	59	T&P T.8S.	Johnson Drilling-Stocks #1, A1777H GRN, 3872 GL Tops: No correlations--reef zone?
A1 and A2	38	62	T&P T.1S.	Pennsylvania Drilling-Cowden: Drilled for Dr. R. Y. Anderson, Geology Dept., Univ. of New Mexico, Samples from base of Castile Formation
A4	33	62	T&P T.2S.	same as A1 and A2, 1/4 mile south of Culberson-11
B	11	114	PSL	Paul F. Lawlis-James H. Logan #1, ---- SPL, n.a. Tops: Log starts in banded anhydrite at 570, BC 1650
C	30	111	PSL	Cole A. Means-J. H. Fisher "30" #1, ---- SPL, n.a. Tops: Banded anhydrite 612, BC 1980
D	3	52	PSL	Sawnie Robertson-Sherrod, Clare, Caldwell #1, ---- SPL, n.a. Tops: Samples start at 153 in Ru, Sal 310, Limey anhydrite 720, Banded anhydrite 860, BC 2140
E	13	108	PSL	R. B. McGowan, Jr. et al.-Rounsaville #1, ---- SPL, n.a. Tops: Samples start at 200 in banded anhydrite, BC in sample gap 1085-1096
F	17	52	PSL	Stephens Petroleum-Sherrod and Clare #1, ---- SPL, n.a. Tops: Samples start at 305 in Sal, Banded anhydrite 910, BC 2198

Well data: Culberson County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
G	8	60	T&P T.5S.	Hanlon and Boyle, Inc.-Grisham Hunter #1, ---- SPL, n.a. Tops: Samples start at 100 in limy anhydrite (Ca?), BC 1395
H	16	54	PSL	Standard of Texas-Grisham Hunter #2, ---- SPL, n.a. Tops: Banded anhydrite 620, BC 1980
J	2	114	PSL	J. R. Meeker-H. M. Phillips #1, W7874C GR, 3916 KB Tops: Ca 395, BC 1630
U	42	54	PSL	David Flood-Grisham and McAlpine #1, ---- SPL, n.a. Tops: Spud in Ru, Sal 238, Ca 850, BC 2150

Well data: Loving County, Texas

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
1	14	56	T&P T.1S.	Ford Chapman and Associates-W. D. Johnson, Jr. #1-L, W4047G SGR, n.a. Tops: Ca 1070, BC 2860
2	30	56	T&P T.1S.	TXL Oil-W. D. Johnson et al. #1, W1258H SGR, est. 2853 KB Tops: Ca 1425, BC 3070
3	31	56	T&P T.1S.	Texaco-Loving "AD" Fee #2, W3941G SGR, n.a. Tops: Ca 1510, BC 3130
4	32	56	T&P T.1S.	Ray Morris Exploration-Dam #1, W3292H SGR, 2875 KB Tops: Ca 1540, BC 3223
5	38	56	T&P T.1S.	Ambassador Oil-W. D. Johnson, Jr. #1, A1439K GRN, 2819 Top Well Head Tops: Sal 592?, BC 3350
6	47	56	T&P T.1S.	Ambassador Oil-George C. Frazier, TXL "B" #15, A1647M GRN, n.a. Tops: BC 3320
7	47	56	T&P T.1S.	Ambassador Oil-TXL "B" #14, A1439G GRN, 2787 GL Tops: Ru 760, Sal 870, BC 3300
8	31	55	T&P T.1S.	TXL Oil-Loving "P" Fee #1, W799G SGR and W799H GRN-EL, n.a. Tops: Ru 488, Sal 890, Ca 1990, BC 3652
9	44	55	T&P T.1S.	Theiss Drilling-Pure State #1, W3773G SGR, 2845 GL Tops: Ru 570, Sal 870?, Ca 1930, BC 3610
10	15	55	T&P T.1S.	Roy L. Crawford-M. K. Kyle #1, W9475D SGR, 3030 KB Tops: Ru 710, Sal 1050, Ca 2050?, BC 3940
11	35	55	T&P T.1S.	Wilson Germany, Paul Page and Gulf Oil-TXL "BE" #1-35, W8889D SGR, 3064 KB Tops: Ru 810, Sal 1307, Ca 2300, BC 4090
12	25	55	T&P T.1S.	Edgar Davis Drilling and Gulf Oil-TXL "25" #1, W8551B SGR, est. 3033 KB Tops: Ru 970, Sal 1380?, Ca 2433, BC 4143

Well data: Loving County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
13	41	54	T&P T.1S.	R. E. Sutton and Gulf Oil-TXL #1-41, W8587C SGR, 3019 KB Tops: Ru 1085, Sal 1363, Ca 2450, BC 4260
14	20	54	T&P T.1S.	American Trading and Production-Sid Kyle 20 #4, W1824M SGR, 3060 KB Tops: Ru 795, Sal 1165, Ca 2515, BC 4375
15	3	54	T&P T.1S.	Gulf-TXL AZ #2 W9107E SGR, 3105 KB Tops: Ru 430, Sal 830, Ca 2674, BC 4474
16	22	54	T&P T.1S.	Gulf-S. M. Kyle "A" #1, W106L SGR, 3096 KB Tops: Ru 460, Sal 855, Ca 2627, BC 4477
17	27	54	T&P T.1S.	Texaco-Loving "U" Fee #3, W2723K SGR, 3063 KB Tops: Ru 450, Sal 850, Ca 2628, BC 4496
18	35	54	T&P T.1S.	Richardson and Bass-Mangaslag TXL #1, W8098D SGR, est. 3069 KB Tops: Ru 473, Sal 880, Ca 2613, BC 4552
19	36	54	T&P T.1S.	Chase Petroleum-Kyle #1, W38H SGR, 3088 KB Tops: Ru 518, Sal 942, Ca 2760, BC 4607
20	18	76	PSL	Hill and Meeker-Madera #1-18, W1121M SGR, 3092 KB Tops: Ru 580, Sal 975, Ca 2785, BC 4671
21	30	76	PSL	Santana Petroleum-Johnson #5, W2180M SGR, 3081 KB Tops: Ru 570, Sal 970, Ca 2745, BC 4640
22	31	76	PSL	Union Oil of Calif.-Johnson #1-31, W668M SGR, 3089 KB Tops: Ru 540, Sal 943, Ca 2760, BC 4627

Well data: Loving County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
23	5	76	PSL	Blair, Price and Allison-M. R. Madera #1, W1344G SGR, 3254 KB Tops: Ru 750, Sal 1105, Ca 2975, BC 4942
24	39	76	PSL	Ford Chapman and Associates-W. D. Johnson #1-39, W889L SGR, 3074 Top of Control Head Tops: Ru 590, Sal 970, Ca 2990, BC 4855
25	19	55	T&P T.2S.	TXL Oil-Loving Fee "M" #1, W9904A SGR, 2787 KB Tops: Ru 365, Sal 795, Ca 1910, BC 3510
26	30	55	T&P T.2S.	Gulf-H. A. Lindley State #1, W9964D SGR, 2751 KB Tops: Ru 680, Sal 1030, Ca 1830, BC 3460
27	17	55	T&P T.2S.	Gulf-TXL AV (NCT-A) #5, W2472G SGR, 2860 KB Tops: Ru 800, Sal 1086, Ca 1970, BC 3640
28	39	55	T&P T.2S.	Gulf-TXL BE #1, W9141B SGR, n.a. Tops: Ru 755, Sal 1130, Ca 2288, BC 3880
29	23	55	T&P T.2S.	Gulf-TXL "AU" (NCT-A) #1, W9157B SGR, n.a. Tops: Ru 950, Sal 1190, Ca 2160, BC 3934
30	1	55	T&P T.2S.	Texaco-Loving "W" Fee #1, W3074H SGR, 3009 KB Tops: Ru 1080, Sal 1550, Ca 2335, BC 4160
31	41	54	T&P T.2S.	May and Williams-TXL #1, W516H SGR, 2919 KB Tops: Ru 700, Sal 930, Ca 2250, BC 4072
32	10	54	T&P T.2S.	TXL Oil-W. D. Johnson et al. Fee #1-A, W1243L SGR, 2948 KB Tops: Ru 832, Sal 1230, Ca 2465, BC 4410

Well data: Loving County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
33	31	53	T&P T.2S.	Diamond Drilling and Gulf Oil-TXL #1, W8756B SGR, 2865 KB Tops: Ru 390, Sal 825, Ca 2573, BC 4520
34	5	53	T&P T.2S.	Calto Oil, Paul Page and Gulf Oil-TXL "AL" #1-5, W9208E SGR, 2943 KB Tops: Ru 470, Sal 835, Ca 2683, BC 4605
35	21	53	T&P T.2S.	Burford and Sams and Gulf Oil-TXL "AM" #1-21, W1086H SGR, 2938 KB Tops: Ru 485, Sal 905, Ca 2665, BC 4660
36	33	53	T&P T.2S.	Gulf-TXL AM #1, W9235E SGR, 2907 KB Tops: Ru 497, Sal 905, Ca 2849, BC 4605
37	24	53	T&P T.2S.	Hill and Meeker-W. D. Johnson #1-24, W2898H SGR, 2991 KB Tops: Ru 560, Sal 960, Ca 2370, BC 4845
38	48	53	T&P T.2S.	I. W. Lovelady-Sun State #1, W2471L SGR, 2893 KB Tops: Ru 560, Sal 1000, Ca 2827, BC 4708
39	15	C-25	PSL	Redfern and Herd, Inc.-Brunson #1, W981H SGR, 3195 KB Tops: Ru 950, Sal 1290, Ca 3415, BC 5310
40	12	C-25	PSL	Joe N. Champlin et al.-B. W. Ludeman #1, W9964A SGR, 3144 KB Tops: Ru 930, Sal 1280, Ca 3395, BC 5221
41	21	C-24	PSL	Delfern Oil-Ludeman #1, W8618E SGR, 3121 KB Tops: Ru 1035, Sal 1463, Ca 3490, BC 5247
42	5	C-26	PSL	Hill and Meeker-Womack #1-5, W3139M SGR, 3186 KB Tops: Ru 845, Sal 1220, Ca 3440, BC 5245

Well data: Loving County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
43	17	C-26	PSL	Wilson Exploration-Brunson #1, W8401D SGR, 3191 KB Tops: Ru 727, Sal 1093, Ca 3212, BC 5170
44	22	C-26	PSL	Liedtke '62 Ltd. and A. G. Talbot-Brunson #1, W1913H SGR, 3087 KB Tops: Ru 610, Sal 990, Ca 3172 BC 5050
45	21	28	PSL	Rodman, Noel, Black-Haley 21 #1, W8433B SGR, 2932 KB Tops: Ru 908, Sal 1250, Ca 3394, BC 5190
46	41	28	PSL	Ford Chapman-Haley #1, W120M SGR, n.a. Tops: Ru 874, Sal 1210, Ca 3330, BC 5175
47	24	29	PSL	Rodman, Noel and Black-Haley B3 #1, W8608C SGR, 2997 KB Tops: Ru 830, Sal 1170?, Ca 3261, BC 5191
48	45	29	PSL	Delfern Oil-Ollie #1, W9457B SGR, 2778 KB Tops: Ru 547, Sal 980, Ca 2835, BC 4858
49	2	19	ULS	F. W. Holbrook-University #3-A, W2154G SGR, 2809 KB Tops: Ru 588, Sal 910, Ca 2960, BC 4998
50	3	19	ULS	F. W. Holbrook-University "3" #2, W1059K SGR, 2767 KB Tops: Ru 550, Sal 980, Ca 3000, BC 4955
51	3	19	ULS	F. W. Holbrook-University "3" #4, W1224H SGR, 2759 KB Tops: Ru 540, Sal 980, Ca 2905, BC 4937
52	13	19	ULS	Cities Service Petroleum-University BK #1, W2586L SGR, 2802 KB Tops: Ru 640, Sal 1020, Ca 3100, BC 5050

Well data: Loving County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
53	14	19	ULS	Burleson and Huff-State #1, A1723G SGR, est. 2786 KB Tops: Ru 590, Sal 1040, Ca 3010, BC 4945
54	18	19	ULS	Forest Oil-University Lands "O" #1, W4418H SGR, 2818 KB Tops: Ru 615, Sal 1015, Ca 3395, BC 5050
55	3	27	PSL	Humble-J. C. Arrington #1, W7956E SGR, n.a. Tops: Ru 500, Sal 950, Ca 2665, BC 4655
56	2	C-27	PSL	Mangaslag Inc.-State #1, W8325C SGR, 2875 KB Tops: Ru 505, Sal 940, Ca 2650, BC 4625
57	75	1	W&NW	McKinney and Leonard-Pierce #1, W9452B SGR, n.a. Tops: Ru 490, Sal 900, Ca 2550, BC 4580
58	42	1	W&NW	Humble-W. D. Johnson #11, W9822C SGR, 2791 KB Tops: Ru 610, Sal 1050, Ca 2800, BC 4854
59	84	33	H&TC	Knickerbocker Operating-Hazel #1, W9126E SGR, 2702 KB Tops: Ru 135, Sal 570, Ca 2185, BC 4210
60	80	33	H&TC	Jack S. Reaves-Sue Smith #1, W4168K SGR, 2673 KB Tops: Ru 890, Sal 1255, Ca 2035, BC 4195
61	77	33	H&TC	Jack S. Reaves-Hammarlund #1, W3507K SGR, 2664 KB Tops: Ru 925, Sal 1415, Ca 2055, BC 4240
M	23	C-26	PSL	Pinal Dome Oil-Means #1, ---- SPL, 3247 GL Tops: Ru 550, Sal 920, Ca 3000, BC 4990

Well data: Pecos County, Texas

Ref. no.	Location Sec.	Location Blk.	Location Survey	Operator, lease, well number, log reference number and log type, elevation
1	5	C-3	PSL	Socony Mobil Oil-Wayne Moore et al. #1, W1325M SGR, 2597 DF Tops: Ru 1835, Sal 2150, Ca 2975, BC 4738
2	7	C-3	PSL	Sun Oil-Hodge #2, W354G SGR, 2572 KB Tops: Ru 1880, Sal 2230, Ca 3200, BC 4812
3	26	C-2	PSL	American Trading and Production Corp.-Max D. Shaffrath et al. #1, W1995H SGR, 2712 KB Tops: Ru 1108, Sal 1610, Ca 3568, BC 5148
4	29	C-2	PSL	Ângeo Oil and Gas-W. J. Worsham et al. #1, W919G SGR, 2697 KB Tops: Ru 1960, Sal 2190, Ca 3518, BC 5150
5	18	C-2	PSL	George F. Thagard-Thagard Fee #1, W1818G SGR, 2633 KB Tops: Ru 1960, Sal 2215, Ca 3128, BC 4810
6	18	48	T&P T.8S.	Mobil Oil-Weatherby #2, W1970L SGR, 2754 KB Tops: Ru 1555, Sal 1800, Ca 3870, BC 5255
7	19	48	T&P T.8S.	Socony Mobil Oil-Kathleen J. Moore #1, W9775E SGR, 2770 KB Tops: Ru 835, Sal 1290, Ca 3820, BC 5231
8	20	48	T&P T.8S.	Socony Mobil Oil-Ivy B. Weatherby #4, W2333M SGR, 2759 DF Tops: Ru 950, Sal 1410, Ca 3645, BC 5221
9	32	48	T&P T.8S.	Patoil Corp. et al.-J. H. McIntyre #2, W353K SGR, 2797 KB Tops: Ru 1060, Sal 1500, Ca 3795, BC 5320
10	21	48	T&P T.8S.	Gulf-R. B. Cross et al. #1A-P, W2003L SGR, 2766 KB Tops: Ru 1220, Sal 1680, Ca 3540, BC 5240

Well data: Pecos County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
11	15	48	T&P T.8S.	Hankamer and Kirklin-Athey #1, W7297D GR-EL, 2732 KB Tops: Ru 1860, Sal 2250, Ca 3440, BC 5200
12	24	48	T&P T.8S.	Sun Oil-J. H. McIntyre #1, A92K GR, 2737 KB Tops: Ru 2008, Sal 2530, Ca 3353, BC 5194
13	38	49	T&P T.8S.	Fred A. Davis-Mendel #1-38, A8700C GRN, 2828 RT Tops: Ru 985, Sal 1455, Ca 3725, BC 5380
14	48	49	T&P T.8S.	Gregg Oil-H. D. Mendel #1, W212H SGR, n.a. Tops: Ru 1135, Sal 1615, Ca 3750, BC 5355
15	101	1	H&TC	Joseph I. O'Neill, Jr.-Popham Land and Cattle Co. #1, W1125L SGR, 2954 KB Tops: Ru 995, Sal 1440, Ca 3572, BC 5155
16	19	49	T&P T.9S.	Fred A. Davis-Ammer #1, W8663C SGR, 2935 KB Tops: Ru 1157, Sal 1555, Ca 3600, BC 5187
17	16	49	T&P T.9S.	Davis, Chambers, Kennedy and Sutton-Mendel #1-16, W8943A SGR, 2878 KB Tops: Ru 1520?, Sal 1940, Ca 3654, BC 5217
18	16	49	T&P T.9S.	Jack S. Reaves-Mendel #1-16, W385K SGR, 2873 KB Tops: Ru 1670, Sal 2066, Ca 3660, BC 5203
19	10	49	T&P T.9S.	Turnkey Drilling-Mendel #1-10, W136G SGR, n.a. Tops: Ru 1387, Sal 1870, Ca 3700, BC 5272
20	26	49	T&P T.9S.	M and M Drilling-Mendel #1-26 A9344E GRN, est. 2943 KB Tops: Ru 1610, Sal 2000, Ca 3640, BC 5210

Well data: Pecos County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
21	18	48	T&P T.9S.	Fred A. Davis, Chambers, Kennedy and Sutton-Mendell #1-18, A8698E GRN, 2895 KB Tops: Ru 1775, Sal 2255, Ca 3627, BC 5250
22	24	48	T&P T.9S.	Romack Drilling-Mendel #1-24, W2G SGR, 2939 KB Tops: Ru 1910, Sal 2335, Ca 3432, BC 5248
23	5	51	T&P T.10S.	Shell Oil-Hershenson "5" #1, W2773K SGR, 3293 DF Tops: Ru 1110, Sal 1618, Ca 3803, BC 5353
24	7	51	T&P T.10S.	Atlantic-Willbank-Hershenson Gas Unit #1, W895H SGR, est. 3235 datum 22 ft. above GL Tops: Ru 980, Sal 1440, Ca 3667, BC 5195
25	22	51	T&P T.10S.	Gulf-Fulcher et al. State #1, A1439E GRN, n.a. Tops: Ru 900, Sal 1380, Ca 3650, BC 5215
26	9	51	T&P T.10S.	Atlantic-Gallaher Estate #1, W1339L SGR, est. 3243 KB Tops: Ru 990, Sal 1450, Ca 3560, BC 5118
27	8	50	T&P T.10S.	Atlantic-Lucas State #1, W674L SGR, 3140 KB Tops: Ru 955, Sal 1380, Ca 3460, BC 5008
28	29	50	T&P T.10S.	Tom Brown Drilling, May and Williams-R. H. Hayter #1, W9951D SGR, 3204 KB Tops: Ru 1220, Sal 1617, Ca 3510, BC 5030
29	31	49	T&P T.10S.	Pure Oil-Fraser #1-A, 438C EL, n.a. Tops: Ru 1150?, Sal 1600, Ca 3530, BC 5040
30	20	49	T&P T.10S.	Jake Lawless Drilling-C. M. Caldwell et al. #1, W1754L SGR, 3177 KB Tops: Ru 1132, Sal 1500, Ca 3450, BC 4947

Well data: Pecos County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
31	16	48	T&P T.10S.	O. P. Haschke and Zapata Drilling-Olds, Cecil, Wooten #1, A5527D GRN, 3046 KB Tops: Ru 1405, Sal 1780, Ca 3305, BC 4952
32	133	11	GH&SA	Humble-L. W. Stone #1, A8963D GRN, 3578 KB Tops: Ru 1005, Sal 1310, Ca 3540, BC 5095
33	45	11	GH&SA	Santana Petroleum-Cartledge State #1, W596H SGR, 3523 KB Tops: Ru 904, Sal 1257, Ca 3025, BC 4540
34	203	3	T&P	Pure Oil-Harrison #1, W344C EL, 3507 RDB Tops: BC 4270
35	137	3	T&P	TXL Oil et al.-Pecos Fee #1, W1466H SGR, 3361 KB Tops: Ru 855, Sal 1370, Ca 2510, BC 3910
36	26	3	T&P	Stanolind Oil and Gas-State of Texas A #1, W2658D GR-EL and Scout Report, 3052 RDB Tops: Ru 1455, Sal 1690, Ca 3350, Capitan Ls.? 3542
37	100	OW	GC&SF	Stanolind Oil and Gas-I. T. Pryor #1, A2396C GRN, 3098 RDB Tops: Ru 1335, Sal 1710, Ca 3220, BC 4210
38 and 39				Not used
40	7	A	GC&SF	Hunt Oil-Elsinore Royalty #56, W3144L GR-EL, 3479 KB Tops: Ru 1225, Sal 1620, Ca 2305? 2565?, BC 3875
41 - 47				Not used
48	52	8	H&GN	H. T. Porter Drilling-Blaydes #1, W2554K SGR, n.a. Tops: Ru 1715, Sal 2200, Ca 3055, BC 4550? 4665?

Well data: Pecos County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
49 - 51				Not used
52	118	8	H&GN	Continental Oil-E. E. Bonebrake 118 #1, W739H SGR, 2581 KB Tops: Ru 1610, Sal 1960, Ca 3050?, BC 4300
53 - 59				Not used
60	59½	OW	E. Hood	Brahaney, Leed and Zoller-Maxson #1, W1171L SGR, 2600 KB Tops: Ru 1830, Sal 2340, Ca 3155, BC 4832
61	117	OW	GC&SF	Inman and Swink-Splawn #1, W1830L SGR, 2628 KB Tops: Ru 1800, Sal 2220, Ca 3100, BC 4775
62	44	OW	T&P	Socony Mobil Oil-Athey Unit #1, W2496K SGR, 2678 KB Tops: Ru 1710, Sal 2050, Ca 3148, BC 4730
63	48	OW	TM RR	Socony Mobil Oil-Effie Potts Sibley #1, W2856L SGR, 2681 KB Tops: Ru 1765, Sal 2150, Ca 3035, BC 4710
64	51	OW	TM RR	Atlantic-Roxie Neal 51 #1, W3519H SGR, 2660 KB Tops: Ru 1900, Sal 2190, Ca 3100, BC 4615
65	43	OW	TM RR	Atlantic-J. O. Neal "43" #1-A, W4094K SGR, 2691 KB Tops: Ru 1765, Sal 2155, Ca 3175, BC 4810
66	45	OW	TT RR	Humbel-Effie Potts Sibley #2, W218L SGR, 2695 KB Tops: Ru 1820, Sal 2270, Ca 3070, BC 4750
67	16	OW	F. M. Hoffman Grantee	Gulf-H. F. Raynolds Trust "A" #1, W1488M SGR, 2692 KB Tops: Ru 1890, Sal 2250, Ca 3380, BC 4715

Well data: Pecos County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
68	41	OW	TT RR	Sun Oil-James Neal #8, W3962L SGR, 2706 KB Tops: Ru 1872, Sal 2260, Ca 3210, BC 4755
69	40	OW	TT RR	B. M. Hanson-W. M. Palmer, Jr. #1, W2527M SGR, est. 2699 DF Tops: Ru 1855, Sal 2270, Ca 3200, BC 4770
70	28	OW	TC RR	May and Williams and Tom Brown Drilling-Boydston Estate #1, W910L SGR, 2742 KB Tops: Ru 2025, Sal 2445, Ca 3525, BC 5070
71	17	OW	TC RR	Ralph Lowe-Jim Neal #1, W9116E SGR, 2846 KB Tops: Ru 1720, Sal 2105, Ca 3335, BC 4860
72	70	OW	C. M. Foster	Continental Oil-E. E. Lynch #1, A2743D GRN, 2884 KB Tops: Ru 1625, Sal 2000, Ca 2830, BC 4460
73	30	142	T&ST.L RR	Marcum Drilling-Roxie Neal #1, W2587H SGR, 2703 KB Tops: Ru 1980, Sal 2370, Ca 3230, BC 4365
74	2	115	GC&SF	Pure Oil-W. C. Tyrrell #1, W2597L SGR, 2800 Surface Casing Flange Tops: Ru 1685, Sal 1980, Tansill 2710, Yates 2990, El Capitan (Seven Rivers?) 3385, Lamar Ls. Member of Bell Canyon Formation 4700
75				Not used

Well data: Reeves County, Texas

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
1	12	58	T&P T.1S.	Continental Oil-G. E. Ramsey, Jr. 12 A #1, W1869G SGR, 2901 KB Tops: Ca 1065, BC 2620
2	31	57	T&P T.1S.	Continental Oil-TXL "31" #3, W3843L SGR, 2957 KB Tops: Ca 1050, BC 2615
3	17	57	T&P T.1S.	Texaco-Reeves "E" Fee #2, W3601H SGR, 2851 KB Tops: Ru 100, Sal 620?, Ca 1090, BC 2690
4	29	57	T&P T.1S.	Gulf-TXL "BL" (NCT-B) #4, W4098H SGR, 2875 KB Tops: Spud in Ru, Sal 315?, Ca 1100, BC 2655
5	22	57	T&P T.1S.	Ford Chapman-Red Bluff #1-22, W4205K GR, n.a. Tops: Ca 1195, BC 2765
6	26	57	T&P T.1S.	J. M. C. Ritchie-Red Bluff Water Power Dist. 26 #1, W4201K SGR, 2846 KB Tops: Ca 1300, BC 2870
7	14	58	T&P T.2S.	Patoil Corp.-Garton #1, W325M SGR, 3017 KB Tops: Ca 955, BC 2483
8	36	58	T&P T.2S.	American Trading and Production-Antone Estate State #1, W3477L SGR, 2955 KB Tops: Ca 1120, BC 2518
9	8	57	T&P T.2S.	J. E. H. Oils-Olson #1, W3219H SGR, 2878 KB Tops: Ru 517, Sal 905, Ca 1110, BC 2600
10	41	57	T&P T.2S.	Texaco-Reeves "AA" Fee #2, W4231H SGR, n.a. Tops: Ru 130?, Sal 764, Ca 1500, BC 2857
11	27	57	T&P T.2S.	Gulf-TXL NCT-A #2-CB, W8922D SGR, 3023 KB Tops: Ca 1390? 1540?, BC 2943
12	18	56	T&P T.2S.	Humble-Sally Wynne Reynaud #5, W3246M SGR, 2824 KB Tops: Ca 1400, BC 2973

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
13	18	56	T&P T.2S.	Humble-Sallie Wynne Reynaud #4, W3235G SGR, 2825 KB Tops: Ru 80?, Sal 415?, Ca 1475, BC 3005
14½	41	56	T&P T.2S.	Texaco-Reeves "AG" Fee #1, W3857K SGR, 2852 KB Tops: Ru 445, Sal 830?, Ca 1500, BC 3131
14	40	56	T&P T.2S.	Texaco-State of Texas "EX" #1, W4040L SGR, 2862 KB Tops: Ru 430, Sal 795, Ca 1470, BC 3150
15	34	56	T&P T.2S.	TXL Oil-State Northrup et al. #1, W1221K SGR, n.a. Tops: Ru 610, Sal 990, Ca 1550, BC 3315
16	14	56	T&P T.2S.	Texaco-Reeves "AG" Fee #2, W3989H SGR, 2873 KB Tops: Ru 420, Sal 845, Ca 1415, BC 3158
17	2	45	PSL	Hill and Meeker-Hill State "2" #1, A9860C GRN, 3069 DF Tops: Ru 670, Sal 976?, Ca 1240, BC 2638
18	31	57	T&P T.3S.	Vaught Drilling Co. and Gulf Oil-TXL #1, A9106E GRN, 3158 KB Tops: Ru 535, Sal 1020, Ca 1610, BC 2910
19	32	57	T&P T.3S.	Gulf-TXL BW #1, W9135C SGR, 2997 KB Tops: Ru 320?, Sal 560?, Ca 1605, BC 3148
20	9	57	T&P T.3S.	Gulf-TXL (HCT-A) BZ #1, W9121D SGR, 3129 DF Tops: Ru 670, Sal 964?, Ca 1505, BC 2980
21	45	57	T&P T.3S.	Wilson Germany, Paul Page and Gulf Oil-TXL "BX-45" #1, W8986A SGR, 3181 KB Tops: Ru 460, Sal 763, Ca 1630, BC 3082

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
22	37	57	T&P T.3S.	Gulf-TXL "BU" (NCT-A) #1, W9065D SGR, 2981 KB Tops: Ru 340?, Sal 640?, Ca 1535, BC 3078
23	21	56	T&P T.3S.	John K. Skaggs and Gulf Oil-Gulf TXL #1-21, W8744A SGR, 2930 KB Tops: Ru 695, Sal 980?, Ca 1675, BC 3318
24	11	56	T&P T.3S.	Texaco-Reeves "AK" Fee #1, W4386H SGR, est. 2883 KB Tops: Ca 1690, BC 3264
25	7	56	T&P T.3S	O. K. Oil and Gulf Oil-TXL "BP" #1, W4384H SGR, 2872 KB Tops: Ru 735, Sal 1070, Ca 1780, BC 3283
26	29	56	T&P T.3S.	Gulf-TXL "BR" #1, W9152A SGR, n.a. Tops: Ca 1750, BC 3540
27	5	C-20	PSL	McKinney, May and Williams-O. Dale Smith #1, W1158G SGR, 2789 KB Tops: Ca 1940, BC 3390
28	8	C-20	PSL	May and Williams-Bell #1, W2996K SGR, 2830 KB Tops: Ru 640, Sal 1090, Ca 1700, BC 3630
29	6	55	T&P T.3S.	Ralph H. Meriwether-Baker #1, W2932H SGR, 2870 KB Tops: Ru 705? 815?, Sal 1150?, Ca 1800, BC 3730
30	10	2	H&GN	Texas Pacific Coal and Oil-Ollie Anderson #1, W1710L SGR, 2732 KB Tops: Ru 945, Sal 1140, Ca 1970, BC 3780
31	34	2	H&GN	Hayes and V-T Drilling-Mansanto-Bell #1, W8924A SGR, 2722 KB Tops: Ru 425, Sal 850, Ca 1910, BC 4070
32	15	53	PSL	F. R. Jackson-Henderson Estate #1, W8537E SGR, n.a. Tops: Ru 335, Sal 803?, Ca 1560, BC 2831

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
33	7	56	PSL	Francis K. Campbell and H. L. Hawkins-Howard B. Cox A #1, W6866B GR-EL 3240 RT Tops: Ru 715, Sal 1120, Ca 1775
34	27	56	PSL	Francis K. Campbell-P. B. Wilson #1, W4306A GR-EL, 3257 KB Tops: Ru 1110, Sal 1400, Ca 2170, BC 3420
35	19	55	T&P T.4S.	Fred A. Davis-TXL #1-19, W8558A SGR, 2887 KB Tops: Ru 710, Ca 2530, BC 3932
36	10	55	T&P T.4S.	TXL Oil-Reeves State A #2, W1844K SGR, 2849 KB Tops: Ru 1100, Sal 1413, Ca 2185, BC 3945
37	10	55	T&P T.4S.	TXL Oil-Reeves State A #1, W8375E SGR and W8375D EL, 2823 KB Tops: Ca 2185, BC 3963
38	3	54	T&P T.4S.	Texaco-Reeves "X" Fee #1, W2961M SGR, 2815 KB Tops: Ru 585, Sal 1100, Ca 2072, BC 4095
39	12	54	T&P T.4S.	Reeves, Grice and McCall-Clateworthy State #1, W1344K SGR, est. 2822 KB Tops: Ru 1340, Sal 1745, Ca 2330, BC 4405
40	33	54	T&P T.4S.	Wilson Germany, Paul Page and Gulf Oil-TXL "33" #1, W9065E SGR, 2700 KB Tops: Ru 1485, Sal 1820, Ca 2480, BC 4173
41	6	3	H&GN	Ralph Lowe-Reeves State #1, W4182H SGR, 2741 KB Tops: Ru 1388, Sal 1880, Ca 2320, BC 4380
42	5	59	PSL	Francis K. Campbell-R. L. Umbenhour #1, A2793D GRN, 3274 KB Tops: Ru 800, Sal 1200, Ca 2135, BC 3250
43	23	59	PSL	Ralph E. Fair-Camp #1, W871M SGR, 3070 KB Tops: Ru 700, Sal 1100, Ca 2050, BC 3157

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
44	31	58	PSL	H. L. Hunt Oil-Grider #1, A406B GRN, 3046 KB Tops: Ru 998, Sal 1380, Ca 2245, BC 3250
45	17	58	PSL	Ibex Co.-Bush State #1, A4263D GRN, n.a. Tops: Ru 1380, Sal 1680, Ca 2315, BC 3410
46	9	58	PSL	T. M. Evans-Miller State #1, A8331E GRN, 3137 Casing Head Tops: Ru 1540, Sal 1870, Ca 2585?, BC 3690
47	40	58	PSL	Hunt Oil-Fite #1, 594A GR-EL, est. 3012 RT Tops: Ru 930, Sal 1385, Ca 2450
48	17	55	T&P T.5S.	Gulf-TXL "CG" #1, W9202E SGR, 3005 KB Tops: Ru 1080, Sal 1460, Ca 2560, BC 3720
49	2	55	T&P T.5S.	TXL Oil-Halamicek State #1, W63G SGR, 2857 KB Tops: Ru 1480, Sal 1850, Ca 2390, BC 3965
50	27	C-18	PSL	Continental Oil-T. A. Kirk #1, W8467A SGR, 2684 KB Tops: Ru 1720, Sal 2090, Ca 2580, BC 4130
51	7	C-19	PSL	Cities Service Petroleum-State "A" #1, W1481M SGR, 2663 KB Tops: Ru 1832, Sal 2150, Ca 2530, BC 4155
52	60	4	H&GN	L. D. Crumly, Jr.-Thornton #1, W1108L SGR, 2645 GL Tops: Ru 1732, Sal 2050, Ca 2495, BC 4300
53	57	4	H&GN	Frazier and Hendon-Tom S. Flack #1, W8746E SGR, 2650 KB Tops: Ru 1780, Sal 2100, Ca 2597, BC 4340

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
54	13	71	PSL	W. B. Yarborough-Caldwell #1, W8651B SGR, 3186 KB Tops: Ru 624, Sal 1150, Ca 2100, BC 3360
55	5	70	PSL	Continental Oil-Warren Wright #1, W2129A GR-EL, est. 2195 KB Tops: Ru 1168, Sal 1620, Ca 2200, BC 3430
56	W. B. King Survey			Cree Oil and Armour Prop.-Von Trotha #1, W9050D SGR, 2878 KB Tops: Ru 1230, Sal 1616, Ca 2816, BC 3850
57	24	C-17	PSL	Gulf Oil and Phillips Petroleum-State School Board MM #3, A4166D GRN, 2846 KB Tops: Ru 1700?, Sal 1950?, Ca 2710, BC 3810
58	13	72	PSL	Gulf-W. L. Todd Trustee et al. #1, W8655C GR-EL and Scout Report, 2812 KB Tops: Ru 1718, Sal 2150, Ca 2970, BC 4035
59	5	C-8	PSL	Pico Drilling-T&P RR #1, W1387M SGR, 3016 KB Tops: Ru 1604, Sal 2000, Ca 2690, BC 3900
60	34	6	H&GN	American Trading and Production-State B. Graebner #1-34, W1974M SGR, 2587 KB Tops: Ru 1295, Sal 1730, Ca 3020, BC 4882
61	33	6	H&GN	Texas Crude Oil-Finklea "33" #1, W499H SGR, 2577 KB Tops: Ru 1385, Sal 1870, Ca 3075, BC 4920
62	27	C-7	PSL	McBee Oil-Continental Regan #1, W1642G SGR, 2581 KB Tops: Ru 1115, Sal 1610, Ca 3079, BC 4846
63	17	C-6	PSL	Gulf-Bertha Hoefs et al. #1, W1144K SGR, 2567 KB Tops: Ru 736, Sal 1200, Ca 2911, BC 4885

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
64	6	7	H&GN	Hissom Drilling-Hathaway #1, W3616M SGR, 2600 KB Tops: Ru 1012, Sal 1440, Ca 3105, BC 5044
65	24	7	H&GN	Gulf-J. C. Trees Estate et al. #4, W3888L SGR, 2563 KB Tops: Ru 925, Sal 1350, Ca 3075, BC 4893
66	4	C-4	PSL	A. J. Vogel et al.-J. N. Rape #7, W3012G SGR, 2651 KB Tops: Ru 1000, Sal 1430, Ca 3168, BC 5020
67	2	C-4	PSL	American Trading and Production-J. D. Bodkins et al. #2, W1240L SGR, 2639 KB Tops: Ru 1012, Sal 1427, Ca 3370, BC 4974
68	28	C-3	PSL	Tom Brown Drilling-McFarland #1, W1421G SGR, 2531 KB Tops: Ru 868, Sal 1300, Ca 3243, BC 4930
69	19	C-3	PSL	Atlantic-J. C. Trees Estate #1, W3868K SGR, 2554 KB Tops: Ru 1150, Sal 1555, Ca 3152, BC 4847
70	9	C-3	PSL	Gulf-Minnie McCarter #1, W2665G SGR, 2581 KB Tops: Ru 1048, Sal 1460, Ca 3100, BC 4866
71	6	C-5	PSL	Holbrook, Inc.-J. M. Rape #1, W1352K SGR, est. 2675 KB Tops: Ru 1008, Sal 1467, Ca 3330, BC 5135
72	11	C-5	PSL	Healey, Le Blond and Tidewater-Goodrich #1, W1489K SGR, 2677 KB Tops: Ru 925, Sal 1375, Ca 3350, BC 5079
73	13	C-5	PSL	Sun Oil-Overton Black #1, W4400G SGR, 2673 KB Tops: Ru 860, Sal 1370, Ca 3288, BC 5051

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
74	11	50	T&P T.7S.	David Fasken-Mobil Young "11" #1, W2674G SGR, 2705 KB Tops: Ru 890, Sal 1400, Ca 3315, BC 5082
75	36	50	T&P T.7S.	Tom Brown Drilling Rape #1-36, W1913L SGR, 2749 KB Tops: Ru 999, Sal 1585, Ca 3463, BC 5173
76	24	51	T&P T.7S.	Sinclair-Jim Young et al. #1, W1340K SGR, 2653 GL Tops: Ru 860?, Sal 1350, Ca 3304, BC 5081
77	31	51	T&P T.8S.	Gulf-Collier #1, 1146E GR-EL, 2835 RT Tops: Ru 1010, Sal 1680, Ca 3560, BC 5230
78	6	50	T&P T.8S.	Tom Brown Drilling, Healy and LeBlond-J. B. Young #3, W1722L SGR, 2778 KB Tops: Ru 740, Sal 1290, Ca 3505, BC 5130
79	27	50	T&P T.8S.	Texas Crude Oil-Gillespie "27" #1, W1332K SGR, 2818 KB Tops: Ru 1022, Sal 1540, Ca 3460, BC 5130
80	97	1	H&TC	Pearl B. Jackson-Pearl B. Jackson Fee #1, W9723B SGR, 2964 KB Tops: Ru 1130, Sal 1635, Ca 3675, BC 5260
81	7	58	T&P T.7S.	Shell-Shell Continental #1, A1565K GRN and W3119K EL, 3445 DF Tops: Ru 850, Sal 1210, Ca 1950, BC 3075
82	35	58	T&P T.7S.	TXL Oil-Reeves "K-T" Fee #1, W9631C EL and Scout Report, 3626 KB Tops: Ru 962, BC 3486
83	44	56	T&P T.7S.	TXL Oil-Atlantic State #1, W8977C GR-EL, 3171 KB Tops: Ca 2620, BC 3940

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
84	34	56	T&P T.7S.	Walling and Chandler-Earl Vest #1, W5370B EL, 3093 KB Tops: Ru 1330, Sal 1800, Ca 2510, BC 3965
85	19	C-10	PSL	M. D. Bryant-Armstrong #1, A3865A GRN, 2746 KB Tops: Ru 1990, Sal 2540, Ca 3258, BC 4755
86	198	13	H&GN	John F. Camp-Mrs. Elmer Wadley #1, W2131G SGR, 2650 KB Tops: Ru 1620, Sal 2120, Ca 3014, BC 4785
87	197	13	H&GN	McElroy Ranch-Waltrip #1, W9328A SGR, 2666 KB Tops: Ru 1702, Sal 2290, Ca 3033, BC 4817
88	272	13	H&GN	Sun Oil-Terrill State Unit #1, W4133H SGR, 2682 KB Tops: Ru 1058, Sal 1510, Ca 3175, BC 4935
89	252	13	H&GN	Blair Petroleum-Carrie Eisenwine #1, W2650M SGR, 2712 DF Tops: Ru 1143, Sal 1630, Ca 3245, BC 5000
90	238	13	H&GN	W. Clyde Ikins and R. B. Keljikan-Rampy #1, A5257C GRN, 2911 RT Tops: Ru 1040, Sal 1610, Ca 3425, BC 5015
91	326	13	H&GN	El Paso Natural Gas-Hoefs #1, W1868M GR, 3151 KB Tops: Ru 987, Sal 1520, Ca 3520, BC 5135
92	125	13	H&GN	Mac Jones-Weinacht #1, W4179G SGR and W4178M EL, 3021 KB Tops: Ru 1752, Sal 2144, Ca 3112, BC 4545
93	122	13	H&GN	Standard Oil of Texas-Balmorhea Ranches 1 #2, W8773E GR-EL, 3156 KB Tops: Ca 2875, BC 4182

Well data: Reeves County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
94	100	13	H&GN	Mac Jones-Wynne #1, W3993L SGR, 3050 KB Tops: Ru 1753, Sal 2210, Ca 3148, BC 4505
95	50	13	H&GN	Jack S. Reaves-Albert Moore #1, W1998G SGR, 3119 KB Tops: Ru 1985, Sal 2420, Ca 3150, BC 4678
96	34	13	H&GN	Standard Oil of Texas-L. A. Weinacht #1, W2853L EL, 3199 KB Tops: Ru 1823, Sal 2048, BC 4475
97	52	13	H&GN	Brandywine Oil-Balmorhea Ranch #1, W4147M SGR, 3232 KB Tops: Ru 1908, Sal 2370, Ca 3000, BC 4510
98	8	13	H&GN	Burford and Sams-Kingston #1, W3738H SGR, 3415 KB Tops: Ru 1800, Sal 2210, Ca 2890, BC 4602
A	146	1	H&TC	Sun Oil-Balmorhea Ranches #2, ---- Scout Report, 2926 DF Tops: Ru 895, BC 5190
B	176	1	H&TC	Sun Oil-Balmorhea Ranches #1, ---- Scout Report, 2904 DF Tops: Ru 950, BC 5195

Well data: Ward County, Texas

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
1	67	33	H&TC	Wilson Exploration-D. D. Feldman #2-67, W9599C SGR, 2648 KB Tops: Ru 590, Sal 1015, Ca 2395, BC 4540
2	37	33	H&TC	Hamm and O'Brien-Miller #1, W139G SGR, 2562 KB Tops: Ru 1790, Sal 2240, Ca 3015, BC 4782
3	31	33	H&TC	Continental Oil-F. M. Scott #1, W3575D GR-EL and Scout Report, 2549 KB Tops: Ru 1255, BC 4824
4	18	SF 7082, G. G. Houston Survey		Gold Metals Cons. Mining and Santana Petroleum-Houston Heirs #1, W1692L SGR, 2507 KB Tops: Ru 1070, Sal 1450, Ca 2990, BC 4815
5	71	1	P. A. Black	Kay Kimbell-Dunagan #1, W537G SGR, n.a. Tops: Ru 900, Sal 1290, Ca 2535, BC 4640
6	36	1	W&NW	Continental Oil-Mize and Gaskill #1, W8383B SGR, 2755 KB Tops: Ru 643, Sal 1060, Ca 2745, BC 4870
7	22	1	W&NW	Fred A. Davis-Jerry Covington #1, W8955B SGR, 2765 KB Tops: Ru 632, Sal 1070, Ca 3070, BC 5017
8	11	1	W&NW	Forrest Oil-G. W. Riley #1, W1458L SGR, 2669 KB Tops: Ru 640, Sal 1040, Ca 2900 BC 4892
9	228	34	H&TC	Pure Oil-C. L. Monroe #1, W2192G SGR, 2608 Surface Casing Flange Tops: Ru 1540, Sal 1830, Ca 2850, BC 4620
10	209	34	H&TC	Chambers and Kennedy-Clark #1, W6192C GR, est. 2582 KB Tops: Ru 690, Sal 1105, Ca 2670?, BC 4720

Well data: Ward County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
11	191	34	H&TC	Argo Oil-Olson #B-2, A2501B GRN, 2707 KB Tops: Ru 700, Sal 1155, Ca 2940, BC 4917
12	191	34	H&TC	Argo Oil-Argo Olson #1-D, A2822D GRN, 2680 RT Tops: Ru 575, Sal 1085, Ca 2975, BC 4920
13	165	34	H&TC	Sun Oil-Lois McDaniel #1, W2729G SGR, 2790 KB Tops: Ru 723, Sal 1100, Ca 3060, BC 5025
14	165	34	H&TC	H. L. Brown, Jr. and Clem E. George-Fritz #1, W1944G SGR, 2780 KB Tops: Ru 740, Sal 1110, Ca 3040, BC 5020
15	163	34	H&TC	Liedtke '60 Ltd.-Chapman #1, W719H SGR, 2769 KB Tops: Ru 700, Sal 1080, Ca 3107, BC 5060
16	148	34	H&TC	Liedtke '60 Ltd.-Cynthia Monroe #1, W503H SGR, 2751 KB Tops: Ru 702, Sal 1080, Ca 3090, BC 5035
17	127	34	H&TC	Harvey L. Hurley-Wilson #1, W65L SGR, 2606 DF Tops: Ru 615, Sal 1015, Ca 3110, BC 5035
18	108	34	H&TC	Eastland Drilling-G. T. Hall #1, W1875L SGR, 2619 KB Tops: Ru 1720, Sal 2050, Ca 2950?, BC 4992
19	98	34	H&TC	Sunray Mid-Continent Oil-A. L. Herring #1, W110M SGR, 2647 KB Tops: Ru 1620, Sal 1930, Ca 2940, BC 5047
20	99	34	H&TC	T. F. Hodge-Edwards Lumber Co. #1, W667G SGR, 2628 KB Tops: Ru 1553, Sal 1970, Ca 2948, BC 5050

Well data: Ward County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
21	94	34	H&TC	T. F. Hodge-Anna Herring #2, W1258L SGR, 2625 KB Tops: Ru 1600, Sal 2050, Ca 3050, BC 5026
22	87	34	H&TC	Norwood Drilling and Amarillo Oil-Lura Newman #1, W826M SGR, 2587 KB Tops: Ru 920, Sal 1345, Ca 2895, BC 4930
23	71	34	H&TC	Hill and Meeker-Belo "71" #1, W43G SGR, 2575 KB Tops: Ru 880, Sal 1295, Ca 2978, BC 4917
24	70	34	H&TC	Harper, Huffman and Hissom-Triple "H" #1, W994H SGR, 2509 KB Tops: Ru 788, Sal 1218, Ca 2877, BC 4944
25	57	34	H&TC	Harlan Production-R. H. Dorsey #1, W2314L SGR, 2572 KB Tops: Ru 1670, Sal 2180, Ca? 3230, BC 4780
26	23	34	H&TC	Harlan Production-Elliott #3-PW, W2714L SGR, 2541 KB Tops: Ru 805, Sal 1005, Carlsbad 2490
27	38	18	ULS	Charles B. Read-University #1, W2414L SGR, 2788 KB Tops: Ru 726, Sal 1105, Ca 3190, BC 5105
28	30	18	ULS	Texaco-State of Texas DP #1, W9644E SGR, 2797 KB Tops: Ru 755, Sal 1140, Ca 3200, BC 5078
29	19	18	ULS	Pure Oil-University "I" #1, W2221M SGR, 2762 Surface Casing Flange Tops: Ru 725, Sal 1120, Ca 3160, BC 5002
30	14	18	ULS	Texaco-State of Texas DF #1, W9336C SGR, 2727 KB Tops: Ru 770, Sal 1100, Ca 3170, BC 4973

Well data: Ward County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
31	15	18	ULS	Texaco-State of Texas DM #;. W9645D SGR, 2713 KB Tops: Ru 775, Sal 1163, Ca 3150, BC 4977
32	3	18	ULS	Texaco-State of Texas DC #1, W9377D SGR, 2700 KB Tops: Ru 800, Sal 1200, Ca 3042, BC 4935
33	2	18	ULS	Texaco-State of Texas DN #1, W9645E SGR, 2679 KB Tops: Ru 870, Sal 1265, Ca 3060, BC 4913
34	8	18	ULS	Texaco-State of Texas DE #1, W9372B SGR, 2754 KB Tops: Ru 704, Sal 1080, Ca 3110, BC 4948
35	31	17	ULS	Shell-University 17 C #1, W9479D SGR, 2744 KB Tops: Ru 690, Sal 1050, Ca 3030, BC 4950
36	32	17	ULS	Jake L. Hamon-University K #1, W9548B SGR, 2773 KB Tops: Ru 735, Sal 1100, Ca 3183, BC 5040
37	33	17	ULS	Hanley Co.-University "17-33" #1, W9013B SGR, n.a. Tops: Ru 1360, Sal 1650, Ca 3112, BC 5030
38	36	17	ULS	Texaco-State of Texas DO #1, W9637E SGR, 2694 KB Tops: Ru 1052, Sal 1440, Ca 3180, BC 5012
39	24	17	ULS	Ormand Bros. Drilling-University B #1, W647L SGR, 2671 KB Tops: Ru 1750, Sal 2048, Ca 3175, BC 4950
40	16	17	ULS	Ormand Bros. Drilling-Shell University #1, W9836B SGR, n.a. Tops: Ru 1200, Sal 1550, Ca 3280, BC 4955

Well data: Ward County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
41	3	17	ULS	Liedtke '60 Ltd.-Ohio University #1, W75G SGR, 2666 KB Tops: Ru 1655, Sal 2030, Ca 3060, BC 4931
42	88	F	G&MMB&A	Magnolia Petroleum-Geo. Sealy Sec. 88 #1, W8265C SGR, 2705 KB Tops: Ru 1810, Sal 2350, Ca 3485, BC 4320
43 and 44				Not used
45	57	F	G&MMB&A	Socony Mobil Oil-George Sealy "C" #1-57, W9813C SGR, 2680 KB Rops: Ru 1944, Sal 2280
46	44	F	G&MMB&A	Magnolia Petroleum-Geo. Sealy Sec. 44 #3, W8146B SGR, 2693 KB Tops: Ru 1680, Sal 1960
47 - 49				Not used
50	25	16	ULS	Liedtke '58 Ltd. #2-University "25" #1, W1377L SGR, 2600 KB Tops: Ru 1939, Sal 2250
51	17	B-20	PSL	Chambers and Kennedy-Tubb Estate #1, W2168H SGR, 2566 KB Tops: Ru 460, Sal 650, Equivalent of BC 3937?

Well data: Winkler County, Texas

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
1	23	28	PSL	Hissom Drilling-Tennessee Mac #1, A4555A GRN, n.a. Tops: Ru 882, Sal 1270, Ca 3330, BC 5115
2	11	20	ULS	Magnolia Petroleum-Univ. of Texas 39862 #2, W4723B GR-EL, 2805 DF Tops: Ru 780, Sal 1160, Ca 3320, BC 5090
3	11	20	ULS	Magnolia Petroleum-Univ. of Texas #1-39862, A2474E GRN, 2798 RT Tops: Ru 792, Sal 1190, Ca 3325, BC 5071
4	14	20	ULS	Magnolia Petroleum-Texas Univ. #A-1, W4116D GR-EL, 2799 KB Tops: Ru 785, Sal 1180, Ca 3270, BC 5075
5	26	20	ULS	Texaco-State of Texas EA #1, W699H SGR, 2787 KB Tops: Ru 772, Sal 1125, Ca 3240, BC 5072
6	48	20	ULS	Texaco-State of Texas "DH" #1, W9646C SGR, 2771 KB Tops: Ru 720, Sal 1095, Ca 3115, BC 4965
7	5	27	PSL	Diamond Drilling-John Haley #1, W8615D SGR, 2969 KB Tops: Ru 856, Sal 1195, Ca 3230, BC 5065
8	17	27	PSL	Ford Chapman-J. E. Haley #1, W557L SGR, n.a. Tops: Ru 840, Sal 1200, Ca 3305, BC 5010
9	32	27	PSL	Rodman, Noel and Black-Halley 32 #1, W8399E SGR, 2883 KB Tops: Ru 885, Sal 1240, Ca 3250, BC 5092
10	34	27	PSL	Pan American P. C. and Westbrook Thompson Holding-T. G. Hendrick #1, W4049H GR, 2862 KB Tops: Ru 885, Sal 1270, Ca 3100, BC 5005

Well data: Winkler County, Texas (Cont'd)

Ref. no.	Location Sec.	Location Blk.	Location Survey	Operator, lease, well number, log reference number and log type, elevation
11	39	27	PSL	Pan American P. C.-Ruth M. Bakwin #1, W4048L GRN, 2845 KB Tops: Ru 1643, Sal 2040, Ca 3530, BC 4923
12	7	21	ULS	Ralph Lowe-University #1-7, W354L SGR, 2832 KB Tops: Ru 808, Sal 1150, Ca 3430, BC 5162
13	42	21	ULS	Union Oil of Calif.-University #1-42, W3888G SGR, 2765 DF Tops: Ru 703, Sal 1070, Ca 2995, BC 4983
14	43	21	ULS	Tidewater Oil-State of Texas "Q" #1, W9480A SGR, 2752 KB Tops: Ru 706, Sal 1066, Ca 3035, BC 4950
15	40	21	ULS	Phillips Petroleum-University Lands "M" #1, W4231L SGR, 2778 KB Tops: Ru 670, Sal 1050, Ca 3108, BC 5008
16	28	21	ULS	Shell-University #21-A-1, A6065D GRN, 2776 KB Tops: Ru 770, Sal 1160, Ca 3300, BC 5025
17	26	21	ULS	Ralph Lowe-University #2E, A2959D GRN, est. 2770 RT Tops: Ru 2103?, BC 4860?
18	23	21	ULS	Texaco-State of Texas "EC" #1, A325G GRN, 2797 KB Tops: Ru 1673, Sal 1950, Ca 3475, BC 5098
19	17	C-23	PSL	Cities Service Oil-Buttram #1, A8180E GRN, 2896 KB Tops: Ru 1947, Sal 2275, Ca 3990, BC 5000
20	14	C-23	PSL	Cities Service Oil-Tubb B #1, A7997E GRN, est. 2903 KB Tops: Ru 2035, Sal 2395, Ca 3980, BC 5330

Well data: Winkler County, Texas (Cont'd)

Ref. no.	Location Sec.	Blk.	Survey	Operator, lease, well number, log reference number and log type, elevation
21	6	C-23	PSL	General American Oil of Texas-W. P. Edwards "A" #6, W1345G SGR, 2924 KB Tops: Ru 1270, Sal 1600
22	3	74	PSL	Richard Hughes-Leck #1-AH, W762M SGR, 2895 KB Tops: Ru 1270, Sal 1565
23	24	74	PSL	Texas Co.-J. L. Desmond #1, W5397E GR-EL, 2868 KB Tops: Ru 1800, Sal 2110, Equivalent of BC? 5640
24	30	26	PSL	Pan American P. C.-Hendrick Operating Area "G" #1, A1254G GRN, 2864 KB Tops: Ru 1740, Sal 2130, Ca 3650, BC 5175?
25	33	B-5	PSL	Cactus Drilling-Hendrick B #1, W2685H SGR, 2819 DF Tops: Ru 1480, Sal 1760
26	17	B-12	PSL	Skelly Oil-Halley #171, A261K GRN, est. 2754 KB Tops: Ru 818, Sal 1150, Ca equivalent 3303, BC equivalent 4940?
27	10	17	ULS	Jake L. Hamon et al.-University L #1, W9636A SGR, 2745 KB Tops: Ru 843, Sal 1240, Ca 2990, BC 5018
28	71	F	G&MMB&A	Magnolia Petroleum-George Sealy "B" #1-71, W9220E SGR, 2730 KB Tops: Ru 2080?, Sal 2480?, Ca 3565, BC equivalent 4970
29	89	F	G&MMB&A	Magnolia Petroleum-Geo. Sealy Estate Sec. 89 #B-1, W9073D SGR, 2714 KB Tops: Ru 1658, Sal 2015, Ca 3315, BC 4750
30	15	A-56	PSL	Joseph I. O'Neill, Jr.-Goff #1, W3196G SGR, 3054 KB Tops: Ru 1238, Sal 1550, Ca 3070, BC equivalent? 5165