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Feasibility Study of Heavy Oil Recovery in the Permian Basin (Texas and New Mexico)

Topical Report

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By D. K. Olsen and W. I. Johnson

ABSTRACT

This report is one of a series of publications assessing the feasibility of increasing domestic heavy oil production. Each report covers select areas of the United States. The Permian Basin of West Texas and Southeastern New Mexico is made up of the Midland, Delaware, Val Verde, and Kerr Basins; the Northwestern, Eastern, and Southern shelves; the Central Basin Platform, and the Sheffield Channel. The present day Permian Basin was one sedimentary basin until uplift and subsidence occurred during Pennsylvanian and early Permian Age to create the configuration of the basins, shelves, and platform of today. The basin has been a major light oil producing area served by an extensive pipeline network connected to refineries designed to process light sweet and limited sour crude oil. Limited resources of heavy oil (10° to 20° API gravity) occurs in both carbonate and sandstone reservoirs of Permian and Cretaceous Age. The largest cumulative heavy oil production comes from fluvial sandstones of the Cretaceous Trinity Group. Permian heavy oil is principally paraffinic and thus commands a higher price than asphaltic California heavy oil. Heavy oil in deeper reservoirs has solution gas and low viscosity and thus can be produced by primary and by waterflooding. Because of the nature of the resource, the Permian Basin should not be considered a major heavy oil producing area.

EXECUTIVE SUMMARY

This report is one of a series of publications assessing the feasibility of increasing domestic heavy oil production. Each report covers select areas of the United States. This report covers the Permian Basin of West Texas and Southeastern New Mexico which produces limited heavy oil (10° to 20° API gravity) from consolidated reservoir rocks of Permian and Cretaceous Age. There are a few sandstone reservoirs within the Permian Basin, but carbonate rocks are the dominant type of reservoir rock. Toborg Field located on the extreme southern end of the Central Basin Platform of the Permian Basin is the largest heavy oil field in the basin and has been reported to produce about 41,000,000 barrels of oil, however, only part of it is actually heavy oil. With cumulative heavy oil production of only 72,000,000 barrels, of an estimated 160 to 300 million barrels originally in place (OIP), the Permian Basin is a minor heavy oil producing area as compared to California with about 60 billion barrels OOIP. Cumulative oil production in the Permian Basin (light and heavy) is > 24 billion barrels, thus heavy oil is <0.3% of total oil produced. The Cretaceous Trinity Group fluvial sandstone has produced 56 % of the heavy oil produced in the Permian Basin. Because of the mature state of exploration and production in this basin, the discovery of new, significant heavy oil resources is unlikely. Significant oil production by thermal enhanced oil recovery (TEOR) is unlikely because most of the reservoirs are carbonates and thermal recovery from carbonates has not proven to be commercial. Thermal recovery from consolidated sandstones has not proven to be highly economic. Toborg field, a Trinity Group sandstone reservoir, has been waterflooded on 2.5-acre spacing to recover 57% of the estimated OOIP. Much of the oil in Toborg is believed to have migrated upward into the shallower, low-pressure, sandstones during early development of giant Yates Field. Toborg's sandstones were not protected (isolated by cementing the entire production string) from the high-pressure Yates. Much of Toborg's oil is believed to originate as light oil, >20° API. There are conflicting reports on the API gravity of this oil and the range of gravity across the field because only about 500± acres may actually be a productive heavy oil reservoir.

The Permian Basin has been a major light oil producer having an extensive light oil collection and pipeline network going to predominantly light oil refineries. Heavy oil and Alaskan North Slope oil is transported from California as a blend by the All-American pipeline through the Permian Basin to refineries on the Gulf Coast and the Midwest. The basin has an extensive infrastructure supporting extensive primary production, aging and rapidly declining waterfloods, and a growing production from CO_2 enhanced oil recovery projects. The environmental problems and changes from implementation of limited TEOR processes are low because of the anticipated low cumulative heavy oil production and the nature of the resource. The oil in the Permian Basin is principally paraffinic unlike the asphaltic California heavy crudes. Paraffinic crudes command a higher price than asphaltic oils of the same gravity. Within the Permian Basin, there are deep (>5,000 ft) hot reservoirs with significant solution gas in the heavy oil that produce on primary or are waterfloodable. The Permian Basin is anticipated to be a minor heavy oil producer due to the consolidated nature of the reservoir rock, the internal architecture of the reservoirs, the reservoir depth and the nature of the reservoir rock where most reservoirs are carbonates. Horizontal wells and infill wells may contribute to increased recovery of heavy oil resources in the Permian Basin due to better sweep efficiency in waterfloods. The results of this study show that because of the limited potential for major heavy oil development, this basin bears no further investigation of its heavy oil resources. However, significant improvement in the reservoir data could be achieved by obtaining information directly from field operations.

OBJECTIVE AND STRUCTURE OF REPORT

The objectives of this feasibility study are (1) to investigate from secondary data the known heavy oil resources in the Permian Basin of West Texas and New Mexico (Fig. 1, Ward et al., 1986); (2) to screen this resource for potential thermal or other enhanced oil recovery applications; and (3) to evaluate various economic facets that may impact the development of this resource. If the study determines that expansion of production of heavy oil is economically possible by recent advances in technology, recommendations will be made to facilitate the production of this additional resource.

As one of a series of reports on the feasibility of heavy oil recovery in the U.S., this study analyzed the geologic settings of the Permian Basin heavy oil reservoirs and the limited TEOR projects that have been attempted. This limited review of secondary publicly available data attempts to list the constraints to heavy oil production, define the transportation network, and refining capabilities, review environmental restrictions and economic considerations that impact heavy oil development. NIPER's analysis of the secondary field data is included at the end of this report as Table 1. The approach used in this study reviewed the public literature analyzing each geologic unit in each basin for the presence of heavy oil. The analysis started with the oldest sedimentary rocks. Analysis was also conducted on previously published studies (Crysdale and Schenk, 1990) and used the U.S. DOE crude oil database as a source of information on crude oil and their compositions.

Heavy oil as used in this study is defined as having gas-free viscosity of >100 and <10,000 MPas (centipoise, cP) inclusive at original reservoir temperature or a density of 943 kg/m^3 (20° API gravity) to 1,000 kg/m^3 (10° API gravity) inclusive at 15.6° C (60° F) (Group, 1981). This report uses both the geologic terms "system" a chronostatigraphic (rock) term and "period" a geochronometric (geologic time) as a subdivision of the geologic time scale. Average reservoir data is listed in the Appendix and is sparse because the resource does not justify the effort to judiciously pursue the average reservoir data for heavy oil in carbonate reservoirs.

BACKGROUND AND DISCUSSION

The Permian Basin is located in West Texas and Southeastern New Mexico. In Texas and New Mexico, the Midland Basin, Delaware Basin, Eastern Shelf of the Midland Basin, Southern Shelf of the Permian Basin, Northwestern Shelf of the Permian Basin, Central Basin Platform, Kerr Basin, Val Verde Basin, Sheffield Channel, etc. make up the present day Permian Basin (Fig. 1, Ward et al., 1986; and Jones, 1953). Cumulative oil production, light (>20° API gravity) and heavy oil (10° to 20° API gravity), is > 24 billion barrels (Hance, Sharp and Nugent, 1989). This value includes only cumulative oil produced in Railroad Commission Districts 7B, 7C, 8, and 8A. It does not include cumulative oil produced from the New Mexico part of the Permian Basin. Only 72 million barrels (see appendix A, this report) of this total (< 0.3%) is heavy oil. Most of the productive formations within the Permian Basin are consolidated formations principally carbonates (limestone or dolomite) with a few sandstone reservoirs, although the largest heavy oil reservoir is sandstone (Fig. 2, Toborg field). Most of the oil producing formations are Permian and younger. A stratigraphic column across the Permian Basin is shown in (Fig. 3).

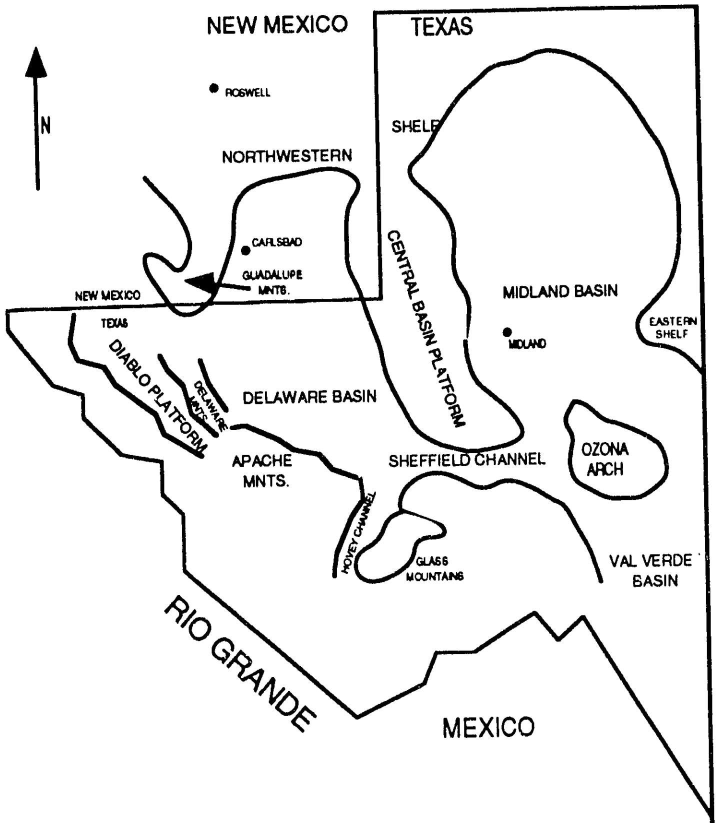

FIGURE 1. - Index map of principal structural elements in the Permian Basin (Ward et al., 1986).

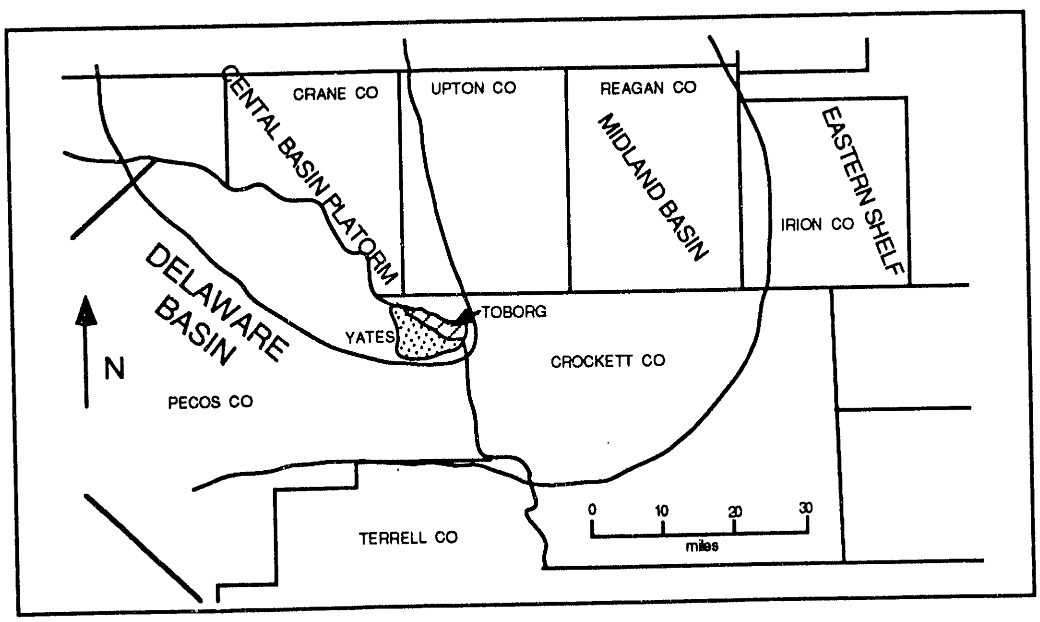

FIGURE 2. - Location map showing Yates and Toborg Fields, Pecos County, Texas (Galloway, Ewing, Barrett, Taylor and Debout, 1983).

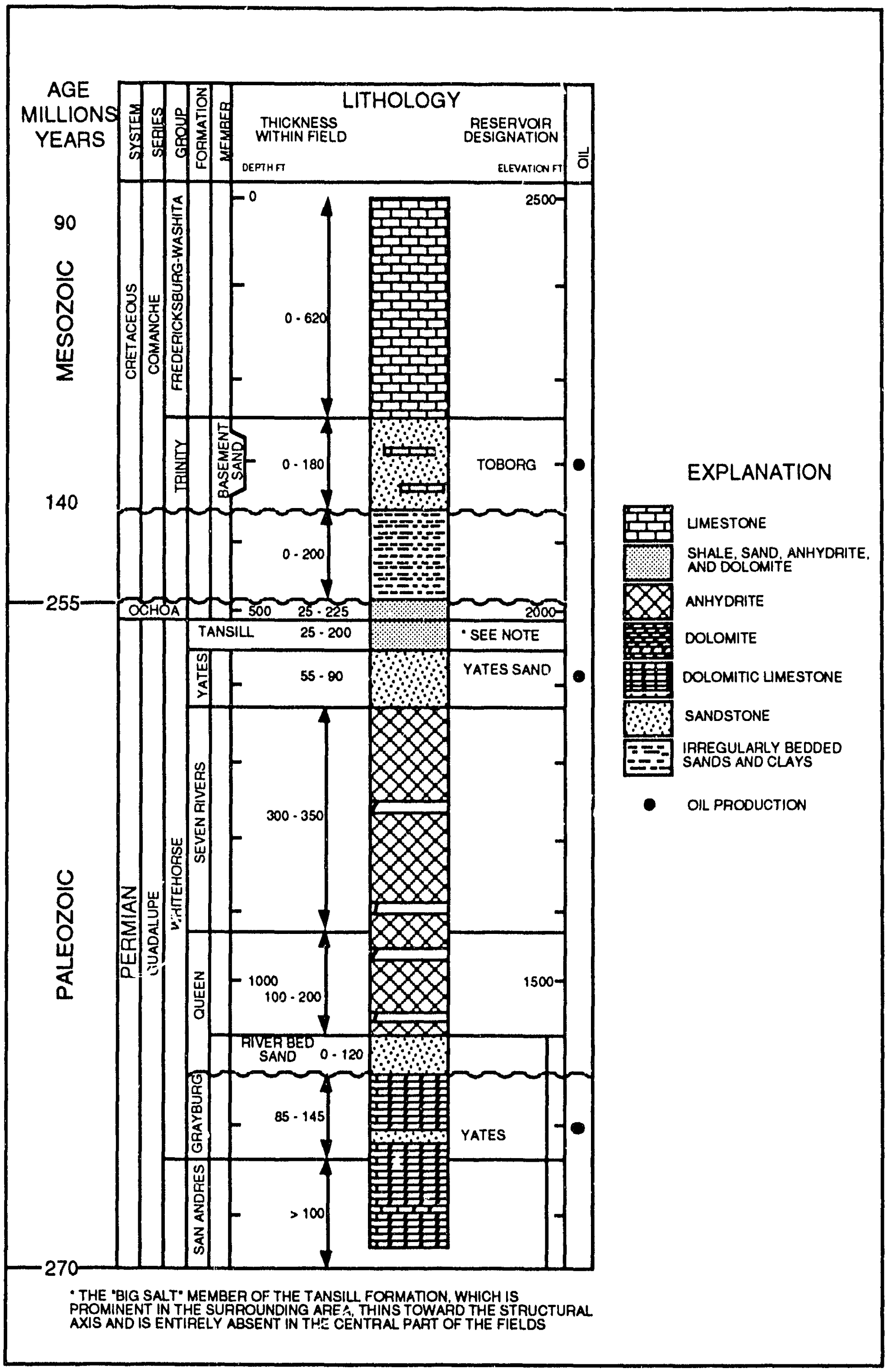

FIGURE 3. - Stratigraphic column for Toborg and Yates fields (Galloway, Ewing, Barrett, Taylor, and Debout, 1983).

Heavy oil is produced from reservoirs of Paleozoic and Mesozoic Age. These reservoirs are composed of mostly carbonates (limestone and dolomites) and a few sandstone reservoirs. Toborg Field is reported to be the most prolific heavy oil reservoir even though the origin of the oil and the API gravity are suspect (Galloway et al., 1983, p. 100, reports 22° API gravity; Crysdale and Schenk, 1990, report 19°, 10° to 30° API gravity; Gariet, 1992, states 500± acres with 10± feet of pay of 20° API oil; and Hance, Sharp and Nugent, 1989, p. II-262, list Toborg as 19° API gravity). This fluvial sandstone reservoir is productive from the Cretaceous Trinity Group consolidated sandstone and is the largest heavy oil field in Permian Basin, (Figs. 2 and 3). Toborg Field has produced 57% of the heavy oil produced in the Permian Basin (Fig. 2). Permian Age formations have produced 44% of the total heavy oil in this basin. Data from New Mexico is sparse, but the NIPER heavy oil database being developed will fill in blanks of tables in the appendix. An extensive bibliography is included at the end of this report.

Review of the Geology Setting of Heavy Oil Reservoirs

In the following pages, the geologic setting of the heavy oil resource in the Permian Basin is summarized. The approach used will be to briefly describe the environment beginning with the rocks of oldest age containing heavy oil and work towards younger aged formations containing heavy oil. Correlation charts (Figs. 3 and 4) are referred to extensively throughout the discussion. Figure 4 shows a correlation chart of formations across West Texas and Southeast New Mexico.

Major Structural Features of the Permian Basin

At the beginning of the Ordovician Period, the present day configuration of the Permian Basin had not been formed. Prominent structural features at this time were the Pedernal Massif, the Texas Peninsula, Tex-Mex Arch and Alpine Arch. Depocenters in the slowly subsiding basin were in West Texas (Fig. 5). During early Ordovician time, Ellenburger Formation carbonates were deposited in this slowly subsiding, shallow marine shelf that extended from Oklahoma across Texas into New Mexico (Wright, 1979).

During Pennsylvanian and Permian time, the major regional and local tectonic movements occurred to form the present subsurface structural architecture of the Permian Basin of West Texas and Southeastern New Mexico. The major structural features of the Permian Basin are the Delaware Basin of Southeastern New Mexico and West Texas, which is separated from the Midland Basin of West Texas by the Central Basin Platform, the Val Verde and Kerr basins (a southern extension of the Midland Basin), and the Sheffield Channel connecting the Delaware and Midland basins south of the Central Basin Platform. Adjacent to these sedimentary basins of Pennsylvanian and Permian periods are the Northwestern and Southern shelves of the Delaware and Midland basins and the Eastern Shelf of the Midland Basin (Fig. 1) (Wright, 1979; Jones, 1953).

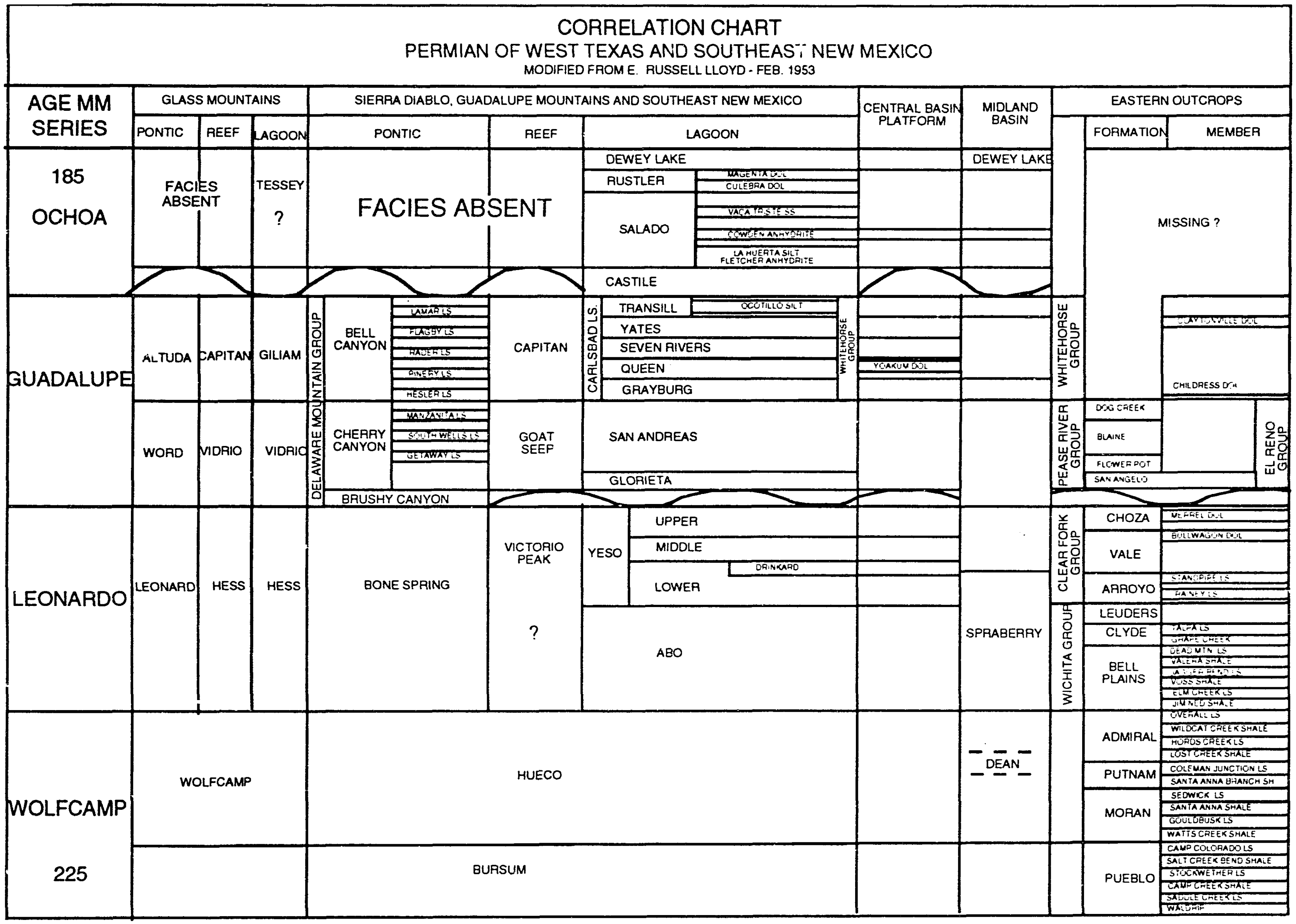

FIGURE 4. - Correlation chart of formations across West Texas and Southeast New Mexico (after Lloyd, 1952).

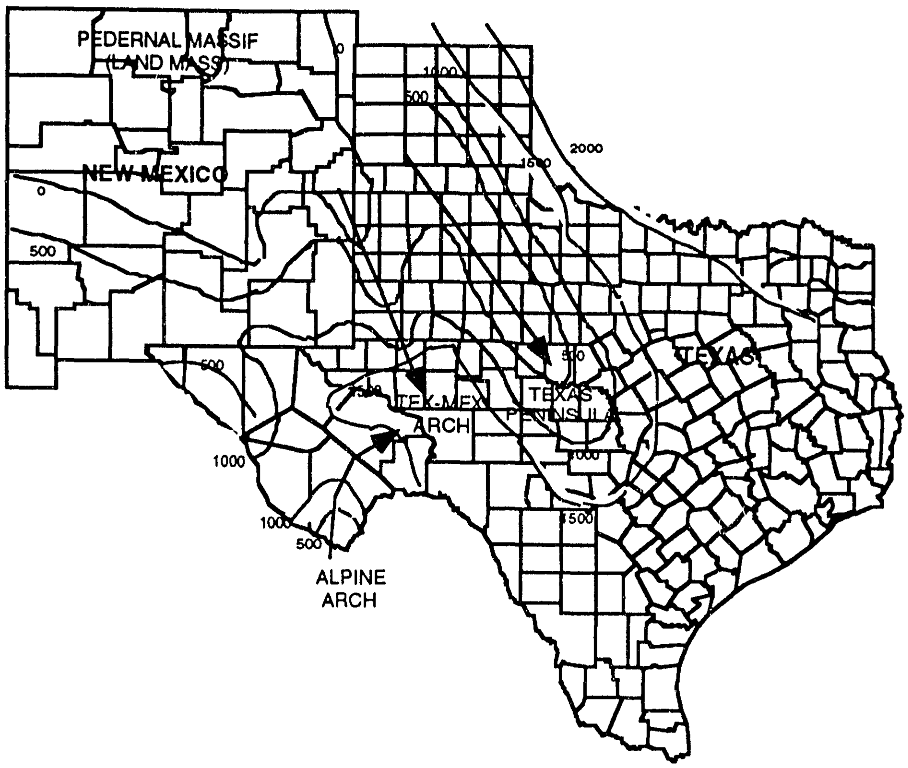

FIGURE 5. - Paleogeographic map of West Texas and Southeast New Mexico during late Ellenburger (Lower Ordovician) time about 415,000,000 years ago, showing isopachs of Ellenburger (Wright, 1979).

Paleozoic Era

The oldest reservoirs in the Permian Basin containing heavy oil are those of the Permian Wolfcamp series (Fig. 4). Within the Permian System, the Wolfcamp is the oldest, then the Leonard series, Guadalupe series, and the youngest is the Ochoa series. Within each are various groups and formations containing heavy oil. Each reservoir is briefly described and general reservoir properties are listed in the appendix A. and references are cited.

Wolfcamp Series

There are three heavy oil fields (Blalock Lake East Field in Glasscock County, Texas; Dollarhide East Field in Andrews County, Texas; and Leeper Field in Hockley County, Texas) producing from Wolfcamp Series reservoir rocks in the Permian Basin, all located in the Midland Basin of West Texas (Fig. 1). Reservoir properties are shown in appendix A. Rocks of the Wolfcamp Series are early Permian in age (Fig. 4). Reservoir rock in these fields are dolomite and limestone (Crysdale and Schenk, 1990). The upper Wolfcamp consists of dark, shaley limestone containing fusulinids and dark shale. The lower Wolfcamp is dark shale with little dark argillaceous limestone or finely crystalline dolomite. The Wolfcamp attains a thickness of 2,500 ft along the Upton-Reagan county line and thins regionally northward (Figs. 6 and 7). Thinning of the Wolfcamp occurs over structures. The contact between the Wolfcamp and the overlying Leonard is difficult to pick on the basis of either lithology or fauna across the Permian Basin (Jones, 1953).

Leonard Series

Eight heavy oil fields, described below and whose general reservoir properties are listed in the appendix A, produce from Leonard Series reservoirs in the Leonard, Wichita-Albany, Bone Spring and Clear Fork formations. The Delaware Basin of New Mexico has one of the heavy oil fields in the Bone Spring Formation. Five heavy oil fields are in the Midland Basin of West Texas; one in the Leonard, one in the Wichita Albany, and three in the Clear Fork formation (Figs. 1, 4, 8 and 9). Two heavy oil fields are on the Southern Shelf of the Permian Basin in the Leonard formation.

Leonard Formation

Two of the Leonard Formation heavy oil fields are located along the Southern Shelf of the Permian Basin (Schuler Field in Pecos County, Texas); and one Leonard Formation heavy oil field is in the Midland Basin (Fluvanna Field in Bordon County, Texas). Reservoir rock in these fields is limestone and dolomite (Crysdale and Schenk, 1990). These carbonate rocks were deposited on a shallow shelf that extended into the Permian Basin (Fig. 8). The Leonard thickens westward

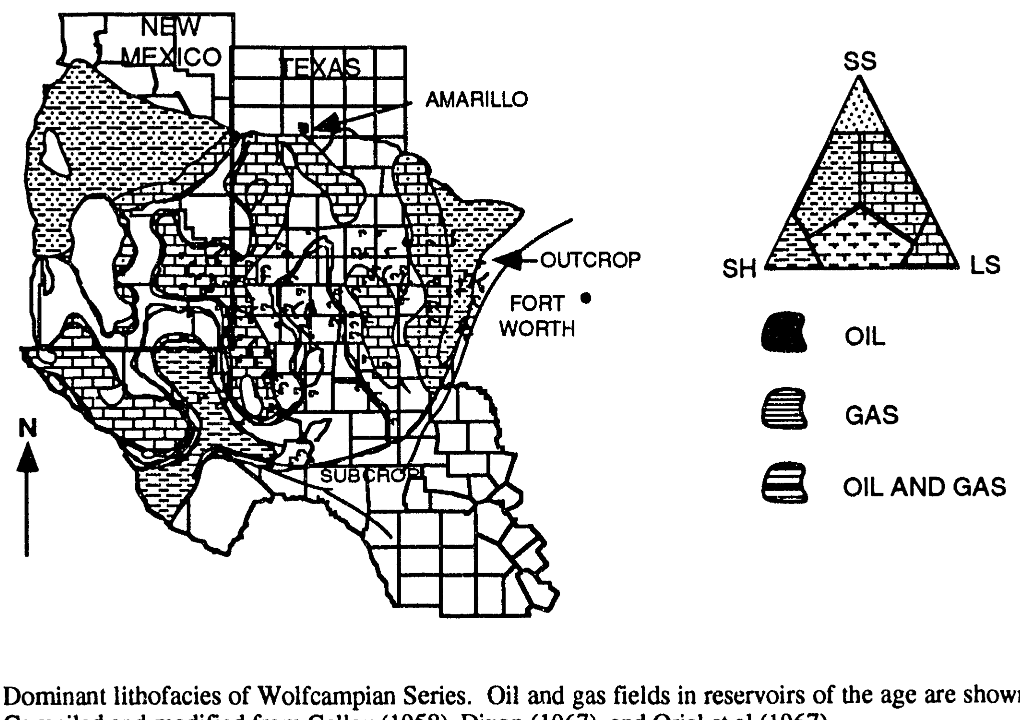

FIGURE 6. - Dominant lithofacies of Wolfcampian Series. Oil and gas fields in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al (1967).

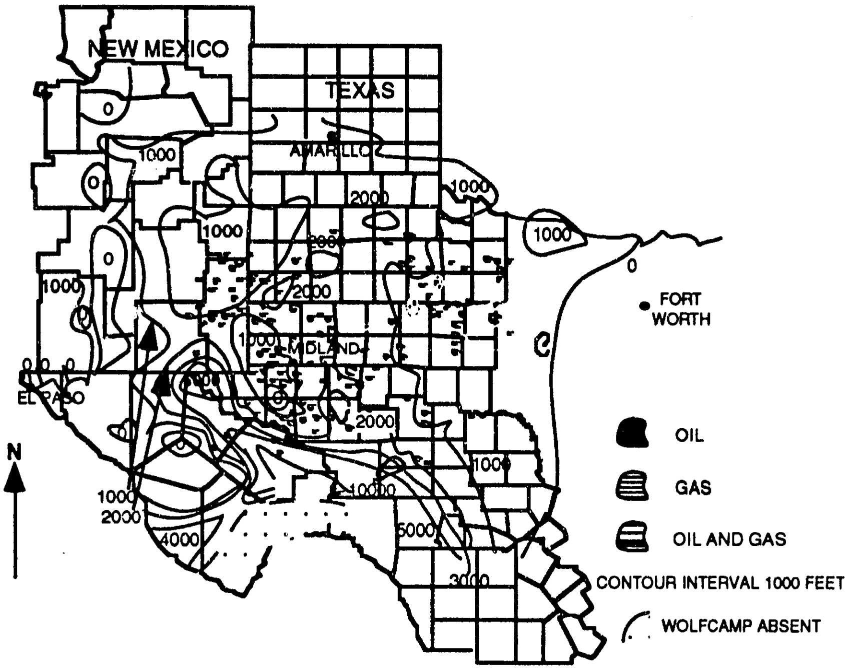

FIGURE 7. - Thickness of Wolfcampian Series. Oil and gas fie'd: in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al (1967) alterations by Hartman and Woodard.

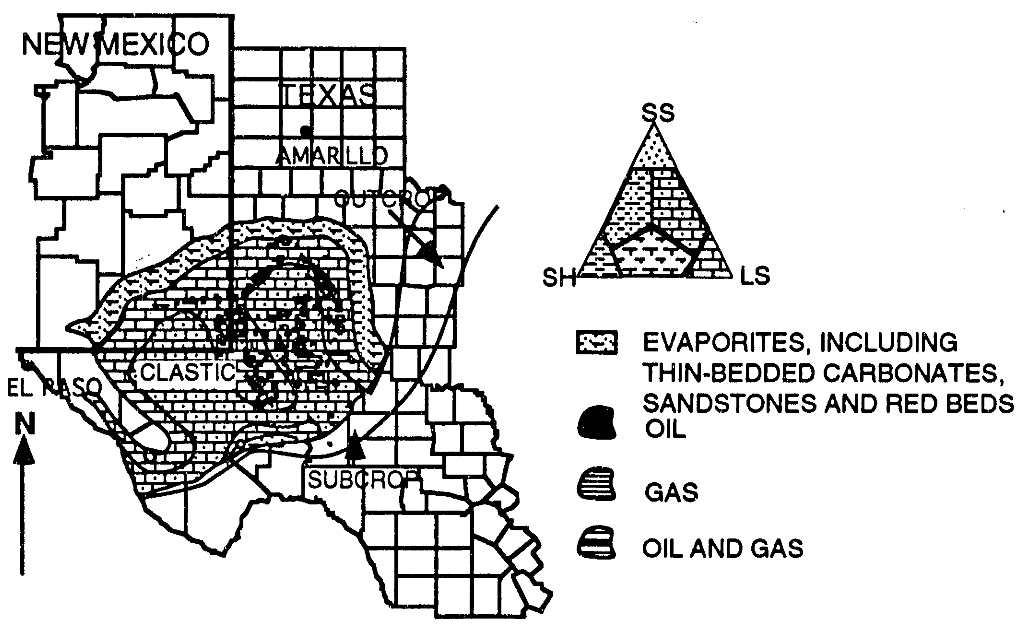

FIGURE 8. - Dominant lithofacies of Leonardian Series. Oil and gas fields in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al (1967) alterations by Hartman and Woodard.

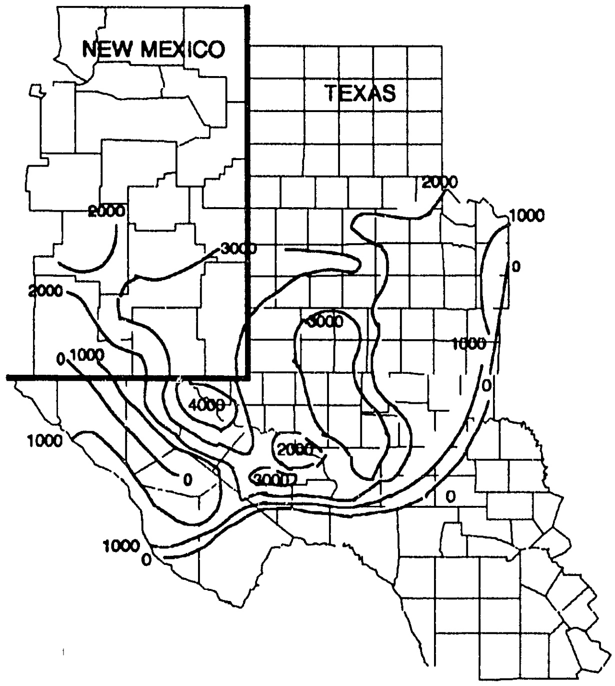

FIGURE 9. - Thickness of Leonardian Series. Oil and gas fields in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al (1967) alterations by Hartman and Woodard.

from the pinchout on the Eastern Shelf of the Midland Basin to a thickness of 3,000 ft in the Midland Basin. It also thickens northward from the pinchout on the Southern Shelf of the Permian Basin to a thickness of more than 4,000 ft in the Delaware Basin of West Texas and New Mexico (Fig. 9) (Hartman and Woodard, 1971).

Wichita-Albany Formation

The Log-Pat Field in Scurry County, Texas produces heavy oil from the Wichita-Albany Formation on the Eastern Shelf of the Midland Basin (Fig. 1). Reservoir rock in this area is limestone and dolomite (Crysdale and Schenk, 1990). Two carbonate facies were deposited along the eastern margin of the Midland Basin, a reef facies and a backreef facies to the east onto the Eastern Shelf (Fig. 8). The reef facies is clean, light-colored, massive dolomite. Locally, it can be limestone associated with dolomite. Thickness of the reef facies averages approximately 800 ft along the eastern margin of the Midland Basin. The backreef facies to the east along the Eastern Shelf which is made up of white to tan to brown, bedded anhydritic dolomite, interbedded with thin beds of gray and green shale and anhydrite with small amounts of chert associated with the dolomite. Dolomite and anhydrite facies suggest that these sediments may be associated with barrier reefs. Locally, there are porous lenses of dolomite developed (Figs. 8 and 10) (Wright, 1979).

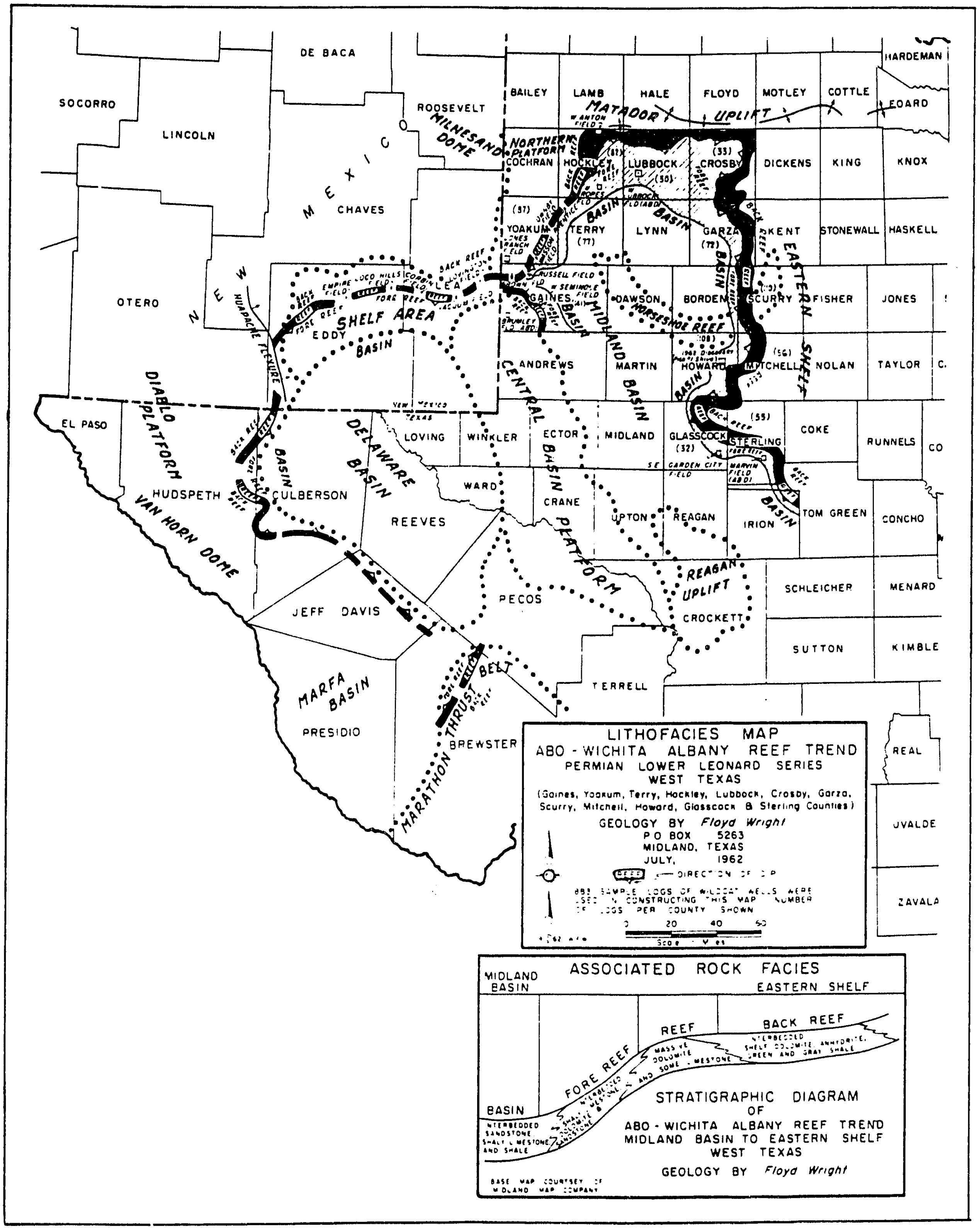

FIGURE 10. - Lithofacies map of the Abo-Wichita Albany Reef Trend Permian, Lower Leonard Series Permian Basin of West Texas and Southeast New Mexico (Wright, 1979).

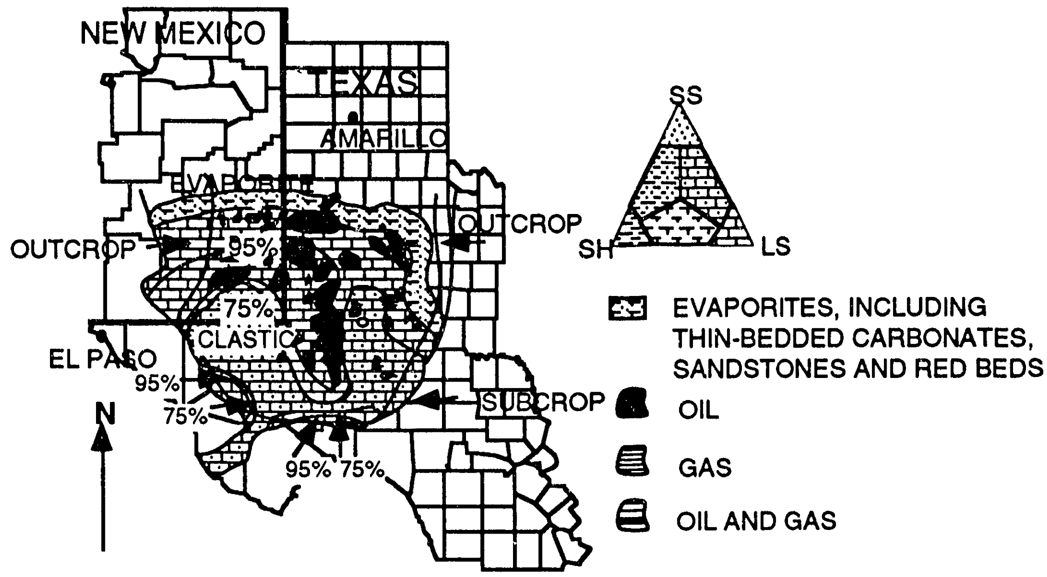

FIGURE 11. - Dominant lithofacies of Guadalupe Series. Oil and gas fields in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al. (1967) alterations by Hartman and Woodard.

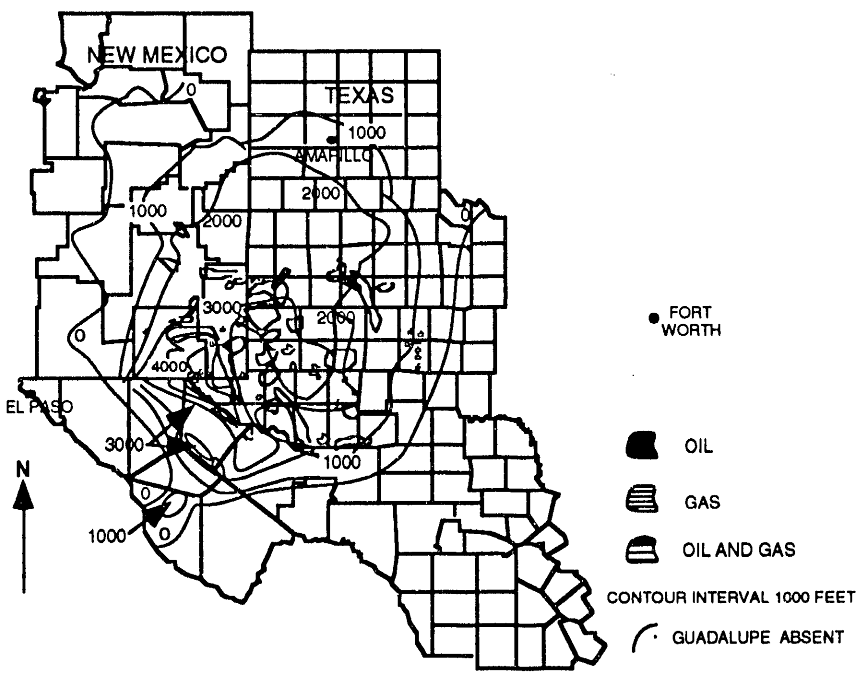

FIGURE 12. - Thickness of Guadalupe Series. Oil and gas fields in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al. (1967) alterations by Hartman and Woodard.

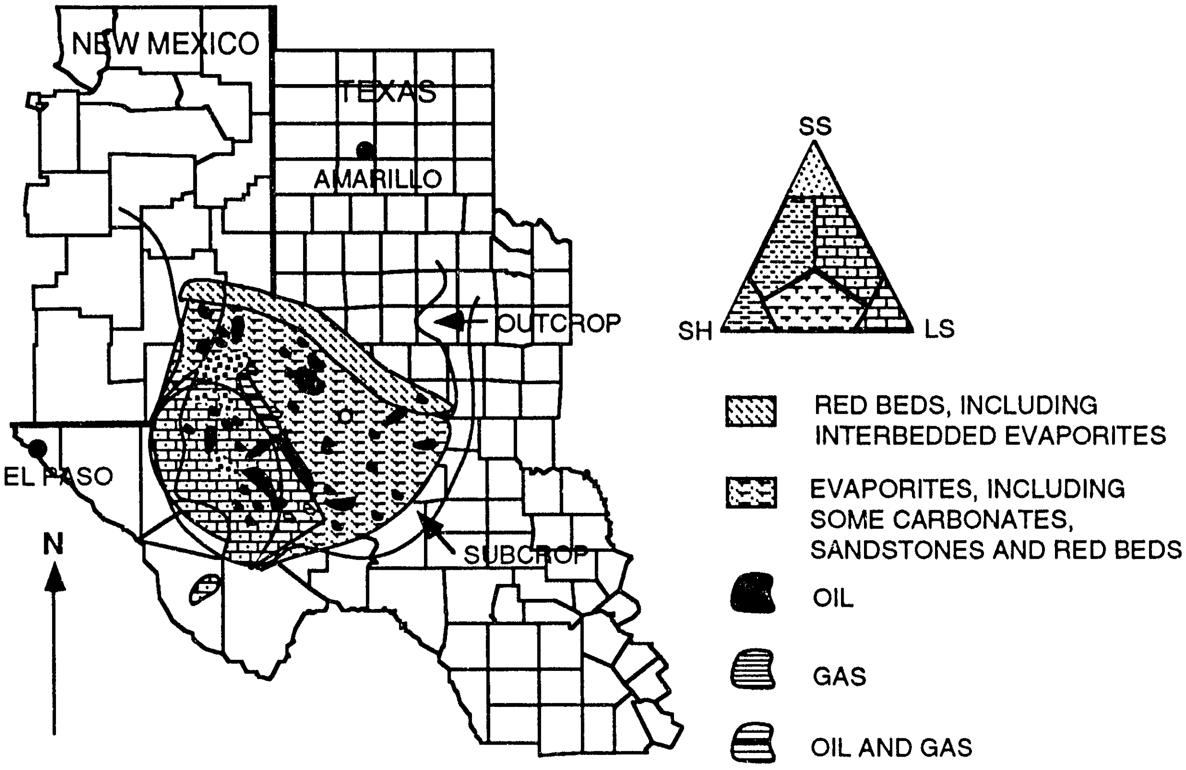

FIGURE 13. - Dominant lithofacies of upper Guadalupe Series. Oil and gas fields in reservoirs of the age are shown. Compiled and modified from Galley (1958), Dixon (1967), and Oriel et al. (1967) alterations by Hartman and Woodard.

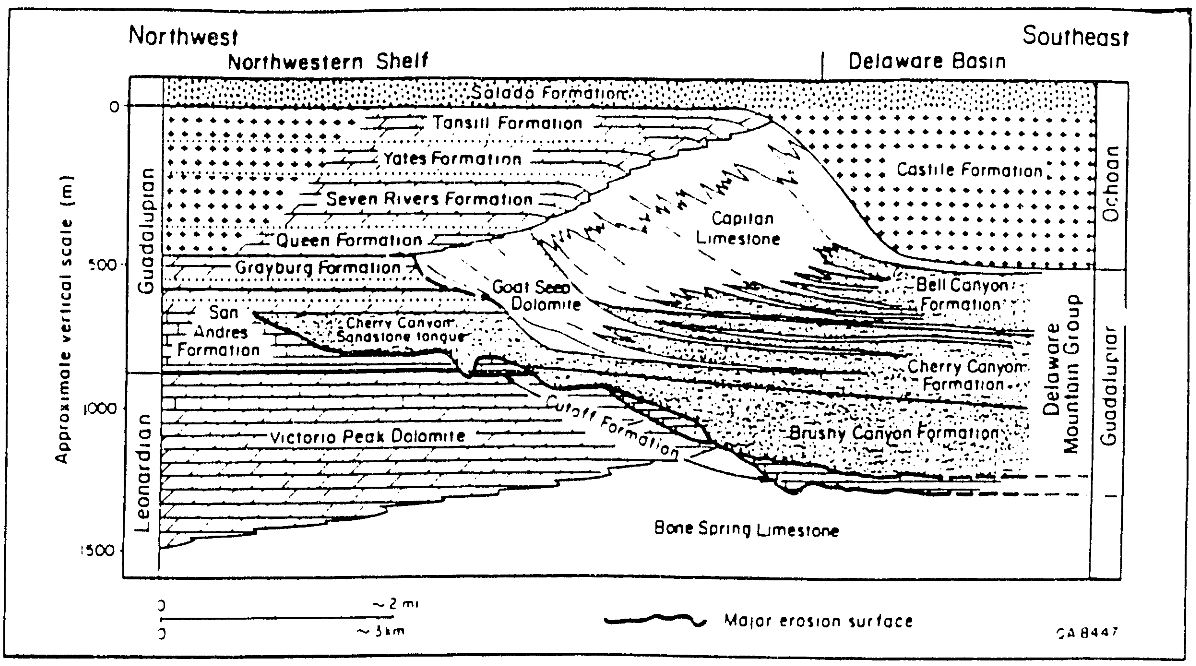

FIGURE 14. - Generalized Permian shelf-to-basin cross section of the Northwestern Delaware Basin. Modified from Fekete et al. (1986).

Bone Spring Formation

The Maroon Cliffs Field in the Delaware Basin in Eddy County, New Mexico produces heavy oil from the Bone Spring Formation (Fig. 1). Reservoir rock for the Bone Spring is limestone (Crysdale and Schenk, 1990). The Bone Spring Formation is the basin limestone equivalent to the reef facies of the Abo formation in the Delaware Basin (LeMay, 1972). On the outcrop in New Mexico, the Bone Spring has a variety of facies from black basin limestone to reef to backreef limestone. The Bone Spring Formation may make up the entire Leonard Series in some locations. Thickness of this formation is greater than 1,500 ft in the subsurface (Jones, 1953).

Clear Fork Formation

Three heavy oil fields produce from the Clear Fork Formation. These fields are located in the Midland Basin (Marholl Field in Dawson County, Texas and Wilson West Field in Lynn County, Texas) and the Northwestern Shelf of the Midland Basin (Ropesville Field in Hockley County, Texas) (Fig. 1). Reservoir rock in these fields are limestone and dolomites (Crysdale and Schenk, 1990). Oil production in Clear Fork carbonates is controlled by porosity development in the limestone and dolomite facies (Galloway, Ewing, Barrett, Taylor, and Debout, 1983).

Guadalupe Series

The Guadalupe Series reservoirs (Figs. 3 and 4) in the Permian Basin produce heavy oil from the Glorieta-San Angleo, San Andres, Grayburg, Seven Rivers, Yates and Tansill formations. Reservoir properties are listed in Appendix A for the various fields.

Glorieta - San Angelo Formation

The Coronet Field in Howard County, Texas produces from the Giorieta - San Angelo Formation. This field is located along the western edge of the Eastern Shelf of the Midland Basin (Fig. 1). The Glorieta is the dolomite equivalent of the sandy upper third of the San Angelo Formation (Figs. 11 and 12). Thickness of the Glorieta ranges from 50 to 180 ft. The San Angelo Formation is sandstone on the outcrop on the Eastern Shelf but it becomes more calcareous as it thickens westward into the Midland Basin (Jones, 1953). Reservoir rock is dolomite that has a 15-ft oil column (Crysdale and Schenk, 1990).

San Andres Formation

Ten heavy oil fields produce from the San Andres Formation. Two of these fields (Olson Field in Crockett County, Texas and Azalea West Field in Midland County, Texas) are in the Midland Basin of West Texas, and eight (Button Mesa South, Crossroads West, Jenkins, Mescalero and Ranger Lake Fields in Lee County, New Mexico; and Chisum, Leslie Spring and Tower Fields in Chaves County, New Mexico) are in the Delaware Basin of New Mexico (Fig. 1). Reservoir rock in these fields is dolomite, limestone, or a combination of dolomite, limestone, sandstone, and anhydrite (Figs. 11 and 14) (Crysdale and Schenk, 1990 and Jones, 1953). In the Midland Basin, the San Andres is light-colored crystalline dolomite that grades eastward to denser dolomite containing gray and green clastics and anhydrite. In the Delaware Basin of New Mexico, the San Andres is made up of fine to coarse crystalline dolomite, limestone, sandstone, and anhydrite. The San Andres has a thickness of > 650 ft (Jones, 1953)

Grayburg Formation

Three heavy oil fields produce from the Grayburg Formation. They are in the Midland Basin (Olson Field, Crockett County, Texas), Delaware Basin (Wentz West Field, Pecos County, Texas), and Central Basin Platform (Hence Field, Ector County, Texas) of West Texas (Fig. 1). These reservoirs are dolomite, limestone, and sandstone (Figs. 13 and 14) (Crysdale and Schenk, 1990). The Grayburg in these areas is composed predominantly of dolomite, sandstone, anhydrite, and limestone. It reaches a thickness of 299 ft (Jones, 1953).

Seven Rivers Formation

The Pyote Field, Ward County, Texas produces from the limestone Seven Rivers Formation. This field is located in the Delaware Basin of West Texas (Fig. 1). The Seven Rivers is composed of gypsum with some red sandstone, shale, limestone, and dolomite (Figs. 13 and 14) (Crysdale and Schenk, 1990; Jones, 1953).

Yates Formation

Four heavy oil fields (PCA, Magruder, Barber and Dirvene) produce from the Yates Formation. These fields are in the Delaware Basin of West Texas and New Mexico (Fig. 1). Reservoir rock for these fields is dolomite and limestone (Figs. 13 and 14) (Crysdale and Schenk, 1990). At the type locality of Yates Formation in the Yates Field, reservoir rock consists of 50 ft of gray and red sand with large frosted quartz grains, thin beds of dolomite, and red and gray shale. In other locations where it is associated with reefing, it consists of gray sand interbedded with dolomite, but mostly red sand where it is associated with anhydrite and salt (Jones, 1953). A schematic of deposition of the red beds in relation to sea level is shown in Fig. 15 (Van Siden, 1958).

Tansill Formation

Two heavy oil fields, Maroon Cliffs and Parallel, produce from the Tansill Formation. These fields are in the Delaware Basin of New Mexico (Fig. 1). Reservoir rock for these fields is anhydrite, dolomite, sandstone, and siltstone (Figs. 13 and 14) (Crysdale and Schenk, 1990). The Tansill Formation consists of 123 ft of primarily dolomite which includes a total of 17 ft of sandstone and siltstone. Where it is associated with reefing, these facies are associated with anhydrite and salt beds (Jones, 1953).

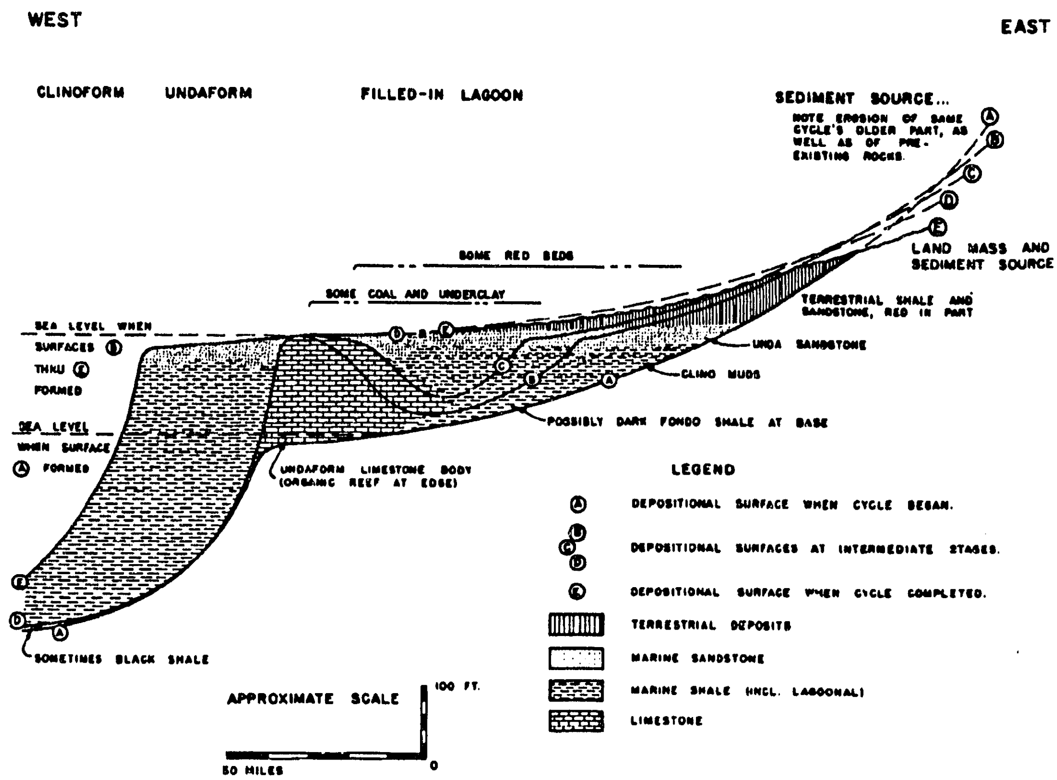

FIGURE 15. - Generalized deposition of the red beds in relation to sea level.

Mesozoic Era

Heavy oil within the Permian Basin occurs in Mesozoic Age formations. Within the Mesozoic Era, three periods of geologic time are represented, Triassic, Jurassic and Cretaceous. Heavy oil occurs within the early Cretaceous (Comanchean) Trinity Group.

Trinity Group

Toborg Field produces from the Trinity Group (undifferentiated) at the extreme southern end of the Central Basin Platform of the Permian Basin (Figs. 2 and 3). Toborg is the most important heavy oil field in the Permian Basin because it has produced 69% of the heavy oil produced in the Texas portion of the basin. Three sources of reservoir data give conflicting information on the API gravity (19°, 10° to 30°, and 22°) of oil produced from the Trinity reservoir in Toborg Field (Hance, Sharp and Nugent, 1990; Crysdale and Schenk, 1990; and Galloway, Ewing, Barrett, Taylor, and Debout, 1983). Toborg Field consists of multiple reservoirs in the Trinity Group. These reservoirs are poorly cemented, discontinuous fluvial sandstones that have high intergranular porosity and permeability. Some of the oil in these reservoirs is oil that migrated upward into the Trinity sandstones from underlying Permian oil reservoirs after the discovery of Yates Field. Protective and production casing were not cemented in early completions in Yates

Field, causing Permian oil to migrate upward into shallow Trinity sandstones. Secondary recovery and close well spacing (2.5 acres) have resulted in an estimated 57% recovery efficiency (Galloway, Ewing, Barrett, Taylor, and Debout, 1983).

Glen Rose Formation

Five heavy oil fields (Billy Holland, Turney, Wardlaw, and Worth Evans Fields in Edwards County, Texas; Millspaugh Field in Crockett County, Texas) produce from the Glen Rose Formation. These fields are in the Midland Basin of West Texas (Fig. 1). Reservoir rock for these fields is limestone (Crysdale and Schenk, 1990). The Glen Rose is 900 ft of partly shaley limestone with a few thin beds of anhydrite (Figs. 14 and 16) (Jones, 1953).

Paluxy Formation

Three heavy oil fields (Massie West and Parmer Fields in Val Verde County, Texas and Walt Field in Edwards and Val Verde County Texas) produce oil from the Paluxy Formation. These fields are in the Midland Basin (Fig. 1). Reservoir rock for these fields is sandstone (Crysdale and Schenk, 1990). The Paluxy consists of medium to coarse sand up to 80 ft thick (Jones, 1953).

Case Studies of Thermal Heavy Oil Projects

Devil's River Field Cyclic Steam Recovery Pilot Project

In 1984, Petro Imperial Corporation, Dallas, Texas, conducted a cyclic steam recovery pilot project to evaluate the feasibility of recovering heavy oil from Devil's River Field in Val Verde County, Texas. This heavy oil reservoir is a stratigraphic trap in a shallow Paluxy Formation sand. Gas to operate the steam generator came from the 9,000 ft Strawn Formation gas reservoir in the field. During a pilot test to investigate the feasibility of cyclic steam to recover heavy oil in this reservoir, oil production in two wells was increased from 0.25 to 0.5 BOPD to a flow of 6 BOPD (Table 1). At the conclusion of the test, Petro Imperial was making plans to develop the 160-acre heavy oil reservoir (Vernetta, 1984). Attempts to determine the current status or reason for termination were unsuccessful.

Holman Ranch Steamflood Heavy Oil Recovery Pilot Project

In 1964, McWood Corp., Abilene, Texas, conducted a steamflood heavy oil recovery pilot project in Holman Ranch Field in Edwards County, Texas. The heavy oil reservoir is a shallow Glen Rose Formation sandstone. The project used a central steam injection well with four producing wells in a 5-spot pattern. The first attempt to recover heavy oil from the reservoir by steamflood ended in failure. The failed attempt was caused by early breakthrough in an old well completed in 1947 with nitroglycerine stimulation. When attempting to drill a replacement well, a blowout occurred while drilling into a live steamflood pattern. Oil/water emulsion problems

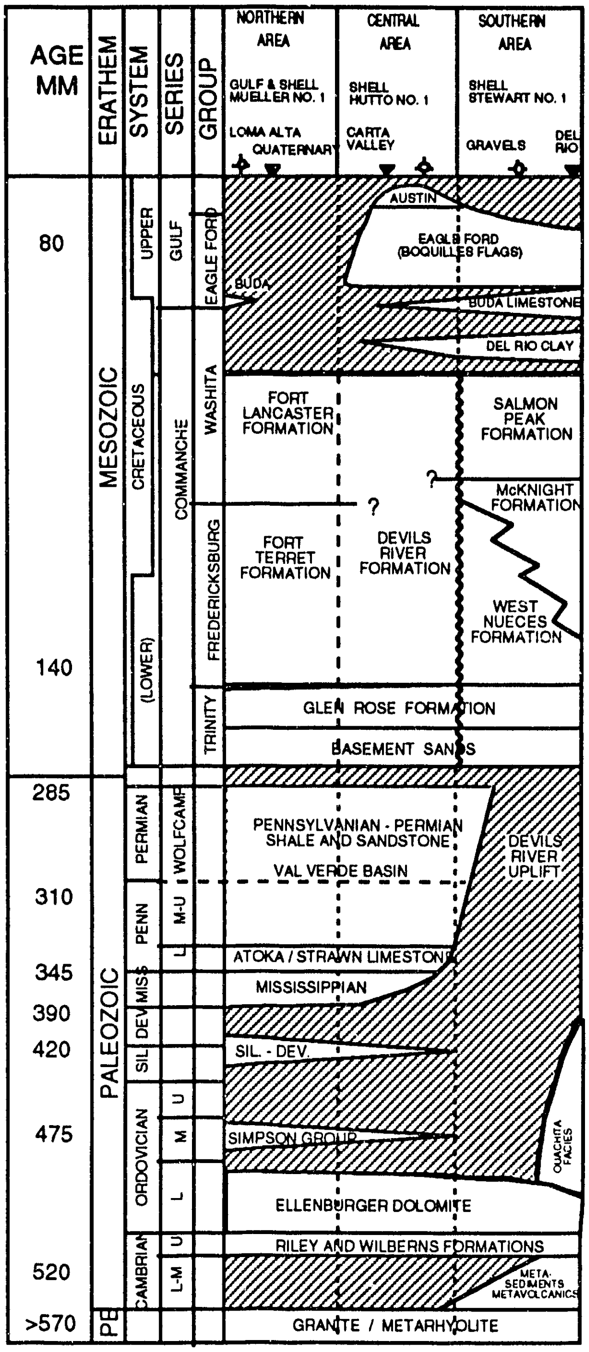

FIGURE 16. - Composite Stratigraphic sections for Devil's River uplift-southern Val Verde Basin, Texas (Webster 1980).

TABLE 1

Devil's River Field Cyclic Steam Recovery Pilot Project
By Petro Imperial Corporation, Val Verde County, Texas

Areal Extent, acres	160
Producing formation	Paluxy
Lithology of reservoir	Sand
Depth, ft	300-350
Pay Thickness, ft	20
Porosity, %	18 to 30
Permeability, mD	200-900
Oil saturation (%)	65
Oil in Place, bbl/acre-ft	800-1300
Reservoir Temperature, °F	50
Gravity of Oil, °API	16-19
Oil Production, Natural, BOPD	0.25-0.5
Oil Production After Steam Stimulation, BOPD	6
Oil Viscosity: cP at 70°F	480
cP at 100°F	165
Estimated recovery factor, %	10-40
Time of steam stimulation, hours	15
Number of wells stimulated	2
Number of wells in pilot project	11
Steam injection pressure, psi	300
Size of steam generator, MMBtu/hr	2
Injection pattern, spot	5

experienced during thermal recovery were overcome by chemical treatment of produced emulsion. The second attempt at recovering heavy oil in a second pattern by steamflood stimulation in Holman Ranch Field was successful. Maximum daily oil production in the second attempt was approximately 119 BOPD, Table 2. At the end of the second pilot project, McWood was considering plans to test the feasibility of recovering heavy oil in this field by cyclic steam injection (Emery, 1966). Attempts to determine the current status or reason for termination were unsuccessful.

CONSTRAINTS

Heavy oil is successfully being produced by cyclic steam, steamflood and in situ combustion from principally thick unconsolidated or friable reservoirs in California, Canada, and Venezuela. In the United States, TEOR is the largest enhanced oil producing technology contributing 69% or 454,000 BOPD of the 656,700 BOPD total U. S. EOR production in 1990 (Moritis, 1990). The consolidated and the thinner laminated nature of the heavy oil bearing formations in the Permian Basin limits economic production. The oil in the Permian Basin is principally paraffinic unlike the asphaltic California heavy crudes. Paraffinic crudes command a higher price than asphaltic oils of the same gravity. Within the Permian Basin, there are deeper hotter reservoirs with significant solution gas in the heavy oil that produce on primary or are easily waterflooded even though they are consolidated.

TABLE 2

Holman Ranch Field Steamflood Recovery Pilot Project By McWood Corp., Edwards County, Texas

Areal Extent of pilot project, acres	12.5
Well spacing: acres	2.5
ft	330
Producing formation	Glen Rose
Lithology of reservoir	Sandstone
Depth, ft	550
Pay thickness, ft	5-15
Average porosity, %	31.4
Permeability, mD	12-2,100
Oil saturation, %	50.8-77.3
Water saturation, %	12
Gravity of oil, °API	15.2
Viscosity of oil, cP at 70° F	1160
Formation volume Factor	1.015
Initial oil production, Natural, BOPD	0.5-2
Steam generator, Btu/hour	11,600,000
Steam injection temperature, °F	500
Steam injection pressure, psi at surface	900
Maximum heavy oil production during pilot project, BOPD for all wells	119

Refining and Transportation

The transportation network in the Permian Basin is dominated by the large volume of light oil produced in the basin. Significant heavy oil above current production levels could be blended to the current light oil streams and pumped to refineries on the Gulf Coast. Currently, Californian heavy oil and Alaskan North Slope oil (28° API gravity) is transported as blended oil from California by the All-American pipeline to the Basin (Fig. 17). The pipeline network ships oil to refineries in the Permian Basin, the Gulf Coast (Gill, 1990; Williams, 1990) and the Midwest. The alternative transport route for California heavy oil has been by tanker transport through the Panama Canal to the U.S. Gulf Coast. The Permian Basin has an extensive infrastructure supporting extensive primary production, aging and rapidly declining waterfloods, and a growing number of CO_2 enhanced oil recovery projects conducted as miscible floods to recover light oil. This oil supplements declining oil production from waterflood operations. The light oil in the Permian Basin has become more sour during waterflood operations conducted over the past 40 years. Most refineries in the basin are designed to process light crude oils. Addition of heavy oil would significantly impact operation since they have limited capability to process heavy ends (Thrash, 1990; Thrash, 1991). A separate heavy oil gathering system with heated pipelines to transport oil to a suitable refinery would require much larger heavy oil production which is not anticipated or justified based on the volume of heavy oil resources in the Permian Basin.

FIGURE 17. - Pipelines carrying heavy oil as a blend into and out of the Permian basin to the Midwest and Gulf Coast.

Environmental

The Permian Basin typifies the U.S. oil patch, and oil is a major industry of the area. Increasing awareness of the environment is becoming incorporated into the petroleum industry's mode of doing business. The arid nature of the Permian Basin limits fresh water use for other than domestic and agricultural applications. Since anticipated thermal oil recovery operations will be minimal, the shortage of water will not be significantly impacted by TEOR demand for fresh water. The air quality of the region is significantly better than that of sections of California, but the State of Texas has not issued a permit for a steam generator other than gas fired since 1986 (Bergrath, 1991). Air and water quality are a concern as both Texas and New Mexico environmental regulations become more stringent and trend toward limits similar to those of California.

Economics of Thermal Heavy Oil Production

The economics of heavy oil recovery in the Permian Basin was analyzed based on the oil recovered, the reported duration of the project, and the 1990 cost of thermal operations as obtained from the assessed evaluation of thermal (steam) operations in Kern County, California (Maples, 1990, Table 3 and Table 4; Sarathi and Olsen, 1992). Numerous operators produce heavy oil on

TABLE 3

Thermal EOR operating costs
(Maples, 1990-91)

Well depth, ft	NEW PRODUCING WELL COSTS Steam wells, $	Injectors, $
0 - 250	37,000	
251 - 750	73,000	30,000
751 - 1,250	89,000	
1,251 - 1,750	121,000	60,000
1,751 - 2,250	160,000	100,000
2,251 - 2,750	200,000	
2,751 - 3,250	240,000	

TABLE 4

Yearly thermal steam operating cost ranges within each field/well
(Maples, 1990-91)

Field	Cyclic steam, $	Steamflood, $
Cymric	20,000	27,500
Kern River	20,000	27,000
Midway-Sunset	18,000	26,000

Steam generator maintenance costs/BTU barrel equivalent of oil burned, in $	
Gas fired = 0.10	Oil fired = 0.20

primary or by waterflooding deeper reservoirs. Because heavy oil is more viscous than light oil, the mobility ratios in waterfloods will be adverse. Operators waterflooding heavy oil reservoirs are probably operating at a lower oil to water ratio than those waterflooding light oils, and thus their operating costs are anticipated to be higher per barrel of oil produced.

For shallow heavy oil operations, primary production per well usually classifies these wells as stripper wells (< 10 BOPD). Since these operations continue, wells were deemed marginally economical and they were not considered in this analysis because the volume of oil produced is small and the recovery efficiency is usually less than 5%. Tabular listing of the royalties and tax liabilities within New Mexico and Texas are shown in Table 5. Operating costs for Kern County, California thermal operations in 1990 aie shown in Table 4. These average costs (as assembled by Maples, the Kern County, California Assessor for 1990) are based on proprietary data supplied by thermal operators. There is reason to believe that none of the thermal projects listed in this report would be operating after the 1986 drop in oil prices, even though the paraffinic crude they produced was selling for as much as West Texas Intermediate (WTI) crude oil (discounted 15 cents

TABLE 5

Comparisons of economic factors affecting oil production from Midcontinent states

	Kansas[a]	Oklahoma[a]	Missouri[b]	New[a] Mexico	Illinois[a]	Texas[a]	Colo.[a]	North[a] Dakota
Land owner royalty, %	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Land surface disruption,	Site specific	Site specific	Site specific	Site specific	Site specific	Site specific	Site specific	Site specific
Direct state tax, %	4.33[c]	7.0[d]	None	3.75[d]	None	4.6[d]	2-5e	5[c,f]
Emergency school tax				3.15[c]				
State Severance Production tax								
Productivity	1. Variable stripper	None	None[g]	None	None	None	Stripper wells	1. Variable stripper
Vintage	2. New oil & gas	None				None	None	2. New oil
Other	3. Tertiary oil	incremental prod. Secondary & tertiary			50% for EOR	None		3. Workovers
Ad Valorum Tax	Yes[h]	None	None	Yes[h]	Yes	Yes	Yes	None
Corporate Income Tax	Yes[i]	Yes[h]	Yes	Yes[i]	Yes	None	Yes	Yes
Corporate Franchise Tax	Yes[k]	Yes[l]	None	Yes[j]	Yes	Yes[l]	None	Flat $150/yr
Effective Average Tax Rate, % on oil & gas production	9.7	7.4	Variable	8.9	1.3	8.4	6.4	10.2

[a] Kansas Inc., Strategic Analysis of the Oil and Gas Industry in Kansas, Arthur D. Little, Inc., Cambridge, Mass., April 1990.

[b] Personal communication with K. Deason, Missouri Dept. of Natural Resources, and S. Evers, Missouri Dept. of Revenue, July 1990.

[c] Gross Lease Revenue (N.B.- Does not discount transportation and marketing costs).

[d] Gross Lease Revenue less Marketing and Transport Costs.

[e] Less than $25,000 at 2%, $25,000-$100,000 at 3%, $100,000-$300,000 at 4%, $300,000 and over at 5% on corporate/individual oil/gas revenues.

[f] An extraction tax is assessed at the rate of 6.5% for old wells and 4% for new wells.

[g] Each state is attempting to mitigate declining oil production and declining revenues to the state and have or are considering economic incentives for enhanced oil recovery.

[h] Ad valorum tax levied on the economic value of each producing unit. Appraisal value calculated by applying present worth factor to future revenue to derive a net worth for each lease.

[i] Tax basis derived from apportioned revenue derived within state as determined by three factor formula equally weighted. A two factor formula is available for qualifying companies. Rates are $0 - $25,000 at 4.5%, >$25,000 at 6.75%.

[j] Separate accounting for oil and gas income on all taxable income.

[k] Of shareholder equity 0.1%, minimum of $20 and maximum of $2,500.

[l] Of business and investment capital 0.125%, minimum of $10 and maximum of $20,000.

per API gravity point). These thermal projects had low oil production rates. Inquiries in August 1991 indicated that Permian Basin heavy oil producers were selling their heavy oil at the posted price for WTI less the penalty for sulfur and API gravity (about $3 under that for WTI). This is significantly more than the posted price for Kern County heavy oil, as shown in Fig. 18. The ratio of posted crude oil prices for Kern River and other oils are shown in Fig. 19. Kern River oil posted price has averaged about two-thirds of the price of WTI over the past decade (Maples, 1991; Oil & Gas J., Statistics, 1984-1992).

CONCLUSIONS

The Permian Basin of West Texas and Southeastern New Mexico is a minor heavy oil producing basin and does not seem destined to increase its role in supplying significant heavy oil. Toborg Field in Pecos and Crockett Counties, Texas, is the field which is reported to be the largest producer of heavy oil but the field should not be considered as all heavy oil on about 500± acres The reason for the high recovery from this field is because it is a low gravity oil with significant solution gas.. Conflicting reports on the API gravity of the oil (22°, 19°, 20° and 10°-30° and the acreage producing heavy oil) indicate that all the oil assigned as heavy oil may not fall within the definition of heavy oil (Group, 1981). Toborg Field produces from multiple fluvial sandstone reservoirs within the Trinity Group as commingled production. Permian Age carbonate reservoirs dominate the heavy oil reservoirs in the Permian Basin, but they have only produced 40% of the heavy oil in this basin.

Thermal operations in fractured carbonates for recovery of heavy oil has recently generated renewed interest in laboratory and modeling and since worldwide this is a sizable resource (Briggs, 1992). Recovery from most heavy oil carbonates is very low, <5%..

Thermal oil recovery methods to produce the heavy oil in the Permian Basin are not anticipated to recover significant heavy oil from the consolidated formations because steam has not proven to be economic in most areas where it has been attempted in tight consolidated formations. Infill drilling can be expected to increase heavy oil recovery in the Permian Basin thus improving the low cumulative heavy oil production on primary and from waterflooding. Environmental problems due to TEOR operations to produce heavy oil are not anticipated for this area because the heavy oil resource is not large enough to warrant implementation of significant TEOR projects. The discovery of a large heavy oil field in the Permian Basin is unlikely because the area is in a mature stage of exploration and development. No further investigation of the Permian Basin heavy oil resource is recommended.

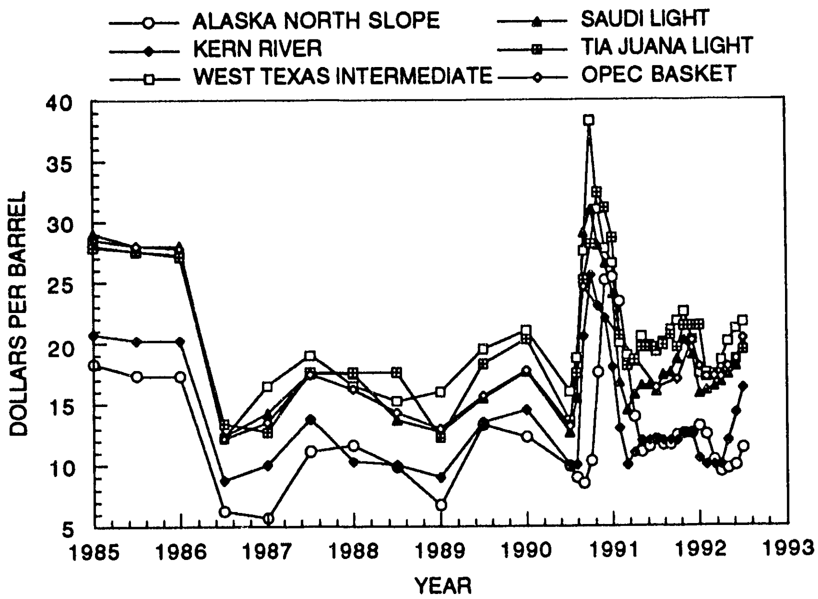

FIGURE 18. - Comparison of average oil price of benchmark crude oils.

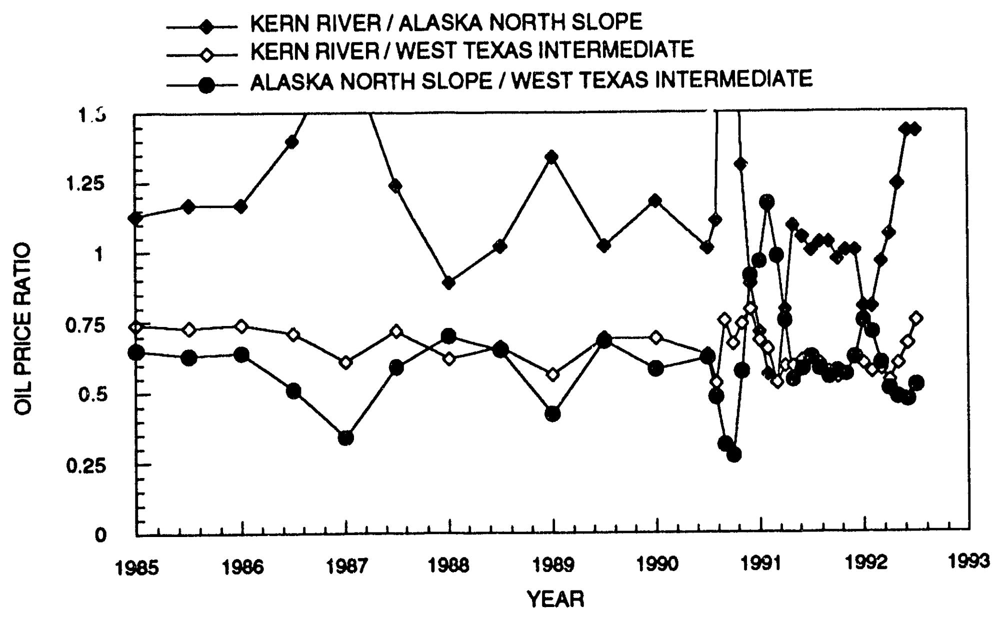

FIGURE 19. - Ratio of oil prices for benchmark heavy and light crude oils.

The database in the appendix of this report lists average data heavy oil reservoirs and heavy oil reservoirs in excess of 1 million barrels of OOIP. No viscosity data is included because of the lack of available data. Only the database with > 1 million barrels OOIP warranted completion of the database and research to find reservoir parameters.

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APPENDIX A

Tables 1 and 2 of this appendix lists average reservoir properties obtained from analysis of the public literature. Table 2 contains data on reservoirs where the original-oil-in-place is larger than 1 million barrels. Due to the size of resource, only those reservoirs with > 1 million barrels OOIP justified research of records to complete the reservoir database, thus Table 1 is a sparse database. Within the constraints of the study, many of the OOIP values are estimated. Table 1 lists reservoir data on all heavy oil reservoirs found in the analysis of secondary data. Estimated values are followed by an asterisk.

TABLE 1

Permian Basin Heavy Oil Reservoir Data
(All Reservoirs)

ST	District	Data Year	Field Name	Reservoir Name	Geo Code	County	API	Depth	Production	Cumulative Production	Estimated OOIP	Estimated OIP	Area	Lithology	Porosity	Perm	Net Pay	Disc Year	Year Cum	Est % Rec	From File	Formation Water	Depositional Environment	Res Temp., °F
TX	RRC 8	1985	Azalea, W.	San Andres	313	Midland	19	4338	0	747	14940*	14193*	40*	Dol				1981	1989	5	TX RRC	>100000	Marine Shelf	130
TX	RRC 1	1985	Billy Holland	Glen Rose	218	Edwards	20	540	0	0				SS			11	1948	1989	0	TX RRC	<100000	FDD	73
TX	RRC 8	1991	Blalock Lake, E.	Wolfcampian	319	Glasscock	17	7914	244551	4545062	1601338	11468276	800	Dol/LS	10	36	43	1971	1991	28	TX RRC	>100000	Marine Shelf	185
TX	RRC 8	1985	Coronet	Glorieta (2900)-San Angelo	318	Howard	20	2740	0	532632	10652640*	10120008*	620	Dol	10*	36*	15	1952	1989	5	TX RRC	>100000	Marine Shelf	82
TX	RRC 8A	1985	Dollarhide, E.	Wolfcampian	319	Andrews	18	8350	0	1220	24400*	23180*	40	Dol/LS			25	1956	1989	5	TX RRC	>100000	Marine Shelf	167
TX	RRC 8	1985	Dorvene	Yates	313	Ward	20	2951	0	66871	245926	179055	165*	Dol	8	100	4	1970	1989	27	TX RRC	>100000	Marine Shelf	89
TX	RRC 8A	1985	Fluvanna	Leonard	318	Borden	15	5160	563	43040	860800*	817760*		Dol/LS			22	1969	1989	5	TX RRC	>100000	Marine Shelf	155
TX	RRC 8	1985	Grassroots	Upper Permian	311	Pecos	19	42	4	3836	76720*	72884*	240	SS			3	1942	1989	5	TX RRC	<100000	FDD	68
TX	RRC 8	1985	Hence	Grayburg	313	Ector	20	4473	5413	179067	570161	391094		LS			4	1962	1989	31	TX RRC	>100000	Marine Shelf	134
TX	RRC 1	1985	Holman Ranch	Glen Rose	367	Edwards	14	550	0	168960	9235600	9066640	640	SS	31	174	10	1947	1989	2	TX RRC	<100000	FDD	73
TX	RRC 8	1985	Hurlbut	Sunflower	313	Mitchell	19	126	0	2720	173788	171068	80	SS	20	500	2	1952	1989	2	TX RRC	<100000	FDD	70
TX	RRC 8A	1985	Leeper	Wolfcampian	319	Hockley	18	8492	0	1946	38800*	36854*		Dol/LS				1979	1989	5	TX RRC	>100000	Marine Shelf	170
TX	RRC 8A	1985	Log-Pat	Wichita-Albany	318	Scurry	20	5094	1273	43143	862860*	819717*		Dol/LS			10	1969	1989	5	TX RRC	>100000	Marine Shelf	153
TX	RRC 8A	1985	Marholl	Clear Fork	318	Dawson	20	7403	948	33867	677340*	643473*		LS				1981	1989	5	TX RRC	>100000	Marine Shelf	162
TX	RRC 8	1985	Massey	1000		Pecos	20	1004	2497	35522	710440*	674918*					10	1978	1989	5	TX RRC	>100000		77
TX	RRC 1	1985	Massie West	Paluxy	218	Val Verde	18	360	329	104147	814632	710485	50	SS	30	###	10	1959	1989	13	TX RRC	<100000	FDD	73
TX	RRC 7C	1985	Millspaugh	Glen Rose	218	Crockett	20	368	0	0				SS			3	1965	1989		TX RRC	<100000	FDD	71
TX	RRC 8	1991	Oates	Rustler	312	Pecos	18	790	13322	1037313	7373583	6354230	360	Dol	8*		55	1947	1991	14	TX RRC	>100000	Marine Shelf	85
TX	RRC 7C	1985	Olson	Grayburg-San Andres	313	Crockett	18	1828	189193	14374369	34797455	20423086	2840	Dol	16		40	1940	1991	41	TX RRC	>100000	Marine Shelf	100
TX	RRC 1	1985	Parmer	Paluxy	218	Val Verde	20	473	0	106	2120*	2014*		SS			6	1969	1989	5	TX RRC	<100000	FDD	73
TX	RRC 8	1985	Pyote	Yates-Seven Rivers	313	Ward	19	2827	0	338486	1559840	1221354	80	LS	15		30	1942	1989	22	TX RRC	>100000	Marine Shelf	85
TX	RRC 8A	1985	Ropesville	Clear Fork	318	Hockley	18	5796	0	11277	225540*	214263*		LS/Dol				1978	1989	5	TX RRC	>100000	Marine Shelf	146
TX	RRC 8	1985	Sand Hills, S.	Holt	313	Crane	20	3723	3031	139606	446883	307277	120	LS	8		10	1966	1989	31	TX RRC	>100000	Marine Shelf	112
TX	RRC 8	1985	Schuler	Leonard	318	Pecos	20	4619	0	4939	21017	16078		Dol/LS			19	1964	1989	24	TX RRC	>100000	Marine Shelf	138
TX	RRC 7C	1985	Schuler, S.	Leonard	318	Terrell	17	4324	0	1513	30260*	28747*		Dol/LS			12	1966	1989	5	TX RRC	>100000	Marine Shelf	130
TX	RRC 8	1985	Toborg	Trinity	218	ecos/Crocke	19	350	161651	41549511	72338779	30789268	7000	SS/Cgl	33	###	10	1929	1991	57	TX RRC	<100000	FDD	79
TX	RRC 1	1985	Turney	Glen Rose	218	Edwards	20	568	963	23633	472660*	449027*	80	LS			10	1939	1989	5	TX RRC	<100000	Marine Shelf	73
TX	RRC 1	1985	Walt	Paluxy	218	vards/Val V	17	284	0	32371	6727557	6695186	1147	SS	18	###	24	1961	1989	0.4	TX RRC	<100000	FDD	73
TX	RRC 1	1985	Wardlaw	Glen Rose	218	Edwards	18	300	1371	74371	13363620	13289249	550	SS	29	58	##	1947	1991	1	TX RRC	<100000	FDD	70
TX	RRC 8	1985	Wentz, West	Grayburg	313	Pecos	20	1710	0	2112	9732	7620		SS			20	1965	1989	22	TX RRC	>100000	FDD	78
TX	RRC 8A	1985	Wilson, West	Clear Fork	318	Lynn	17	6522	130	14519	290380*	275861*		LS				1981	1989	5	TX RRC	>100000	Marine Shelf	147
TX	RRC 1	1985	Worth Evans	Glen Rose	218	Edwards	20	295	8	21								1984	1989		TX RRC	<100000	FDD	70
NM		1984	Barber	Yates	313	Eddy	20	1400		1779616	35582320*	33812704*	600	Dol	15	36*	5	1937	1984	5	USGS	>100000	Marine Shelf	73
NM		1984	Button Mesa, S.	San Andres	313	Lea	18	4177		112942	2094768	1981826	40	Dol	10*	36*	17	1964	1984	5	USGS	>100000	Marine Shelf	125
NM		1984	Chisum	San Andres	313	Chaves	20	2028		56008	1120160*	1064152*	120	Anh/Dol	7	2.3	5	1951	1984	5	USGS	>100000	Marine Shelf	75
NM		1984	Crossroads, W.	San Andres	313	Lea	18			175519	3510380*	3334861*		Dol	6	29	44		1984	5	USGS	>100000	Marine Shelf	
NM		1984	Jenkins	San Andres	313	Lea	19	4846		52549	1117210	1064661	120	Dol	10*	36*	20	1959	1984	5	USGS	>100000	Marine Shelf	145
NM		1984	Leslie Spring	San Andres	313	Chaves	19	1484		11745	3351629	3339884	400	Dol/LS/SS			18	1964	1984	5	USGS	>100000	Marine Shelf	83
NM		1984	Magruder	Yates	313	Eddy	16	570		19513	390260*	370747*	200	SS/Dol.			2	1953	1984	5	USGS	>100000	Marine Shelf	73
NM		1982	Maroon Cliffs	Tansill	313	Eddy	20	2179		26336	525720*	500384*		Anh/Dol			20	1959	1982	5	USGS	>100000	Marine Shelf	75
NM		1974	Maroon Cliffs	Bone Spring	318	Eddy	20	6786		14946	298920*	283974*		LS			40	1959	1974	5	USGS	>100000	Marine Shelf	136
NM		1984	Mescalero	San Andres	313	Lea	18	4063		5962047	119240940	113278893	160	LS/SS/Dol	10*	36*	67	1962	1984	5	USGS	>100000	Marine Shelf	122
NM		1982	Parallel	Tansill	313	Eddy	20			7746	154920*	147174*		Dol			3		1982	5	USGS	>100000	Marine Shelf	
NM		1984	PCA	Yates	313	Eddy	20	1500		860269	17205380*	16345111*	480	LS	10*	36*		1939	1984	5	USGS	>100000	Marine Shelf	83
NM		1984	Ranger Lake	San Andres	313	Lea	17	4833		864	17280*	16416*		Dol/LS/SS			10	1967	1984	5	USGS	>100000	Marine Shelf	145
NM		1984	Tower	San Andres	313	Chaves	19	4148		2983	59660*	56677*		Dol/LS/SS			17	1970	1984	5	USGS	>100000	Marine Shelf	124
	TOTAL									72450010	275084458	220755230												

TABLE 2

Permian Basin Heavy Oil Reservoir Data
(> 1 Million Barrels Original-Oil-in-Place)

ST	District	Data Year	Field	Reservoir	Geo Age	County	API	Depth	89 Prod	Cum. Prod	OOIP Estimated
NM		1984	Barber	Yates	313	Eddy	20	1400		1779616	35582320*
NM		1984	Button Mesa, S.	San Andres	313	Lea	18	4177		112942	2094768*
NM		1984	Crossroads, W.	San Andres	313	Lea	18			175519	3510380*
NM		1984	Jenkins	San Andres	313	Lea	19	4846		52549	1117210*
NM		1984	Leslie Spring	San Andres	313	Chaves	19	1484		11745	3351629*
NM		1984	Mescalero	San Andres	313	Lea	18	4063		5962047	119240940*
NM		1984	PCA	Yates	313	Eddy	20	1500		860269	17205380*
TX	RRC 8	1989	Blalock Lake, E.	Wolfcampian	319	Glasscock	17	7914	270839	4073582	16013338*
TX	RRC 8	1989	Coronet	Glorieta (2900)-San Angelo	318	Howard	20	2740	0	532632	4328187*
TX	RRC 1	1985	Holman Ranch	Glen Rose	367	Edwards	14	550	0	168960	9235600
TX	RRC 8	1989	Oates	Rustler	312	Pecos	18	790	3715	1019353	7373583
TX	RRC 7C	1989	Olson	Grayburg-San Andres	313	Crockett	18	1828	159858	14042330	34797455*
TX	RRC 8	1985	Pyote	Yates-Seven Rivers	313	Ward	19	2827	0	338486	1559840
TX	RRC 8	1989	Toborg	Trinity	218	Pecos/Crockett	19	500	181923	41233104	72338779
TX	RRC 1	1985	Walt	Paluxy	218	Edwards/Val Verde	17	284	0	32371	1173070*
TX	RRC 1	1989	Wardlaw	Glen Rose	218	Edwards	18	300	1134	71841	13363620*

All numbers with asterisk are estimates

Field	OIP Calculated	Area Acres	Lithology	Porosity	Perm	Net Pay	Disc Year	Year Cum	% Rec Calc	From File	Formation Water Estimate	Depositional Environment	Reservoir Temp °F Estimate	Yrs Prod
Barber	33812704*	600	Dol	15	36*	5	1937	1984	5	USGS	>100000	Marine Shelf	73	47
Button Mesa, S.	1981826*	40	Dol	10*	36*	17	1964	1984	5.4	USGS	>100000	Marine Shelf	125	20
Crossroads, W.	3334861*		Dol	6	29	44		1984	5	USGS	>100000	Marine Shelf		
Jenkins	1064661*	120	Dol	10*	36*	20	1959	1984	4.7	USGS	>100000	Marine Shelf	145	25
Leslie Spring	3339884*	400	Dol/LS/SS	10*	36*	18	1964	1984	0.35	USGS	>100000	Marine Shelf	75	20
Mescalero	113278893*	160	LS/SS/Dol	10	36*	67	1962	1984	5	USGS	>100000	Marine Shelf	122	22
PCA	16345111*	480	LS	10*	36*	10	1939	1984	5	USGS	>100000	Marine Shelf	75	45
Blalock Lake, E.	11939756*	800*	Dol/LS	10*	36*	43	1971	1989	25.4	TX RRC	>100000	Marine Shelf	158	18
Coronet	3796555*	620	Dol	10*	36*	15	1952	1989	12.3	TX RRC	>100000	Marine Shelf	82	37
Holman Ranch	9066640	640	SS	31	174	10	1947	1989	2	TX RRC	<100000	FDD	73	42
Oates	6354230	360	Dol	8*	36*	55	1947	1989	14	TX RRC	>100000	Marine Shelf	73	42
Olson	20754695*	2840	Dol	16*		18	1940	1989	40.3	TX RRC	>100000	Marine Shelf	78	49
Pyote	1221354	80	LS	15		20	1942	1989	22	TX RRC	>100000	Marine Shelf	85	47
Toborg	31105675	7000*	SS/Cgl	33	86	10	1929	1989	57	TX RRC	<100000	FDD	73	60
Walt	1140699*	200	SS	18	2500	6	1961	1989	2.8	TX RRC	<100000	FDD	73	28
Wardlaw	13291779*	550*	SS	29	58	18	1947	1989	0.54	TX RRC	<100000	FDD	73	42

END

DATE
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