COO-2687-5
Distribution Category UC-66

DEVELOPMENT OF AN ASSESSMENT METHODOLOGY FOR GEOPRESSURED ZONES OF THE UPPER GULF COAST BASED ON A STUDY OF ABNORMALLY PRESSURED GAS FIELDS IN SOUTH TEXAS

Final Report

R.K. Swanson, P. Oetking, J.S. Osoba, R.C. Hagens

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78284

Prepared for

THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
UNDER CONTRACT NO. E(11-1)-2687

August 1976

Approved:

John R. Barton

John R. Barton, Vice President
Instrumentation Research Division

DISCLAIMER

ABSTRACT

Detailed study of the producing gas fields in south Texas has identified a total of 47 abnormally pressured fields in a six-county area including Hidalgo, Brooks, Cameron, Willacy, Kenedy, and Live Oak Counties. An assessment methodology for assessing the potential of the deep geopressured zone in south Texas as an energy resource was developed, based on investigation of the reservoir parameters of these fields. This methodology is transferrable to broad areas of the Gulf Coast.

The depth of the geopressured zone in the study area ranges from 7000 ft in western Hidalgo to 12,000 ft in central Cameron County. Except for Live Oak County, which represents Wilcox production, geopressured sediments in south Texas are mainly in the Vicksburg formation. Over much of the area, the top of the geopressured zone approximately coincides with the top of the Vicksburg.

Temperature data from within the fields, corrected to undisturbed reservoir values, yields a 300°F-isogeothermal surface at depths from 10,500 ft to 17,000 ft over the study area. Although control is limited, a 375°F-surface was found to occur at depths from 14,000 ft in southwestern Live Oak County to more than 20,000 ft on the Coast in eastern Kenedy County.

The question of fluid deliverability was found to be paramount in determining the potential of the geopressure-geothermal resource as a practical source of energy. The critical parameter is the effective reservoir permeability throughout the study region. Permeability values range from less than 0.03 md to more than 8 md, with average values over all the fields near 1 md. Permeability was found to be a strong function of depth, and permeability profiles of fields at opposite geographic extremes in the study area exhibit a uniform reduction in permeability with depth which amounts to approximately 1 order of magnitude for each 2000 ft of depth in the range from 6,000 to 14,000 ft.

Individual fields were assessed for their potential to produce large quantities of geothermal fluid based on reservoir study and detailed geological investigation. Five locations within the study region have been selected as potential candidates for further evaluation and possible eventual testing.

Based on investigation of permeability and temperature, the upper limit of fluid temperature likely to be produced in the lower south Texas study region is 300°F. In Live Oak County, the possibility of producing fluid at higher temperatures is somewhat improved, with a reasonable possibility of producing fluid at 350° to 375°F.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

I. INTRODUCTION

The northern coastal region of the Gulf of Mexico basin, from Mexico to Mississippi, is underlain by deep zones of abnormal pressures and elevated temperatures. Knowledge of these temperatures, pressures, and sediments is primarily the result of information gained during the drilling of tens of thousands of petroleum exploration wells over the last 50 years. The abnormal pressures are believed to be the result of arrested compaction of shale with increasing depth of burial, as a result of impaired subsurface drainage. The occurrence of countless major and minor growth faults, generally parallel to the Coast, undoubtedly dominates this process. The resulting abnormal pressure is known as "geopressure." The increased temperature gradients are thought to be the result of the insulating properties of the undercompacted shale. These beds impair the normal flow of heat from below the earth's crust, thus producing subsurface temperatures higher than considered normal.

This report documents a study of one of these prominent geopressured regions on the Gulf Coast. This study is based upon a detailed investigation of production records and other data from a large number of producing gas fields in the area. The region, noted for its history of abnormal pressures, is located in extreme south Texas. It includes the counties of Hidalgo, Brooks, Cameron, Willacy, and Kenedy, which make up the south Texas coastal region, and Live Oak County in south central Texas. Live Oak County was added to the investigation because it represents a region of known high pressure and temperature on a separate geologic trend. The study region is shown on the map in Figure 1.

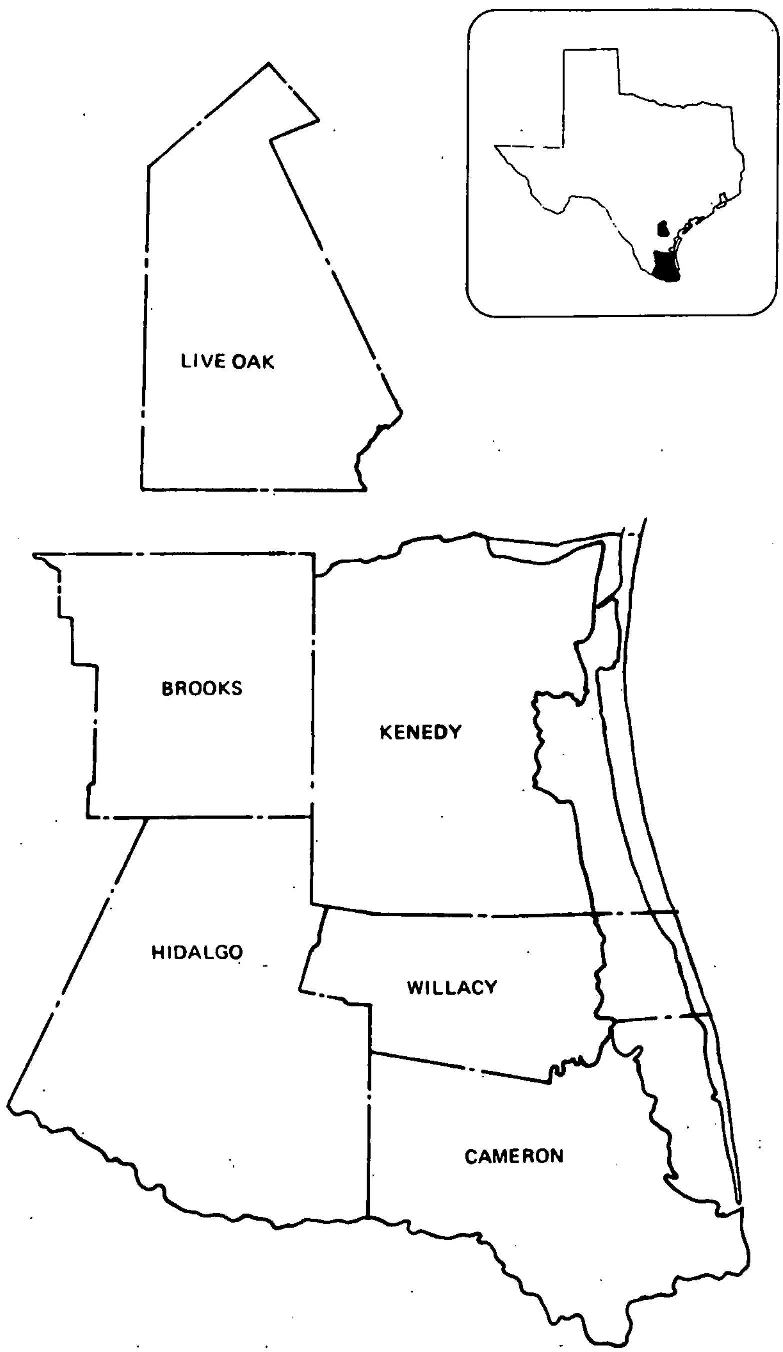


FIGURE 1. SOUTH TEXAS STUDY REGION, SHOWING RELATIVE LOCATION (INSET)

Instrumental to the study was the identification of gas fields with a history of production from geopressured formations. Because of the relatively large number of these fields, their systematic study was expected to illuminate significant outstanding questions concerning the exploitation of the deep geopressured zones, which show promise as a source of geothermal energy. The high-pressure hot water they contain represents hydraulic energy and thermal energy, and, perhaps of overriding importance, the water may also be saturated with methane. If wells can be completed in these zones capable of producing large quantities of hot water, these sandstone reservoirs could comprise a useful energy resource.

Proper assessment of the potential of this resource is at an early stage of development. Petroleum exploration technology is useful, but not complete for the purpose. In order for practical production of energy from this resource to become a reality, several conditions must be coincident. First, large aquifers of considerable thickness at temperatures higher than 150°C (300°F) must be located. Second, these aquifers must be continuous over areas measured in terms of many square kilometers; third, the reservoir rock must have sufficient porosity to contain large quantities of water; and fourth, effective permeability must permit the delivery of tens of thousands of barrels of water per day per well. A reasonable starting point for an assessment of the occurrence of these conditions is a study of the production history of producing petroleum reservoirs in the zones of interest.

II. RESEARCH METHODOLOGY

A. Study Region

The results presented in this report apply to a region in extreme south Texas encompassing Cameron, Willacy, Hidalgo, Brooks, and Kenedy Counties, and the geographically separate south-central Texas County of Live Oak. Geopressure at moderate depth is known to exist throughout the area, and the temperature gradient is among the highest in the Gulf Coast basin. Oil and gas have been produced prolifically over much of the area since the 1930's, and the geothermal potential has been under geologic and hydrologic investigation for a number of years by the USGS and others. However, no comprehensive investigation of reservoir parameters has previously been reported.

The entire region of the study is a sparsely populated, arid geographic area devoted almost exclusively to agriculture and ranching. The three-county segment made up of Hidalgo, Willacy, and Cameron Counties is generally referred to as the "Lower Rio Grande Valley" of Texas. The three largest cities, McAllen, Harlingen, and Brownsville, are all located near the Mexican border in a narrow, irrigated agricultural belt. In large part, the region has only token industrial activity, restricted primarily to canning, oil and gas production, and, in Live Oak County, some uranium mining. The terrain throughout the area is flat and relatively featureless, and has been the site of important natural gas production since the period immediately preceding World War II. Nearly 300 producing fields are listed in Texas Railroad Commission records for the six-county area. Of these fields, 47 have been identified as producing from abnormally pressured zones.

B. Methodology

The purpose of this program is to establish a methodology for assessment of the deep geopressured zone on the Gulf Coast, based on a detailed examination of south Texas gas fields which have produced substantial quantities of fluids from these zones. Of principal importance to this effort was the identification of the number and location of geopressured producing fields in the study region. Such an investigation had not previously been reported.

1. Location of Producing Fields

The first significant task in the project was the location of all producing fields in the region. This task was accomplished by obtaining the Texas Railroad Commission field listings for Southwest Texas, Districts 2 and 4. These listings were placed in a computer file, and the file sorted by county. After the initial county listings were obtained, all fields with producing depths below 7000 ft were identified. This process of preliminary selection was based upon a thorough review of the literature, and knowledge of geopressure as described by notable workers in the field (e.g., Dickinson, 1953; Hottman and Johnson, 1965; Hottman, 1966; Jones, 1969; Wallace, 1970; Bebout, *et al.*, 1975 and others), and by detailed USGS study (to be published) of occurrence of geopressure within the lower part of the study region. No significant occurrence of geopressure has been reported in south Texas at depths less than 7000 ft, and the known geothermal gradients are such as to preclude a useful geothermal source at lesser depths. This initial tabulation of fields deeper than 7000 ft for the six counties in the study appears in Appendix A. A breakdown listing fields with production at depths below 10,000 ft also appears as a matter of interest.

2. Identification of Geopressured Production

In order to identify the geopressured production, all producing wells in each of the listed fields were identified, from two sources.

a. *Geologic Mapping Service*

Early in the project, the mapping service of Geomap of the Gulf Coast, Inc. was obtained. This service provides continually updated regional maps marked with well location, operator identification, and total depth. Regional geology is also mapped and periodically updated. Although the geologic coverage of the deep horizons of principal interest to the geopressure study is not complete, the general geology is extremely useful.

b. *Ownership Maps*

Somewhat more complete well identification, particularly from the older fields, was obtained from ownership maps available from various mapping services. These maps show land ownership, leasing arrangements, and well locations. Wells were identified in each of the producing fields on the basis of production and total depth. The deepest wells drilled in each field were identified.

3. Well Logs and Completion Data

Well logs were obtained from wells from each of the listed fields. Access to several south Texas log libraries was obtained through the services of one of the project consultants, Mr. R. C. Hagens of Corpus Christi. Completion cards on these wells were obtained from a scouting service.

From the logs and completion cards, the average depth of the geopressured zone in each field was established. If the top of geopressure was deeper than the deepest production identified in the field, the field was eliminated from further consideration (some deep-well information was used in the study of temperature and geopressure, however).

If the field had produced from one or more horizons in the geopressured zone, all the available well logs from the field were obtained.

This field identification process was tedious and consumed considerable time. Unfortunately, no simple method was ever developed for accomplishing this task. Identification of the geopressured zone in many of the fields was sufficiently difficult to require all information available. A method originally described by Hottman and Johnson (1965) is based on determination of the resistivity of shale from the amplified short normal on the electric log. It is generally found that shale resistivity increases with depth in the zones of major compaction (generally below 6000 to 8000 ft), when pressures are normal. Reversal of this trend, i.e., reduction in shale resistivity with depth, may signal abnormal pressure, resulting in arrested shale compaction. This "shale resistivity ratio" method was found to be useful in most cases, but required confirmation from casing depth and mud weight. Intermediate casing is usually set near the depth of expected high pressures, and the mud weight record generally assists in isolating the zone of drilling problems caused by abnormal pressure.

In many of the fields, deep control was seriously limited, with only one abnormally pressured well in an otherwise shallow, normally pressured field. Many geopressured fields are one-well producers.

The final result of the sorting process yielded a total of 47 separate geopressured gas fields in the study region. These gas fields are shown on the map in Figure 2 and identified in Table I.

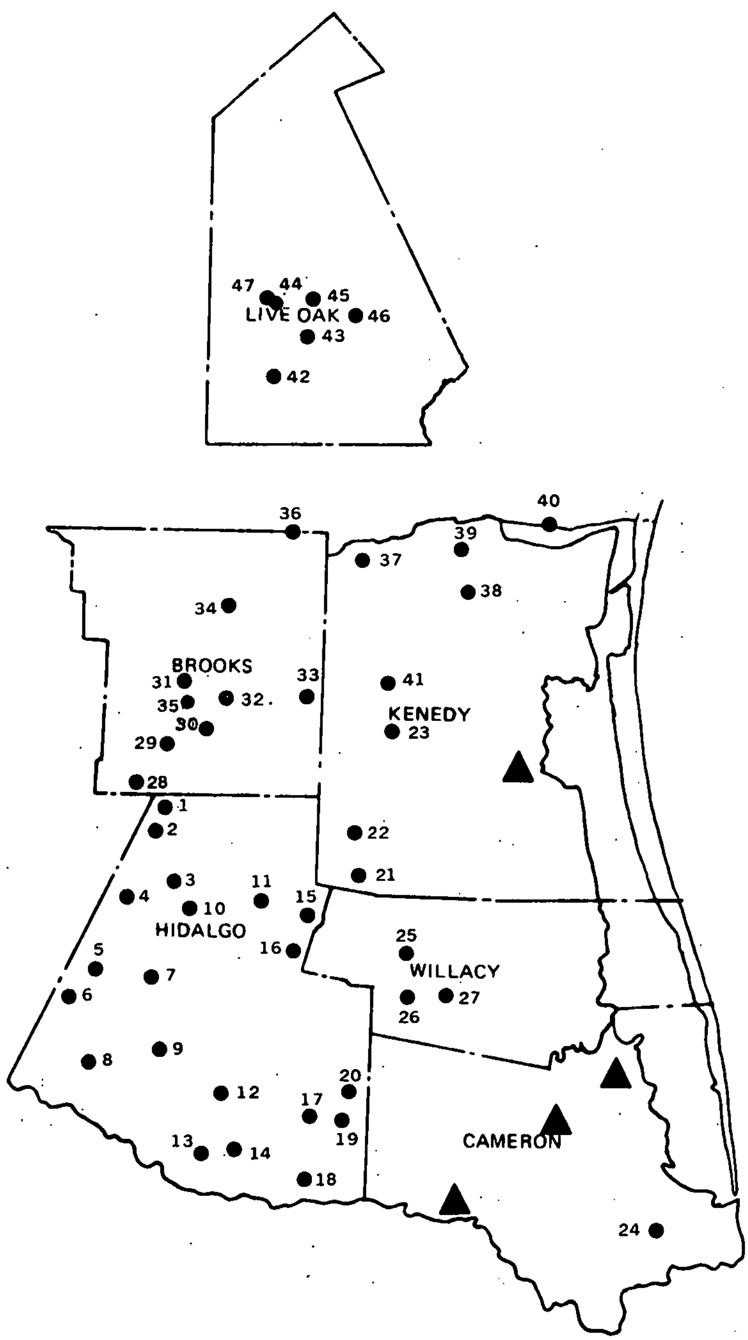


FIGURE 2. GEOPRESSURED GAS FIELDS IDENTIFIED IN STUDY REGION

• GAS FIELDS ▲ DRY HOLES OUTSIDE PRODUCING AREA

4. Geologic Investigation

Geologic investigation of each of the identified geopressured fields was undertaken, depending upon the degree of control and other factors. The geologic setting of each of the fields was established, producing horizons were defined and, where possible on the basis of available control, some determination of field size was attempted. In many cases in south Texas, a geopressured field is represented by a single well, but many times these wells are offset by dry holes, improving overall control. Assistance was sought and obtained from producing and operating companies, which provided various types of data. Many south Texas Vicksburg wells (the formation which was one of the most significant) are located in geologically complex structures. Production from small fault blocks is the rule, and even after many years, experienced geologists disagree on basic features of some of these fields. Nevertheless, sufficient information was obtained to gain a good regional picture, and in the most promising fields from the geothermal standpoint, detailed field geology was established.

5. Temperature Data

Bottom-hole temperatures from well logs were obtained from all available logs in each field. A computer program, based on the generally accepted AAPG correction relationship, was written to correct log temperature readings to undisturbed reservoir temperatures. The program also computes the temperature gradient over each log run, determines the total gradient from the surface to total depth, and calculates the depth of a 150°C (300°F) geotherm, utilizing the gradient at depth. A 190°C (375°F) geothermal surface was also estimated from the data established by the deepest wells in the area.

TABLE I. GEOPRESSURED GAS FIELDS IN SOUTH TEXAS STUDY AREA, WITH REPRESENTATIVE VALUES OF DEPTH GEOPRESSURE, AND 300°F GEOTHERM (FIELD NUMBERS APPLY TO FIGURE 2)

Field	Approx. Depth, Top Geopressure	Approx. Depth, 300° Geotherm
Hidalgo County		
1. Kelsey S.	8,500	11,400
2. McMoran	8,500	11,600
3. McAllen Ranch	7,500	11,700
4. Arrowhead	11,000	–
5. McCook	7,700	11,800
6. Jeffress	7,000	11,200
7. Monte Christo	8,600	11,700
8. Foy	csg 10,100	10,674
9. Oblate	9,700	11,000
10. Santellana	8,000	–
11. Cerda	10,200	12,000
12. S. Edinburg	9,300	11,500
13. McAllen	8,500	11,400
14. Pharr	8,700	11,500
15. La Jara	9,600	12,500
16. Hargill	10,000	12,000
17. N. Weslaco	9,600	12,400
18. S. Weslaco	9,400	13,400
19. SW Mercedes	9,400	11,600
20. Mercedes	9,450	12,000
South Kenedy County		
21. Tordilla	csg 9,480	12,600
22. Stillman	9,500	12,500
23. Candelaria	11,000	12,800
Cameron County		
24. San Martin (Cameron Co.)	9,000	12,000
Willacy County		
25. Niles	9,300	
26. Riggan	9,400	
27. La Sal Vieja	9,500	≈14,000
Brooks County		
28. Kelsey	9,000	10,800
29. Encinitas	8,500	11,400
30. La Encantada	8,400	10,600
31. Scott and Hopper	10,000	10,900
32. Skipper	8,800	11,500
33. Viboras	9,400	12,400
34. Cage Ranch	8,400	11,700
35. Alta Mesa	8,500	11,100
36. Ann-Mag	9,200	12,000
North Kenedy County		
37. Sorillo	10,100	13,900
38. El Paistle	12,200	14,100
39. Sarita	11,200	14,400
40. Baffin Bay	11,500	14,900
41. Rita	10,900	14,500
Live Oak County		
42. Katz-Slick	8,800	11,030
43. Clay West	9,200	12,000
44. East Tom Lyne	7,800	11,200
45. Kittie Burns	8,800	12,300
46. Mikeska	9,500	11,800
47. Tom Lyne	9,200	11,100
Deep Dry-Holes in Cameron County		
48. Pan Am Wentz No. 1	10,200	13,955
49. Shell Cont. Fee No. 1	12,300	12,970
50. Chevron Rodriguez No. 1	12,000	14,939

6. Reservoir Study

Available reservoir information from each of the fields was obtained from a variety of sources, including Railroad Commission production records, operating company completion data, well test records, and scout cards. The fluid pressure gradient in each of the producing horizons was estimated from the initial bottom hole pressure in the discovery well in each field. From the initial production potential, build-up and drawdown tests, and other available records, the critical reservoir parameters were determined. The general capability of each reservoir to produce fluid was assessed. After preliminary results disclosed that permeability was probably the critical parameter in all south Texas reservoirs, permeability calculations were made in as many wells as possible in each of the producing fields.

7. Well Test Results

Details of drill stem and production tests of water zones, inadvertently conducted during completion attempts, were sought, and a number of these was obtained. These results add insight into the water production capability of potential geothermal horizons in the study area.

8. Presentation of Results

The significant results of the study are presented in this report, primarily through a series of regional maps upon which temperature and reservoir information are graphically shown. From these maps the areas of greatest potential can be inferred. Conclusions are drawn and recommendations made, where warranted.

III. STUDY RESULTS

A. Geologic Setting

South Texas is dominated by a series of regional growth fault systems generally parallel to the coast. At least five of these systems in the study area are considered major. A large number of smaller faults, both parallel and transverse, divide the entire region into a countless number of fault blocks in a pattern of great complexity. In Figure 3, the six counties comprising the study area are outlined on a map showing the major fault systems. The productive geopressured fields identified in the five counties comprising the lower part of the study area are distributed along three of these major faults:

(1) The Frio-Vicksburg flexure in eastern Starr County near the Hidalgo County border, and through central Brooks County,

(2) The Tabasco Fault in southwestern Hidalgo County,

(3) The McAllen Fault, extending northward from Hidalgo through Kenedy County.

In Live Oak County, geopressured production is confined to the area immediately to the east of the large Mirando-Gohlke Fault that stretches from Zapata County into the upper Gulf Coast area.

Each of these major fault zones is comprised of numerous branches. Transverse faults are common, and the faulting generally increases in complexity with depth.

B. Occurrence of Geopressure

Geopressure was found to occur at relatively uniform depths throughout the study area, with few exceptions. The shallowest recorded occurrence of abnormal pressures in south Texas was found in the Jeffress field near the western boundary of Hidalgo County, at a depth of 6000 ft. This shallow depth is unusual, however, and the top of the geopressured zone generally ranges from about 7500 ft along the Frio-Vicksburg flexure (western Hidalgo and central Brooks Counties) to 10,500 ft at the Cameron-Hidalgo and Brooks-Kenedy county lines. The depth of occurrence of geopressure is slightly less uniform in Cameron, Willacy, and Kenedy Counties, but deep area wildcats locate geopressured formations at depths ranging from 10,000 to 13,000 ft in all the wells examined. In the productive area in Live Oak County, geopressure generally occurs at depths below 9000 ft. Representative values of the depth of the top of geopressure are shown on the map in Figure 4.

No particular significance has been attached to detailed local variations in the depth of the top of the geopressured zone, since frequently it is coincident with a particular lithologic marker over a fairly large area, and a map of the "top of geopressure" simply defines that boundary. This is typically seen in the case of the "8500" sand in the McAllen-Pharr area and in the Vicksburg "Q" sand in the Jeffress field. Both are blanket sands that always signal the first occurrence of abnormal pressures in these fields. Faulting universally becomes more complex with depth, and for this reason, within the producing zones of interest in deeper horizons, the potential geothermal reservoirs are often confined to small blocks. The continuity of most of these is highly questionable.

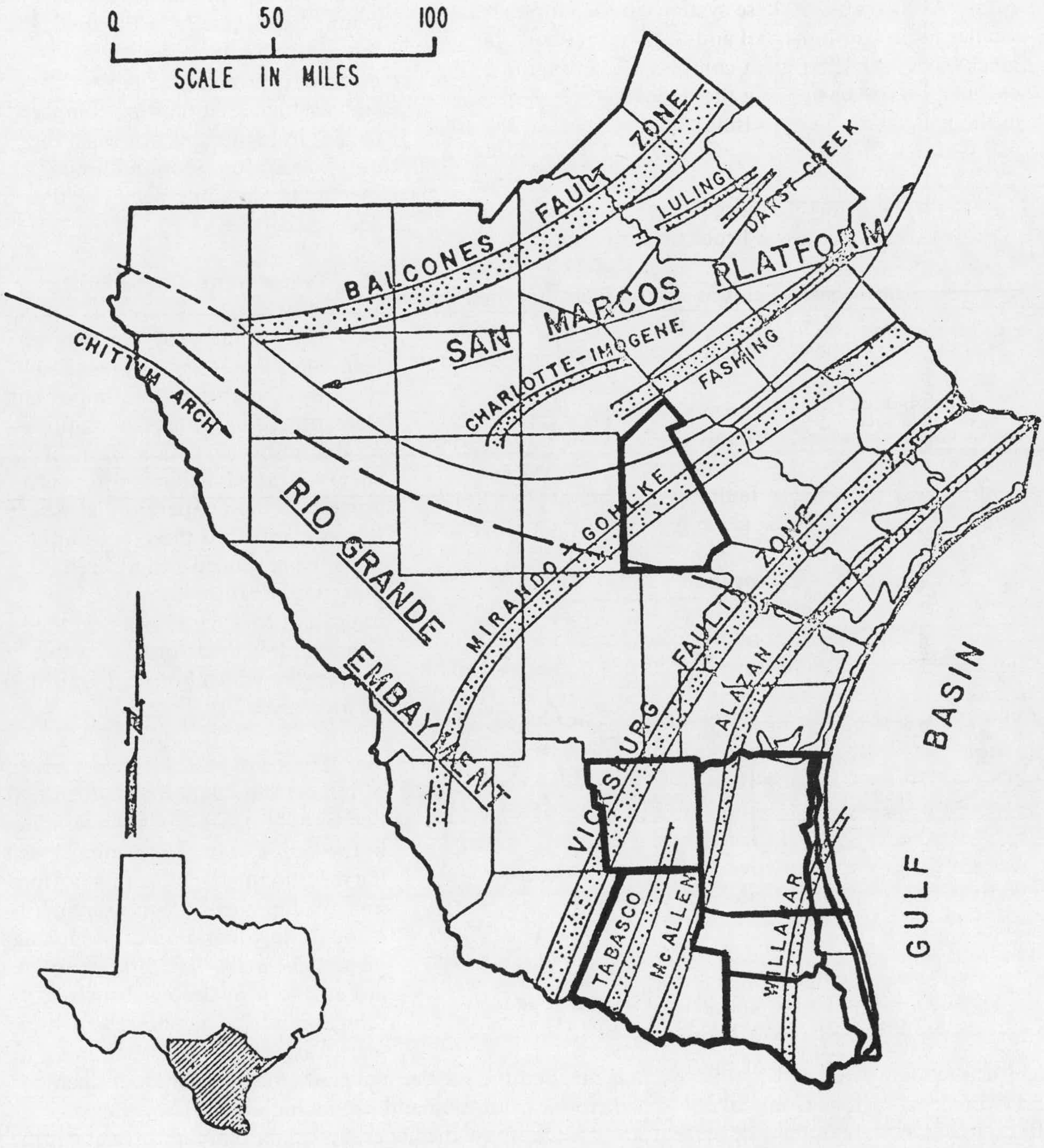


FIGURE 3. SIX-COUNTY STUDY REGION LOCATED IN RELATION TO MAJOR GEOLOGIC FEATURES OF SOUTH TEXAS

. These points are well illustrated in Figures 5, 6, and 7. Figure 5, a structure map on the top of the "8500" (Frio) sand in the McAllen-Pharr area, is in effect also a map of the top of geopressure. The Hansen Sand, mapped structurally in Figure 6, is the approximate top of high geopressure (pressure gradient ≈ 0.9), and the increased faulting compared to that in Figure 5 is obvious. Figure 7 is a cross section through the fields, detailing some of the deeper faulting.

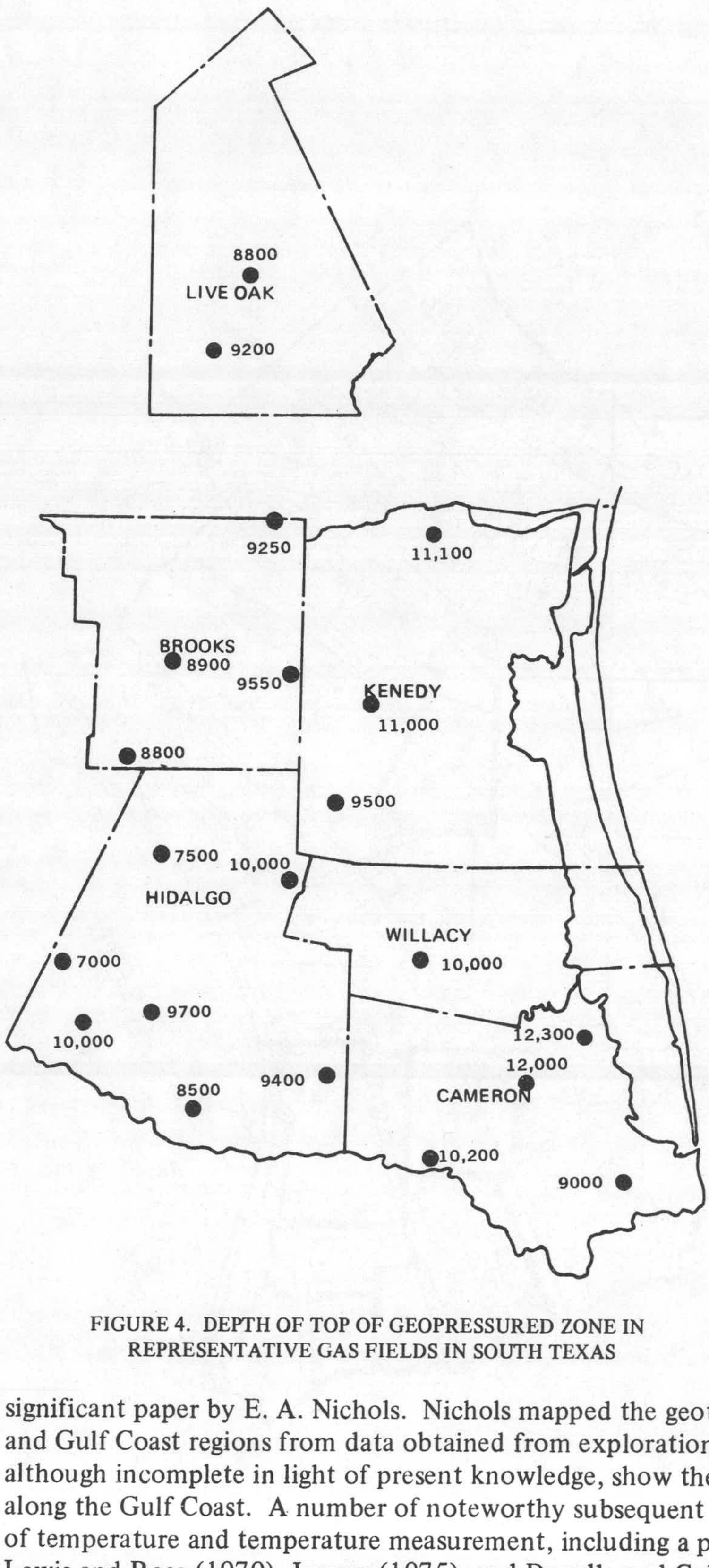


FIGURE 4. DEPTH OF TOP OF GEOPRESSURED ZONE IN REPRESENTATIVE GAS FIELDS IN SOUTH TEXAS

C. Temperature Characteristics

The enthalpy of the natural formation water in geopressured reservoirs comprises one important element of the potential usefulness of this resource. As a form of energy, heat has value in direct proportion to the temperature at which it is available, and the rate at which it can be produced and utilized. Since temperature is critical, it is important to accurately assess the temperature characteristics of the strata from which hot water might be produced.

There are basically two sources of temperature data from which temperatures at depth can be determined in the Gulf Coast. These are (1) well log measurements, including bottom-hole readings, and (2) measurements made during operation of producing oil and gas wells. The first reported attempt to investigate subsurface temperatures on a comprehensive scale was published in 1946 in a significant paper by E. A. Nichols. Nichols mapped the geothermal gradients in the midcontinent and Gulf Coast regions from data obtained from exploration and producing wells. These maps, although incomplete in light of present knowledge, show the generally higher temperatures at depth along the Gulf Coast. A number of noteworthy subsequent studies have been made on the subject of temperature and temperature measurement, including a paper by Schoeppel and Gilarranz (1966), Lewis and Rose (1970), Joyner (1975), and Dowdle and Cobb (1975), among others. Maps of the geothermal gradients of the United States have been published by the American Association of Petroleum Geologists (Kehle, 1971) and others.

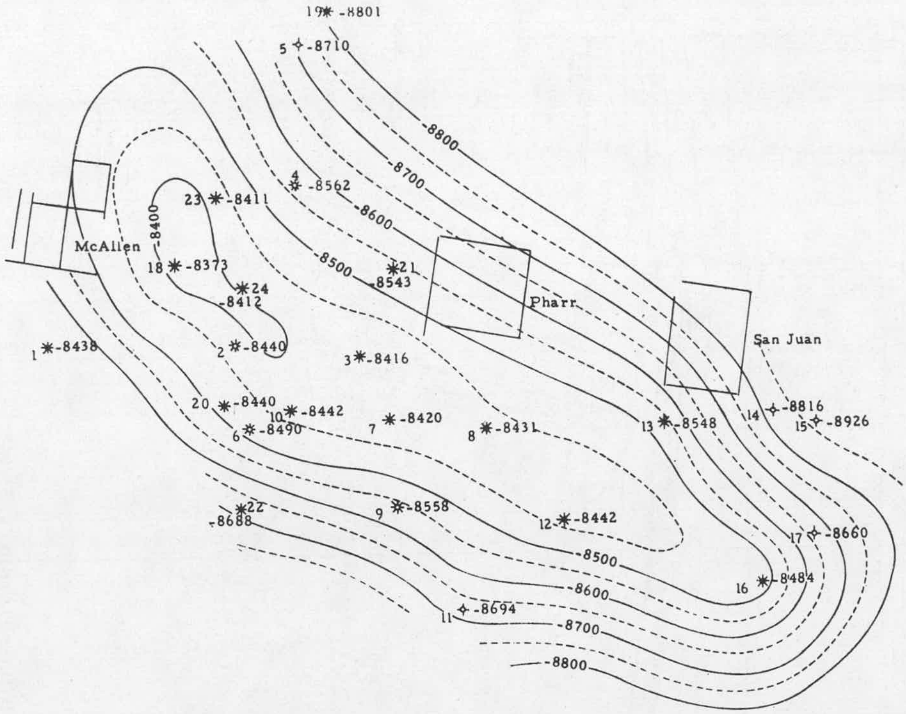


FIGURE 5. STRUCTURE MAP ON TOP OF "8500" SAND (APPROX. TOP GEOPRESSURE) IN McALLEN-PHARR FIELD, HIDALGO CO., TEXAS

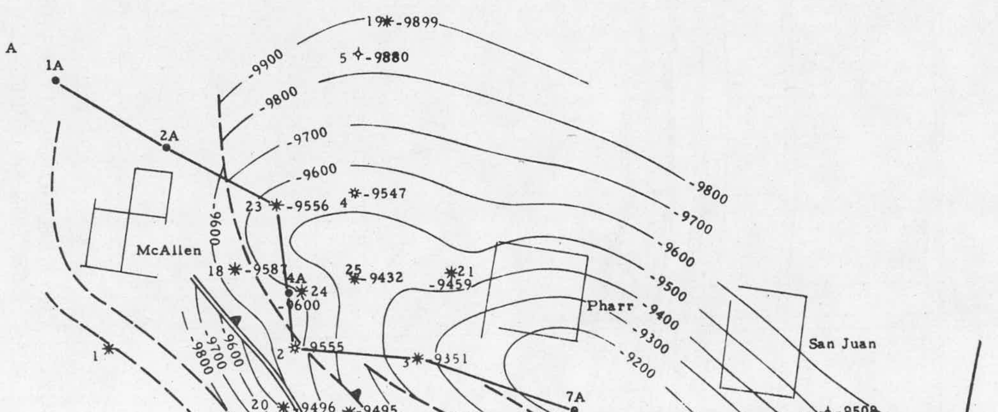


FIGURE 6. STRUCTURE MAP ON TOP OF "HANSEN" SAND, McALLEN-PHARR FIELD, APPROX. 800 FT BELOW DATUM ON FIGURE 5, SHOWING INCREASED FAULTING WITH DEPTH

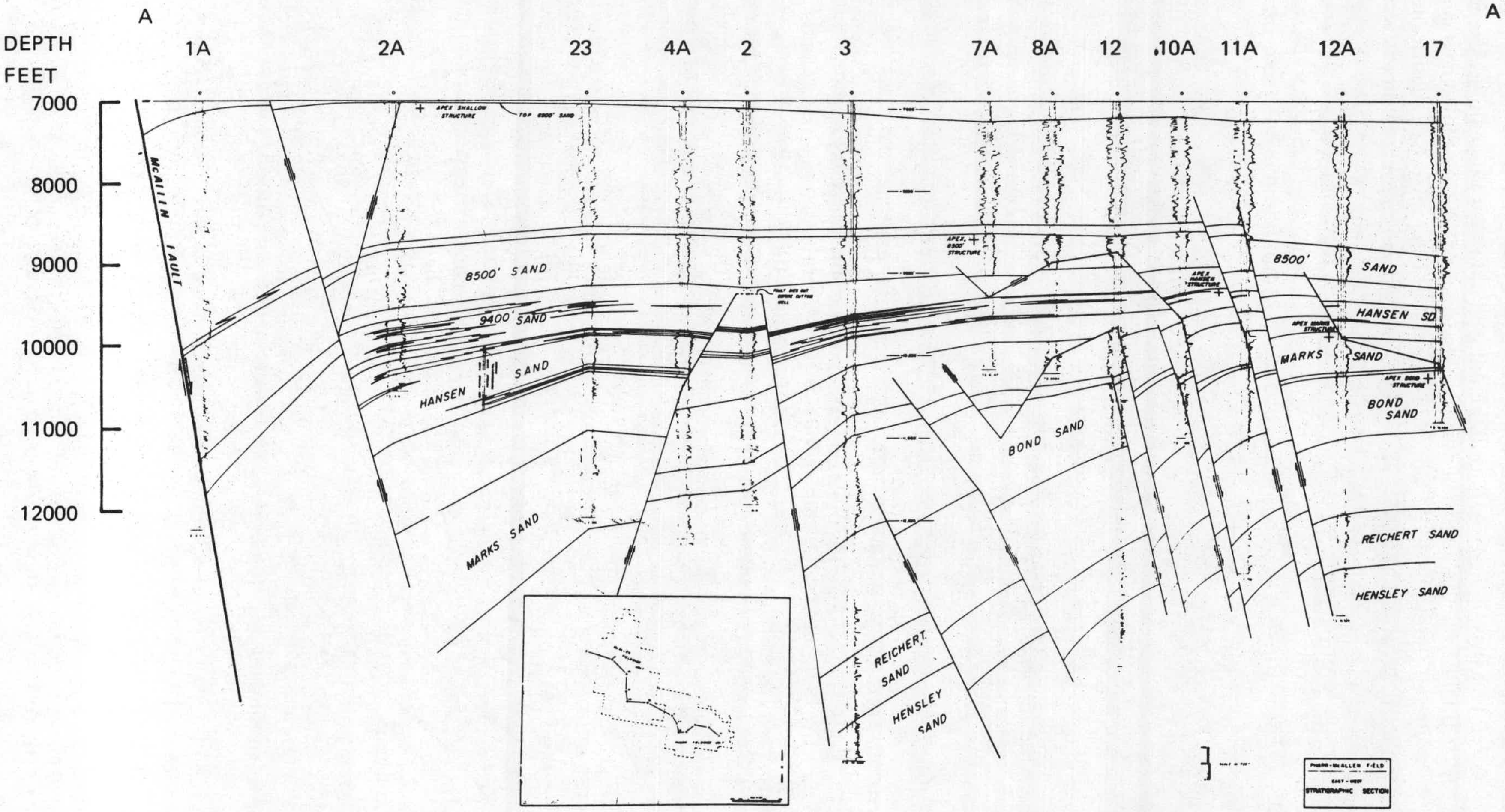


FIGURE 7. CROSS SECTION, McALLEN-PHARR FIELD, HIDALGO COUNTY, TEXAS, SECTION AA ON FIGURE 6 (AFTER COLLINS, 1967)

The Gulf Coast is known to exhibit a thermal gradient ranging from about 1.4 deg per hundred feet to 2.2 deg per hundred feet over the range of available oil well data. All other things being equal, the most promising geothermal prospects should be at those locations exhibiting the highest geothermal gradient. Here the depth of the wells would be minimal, and the cost advantage significant. Obviously, the higher temperatures must be available in conjunction with suitable reservoirs as well.

In order to evaluate the temperature potential in the study area, temperature data were obtained from well logs in each of the geopressured fields and from a random sample of dry holes across the region. Temperature readings from log headings were corrected to equilibrium values from the AAPG-developed relation

$$T_E = T_L - 8.819 \times 10^{-12} D^3 - 2.143 \times 10^{-8} D^2 + 4.375 \times 10^{-3} D - 1.018 \qquad (1)$$

where

T_E --Equilibrium temperature, °F
T_L –Electric log bottom-hole temperature, °F
D –Depth, ft.

A computer program was written to correct each temperature reading from a log heading to the undisturbed reservoir value. These corrected values were used to calculate the depth of 300°F (150°C) and 375°F (190°C) isogeothermal surfaces from the measured temperature gradients. A representative value of the depth of the 300°F surface was assigned for each of the geopressured fields. Only the deepest control points were used to construct the 375°F surface. Figure 8 shows the locations of the fields in which the 300°F geotherm was located at depths less than 11,000 ft. The shallowest depth of the 300°F point was recorded at –10,200 ft (subsea) in Jeffress field, in Hidalgo County, although its average depth in the field is slightly below –11,000 ft.

While the 300°F geotherm is of interest in showing the general temperature trend, the temperature itself is probably too low for almost all practical purposes, certainly for the generation of power with existing technology. Wilson, *et al.* (1976) set the minimum useful temperature for power production at 375°F. This is shown in a general way in Figure 9, in which the hot water required per kWh generated is plotted versus available water temperature (Holt, 1974). So few wells in the Gulf Coast have ever recorded temperatures of this magnitude, that an accurate characterization of this regime is difficult. However, data presented in Figure 10 shed some light on the matter. Temperature plots of deep wells in various parts of south Texas show the general trends to be expected. The highest overall temperature gradient recorded during the study, shown as Curve 1 in the figure, is in the Northeast Thompsonville field located in Jim Hogg County (actually outside the study area). Undisturbed formation (Wilcox) temperature calculated from recorded bottom hole readings in that field, is 390°F at 14,000 ft. Both Live Oak and western Hidalgo Counties also have fields with temperature gradients almost as high.

On the map in Figure 11 it can be seen that 375°F temperatures, from deep-well measurements in the region, occur at depths from 14,000 ft (southwestern Live Oak County) to more than 20,000 ft in central Cameron and eastern Kenedy Counties. The deepest well identified in the study area is a 20,000-ft dry wildcat near the Candelaria field (Kenedy County) with an equilibrium temperature of 375°F at 18,000 ft. An 18,500-ft well in central Cameron County failed to record temperatures above 350°F.

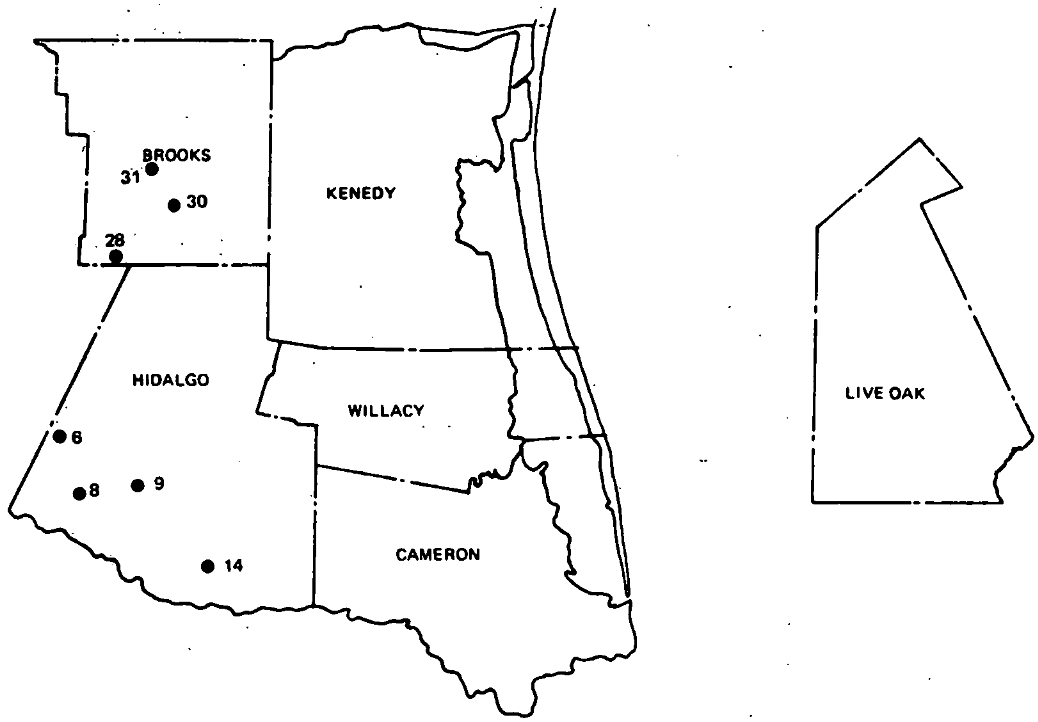


FIGURE 8. FIELDS WITH DEPTH OF 300°F (150°C) GEOTHERM LESS THAN 11,000 FEET

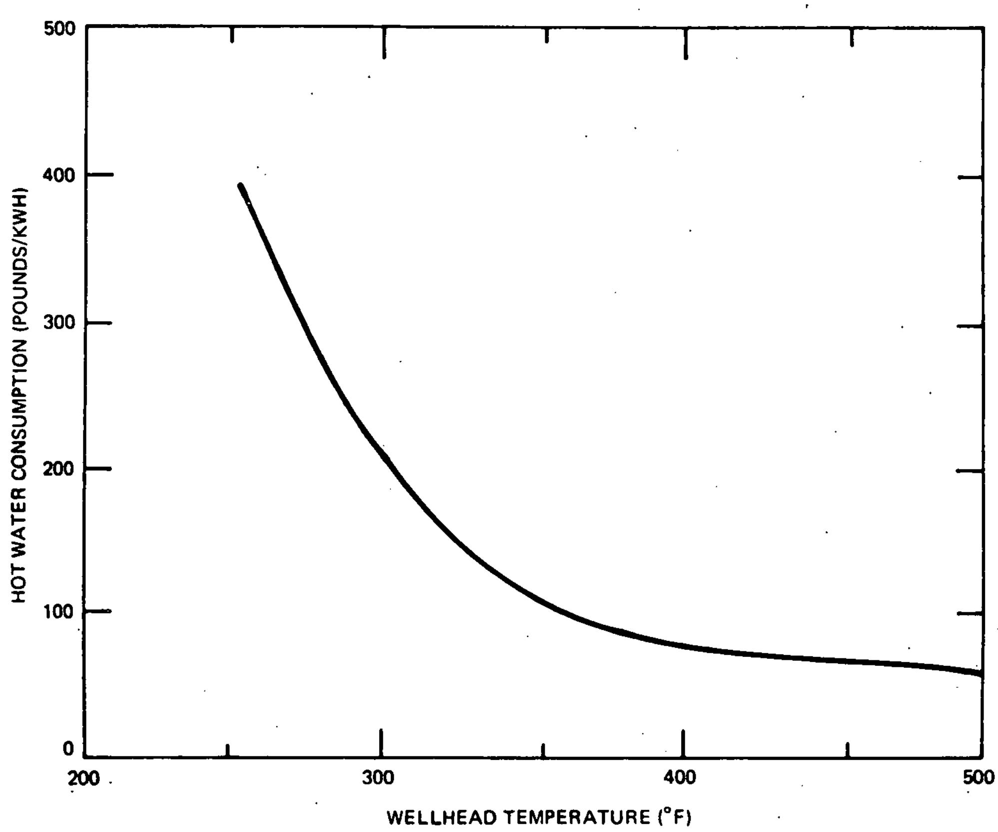


FIGURE 9. EFFECT OF WELLHEAD TEMPERATURE ON HOT WATER CONSUMPTION FOR POWER PRODUCTION (HOLT, 1974)

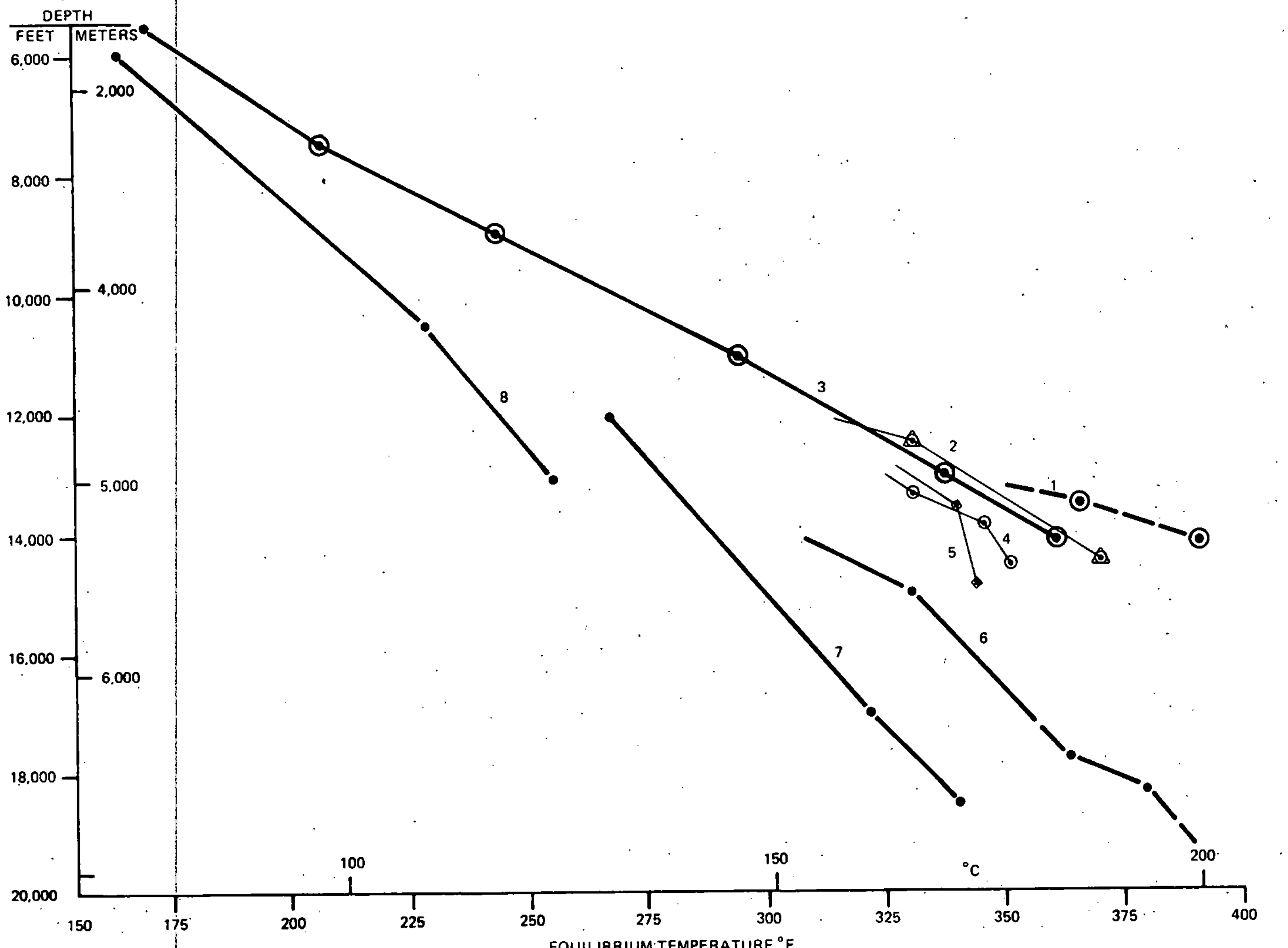


FIGURE 10. TEMPERATURE VS. DEPTH FOR REPRESENTATIVE FIELDS ACROSS SOUTH TEXAS PRODUCING COUNTIES. (1) Western Jim Hogg (Thompsonville); (2) Live Oak (Tom Lynes Area); (3) Western Hidalgo (Jeffress); (4) Central Brooks (Lips Ranch Area); (5) Southern Hidalgo (McAllen); (6) Central Kenedy (Candelaria); (7) Central Cameron; (8) Eastern Kenedy (Tajos Area).

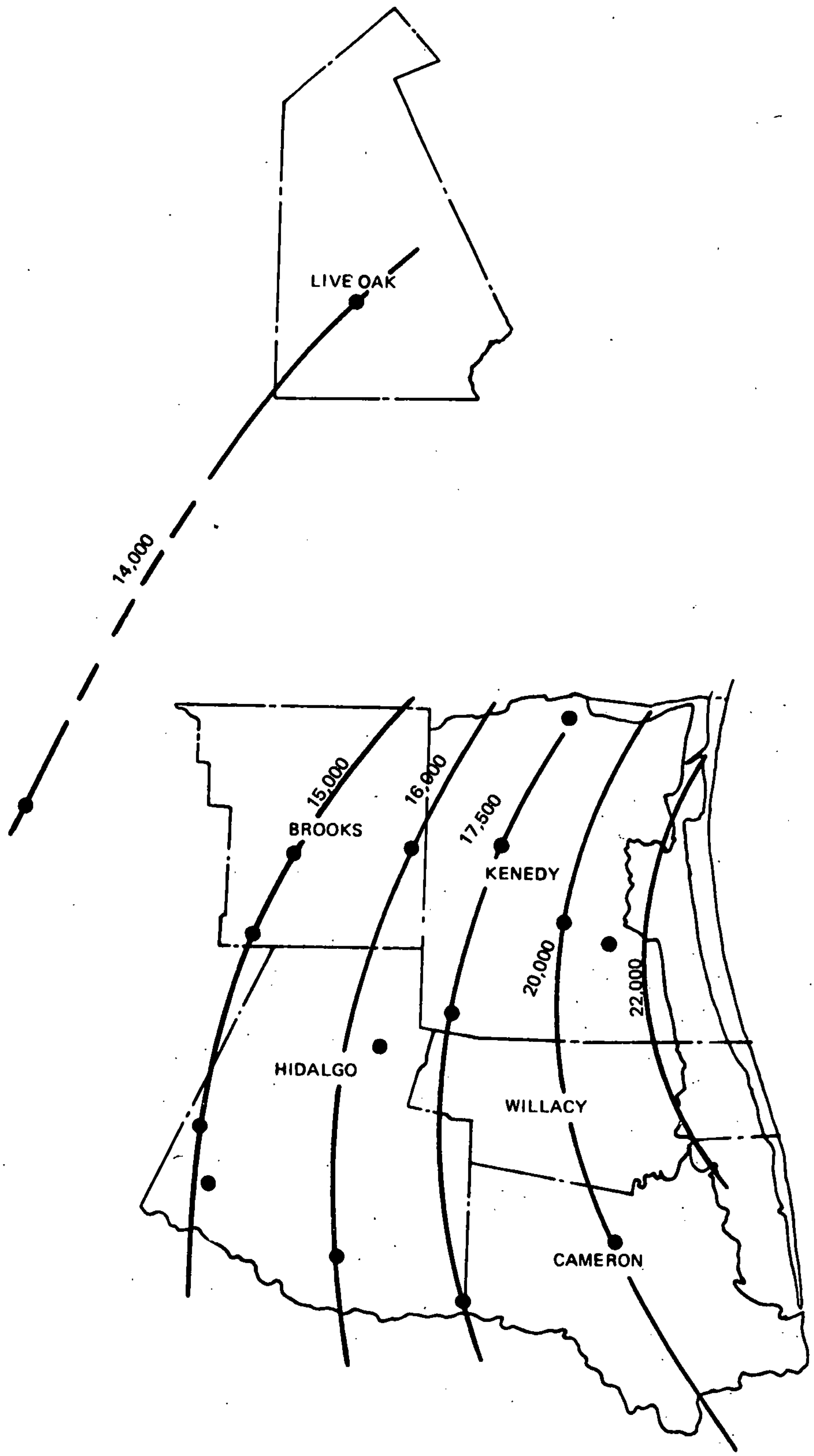


FIGURE 11. APPROXIMATE DEPTH OF 375°F (190°C) GEOTHERMAL SURFACE

1. Geologic Temperature Horizons

With the possible exception (unknown) of the very deepest part of the basin in eastern Cameron County, temperatures as high as 375°F probably do not occur in the Frio formation, but in Vicksburg or deeper sediments. In southwestern Live Oak County, high temperatures are confined to the Wilcox and deeper strata.

There is undoubtedly finer structure to the 375°F geothermal surface than is shown in Figure 11, estimated from the few deep control points in the region. Over most of the mapped area outside Live Oak County, temperatures high enough to be of geothermal interest occur in the Vicksburg formation. For this reason, great attention must be paid to potential reservoirs within this zone. Areas of extensive sand deposition in the Vicksburg are limited, and generally occur along and to the east of the Frio-Vicksburg flexure, and in northern Kenedy County. It is significant that the shallowest 375°F geotherm located in the Rio Grande Valley area (not including Live Oak County) is coincident with the region (although unfortunately not the depth) in which some of the best Vicksburg sand development occurs.

2. Detailed Field Temperature Studies

Detailed study of the localized temperature variations within geopressured gas fields was undertaken in four fields located in a promising area near the McAllen fault. This is the location of extensive deltaic Frio and Vicksburg sand deposition, and includes the Edinburg, South Edinburg, McAllen, and Pharr gas fields in lower Hidalgo County. From well log bottom-hole temperatures, corrected to equilibrium values, a 300°F geothermal surface was mapped and is shown in Figure 12. It is interesting to note that this isothermal surface is warped downward over the structural highs representing Edinburg, South Edinburg, and Pharr, but is warped upward over the McAllen structure, where it is, no doubt, dominated by a local branch of the transverse Shepherd fault. The minimum depth of the 300°F surface appears to center over the barren area between the fields, between the city of Edinburg and the city of San Juan. The complexity of the temperature profile in the area doubtless reflects the countless major and minor growth faults that characterize the region. The study illustrates the great complexity of the entire subject of temperature and geopressure, neither of which conform to any simple, generalized explanations.

Figure 13 shows a plot of temperature versus depth of a deep well in McAllen Ranch field, a highly productive Vicksburg field near the western Hidalgo border. The relatively large number of logging runs made on this well permit the wide variations in localized temperature gradients along the well bore to be observed. These are plotted in conjunction with shale resistivity values, which may be indicative of pressure. The increase in temperature gradient corresponding to the onset of high pressure lends credence to the theory that the high temperatures associated with abnormal pressures are caused by the insulating properties of under-compacted shale beds.

A matter of further interest in this figure is shown by the behavior of the temperature gradient as progressively deeper undercompacted shales are encountered. The maximum temperature gradient occurs immediately below the top of geopressure, and each major shale bed below produces an additional change in gradient. However, each new slope becomes less pronounced, and approaches the normal gradient asymptotically. Presumably if one went to sufficient depth, the gradient above the geopressured zone would be reestablished. In McAllen Ranch, that gradient is about 1.8 deg per hundred feet. Temperature projections made from the gradient below and near the top of geopressure can be misleading, and should not be attempted for depth projections greater than a thousand feet or so. In the well from which Figure 12 was prepared, the gradient at 10,000 ft, used to project the temperature at 14,000 ft, would have overestimated the temperature by more than 100°F.

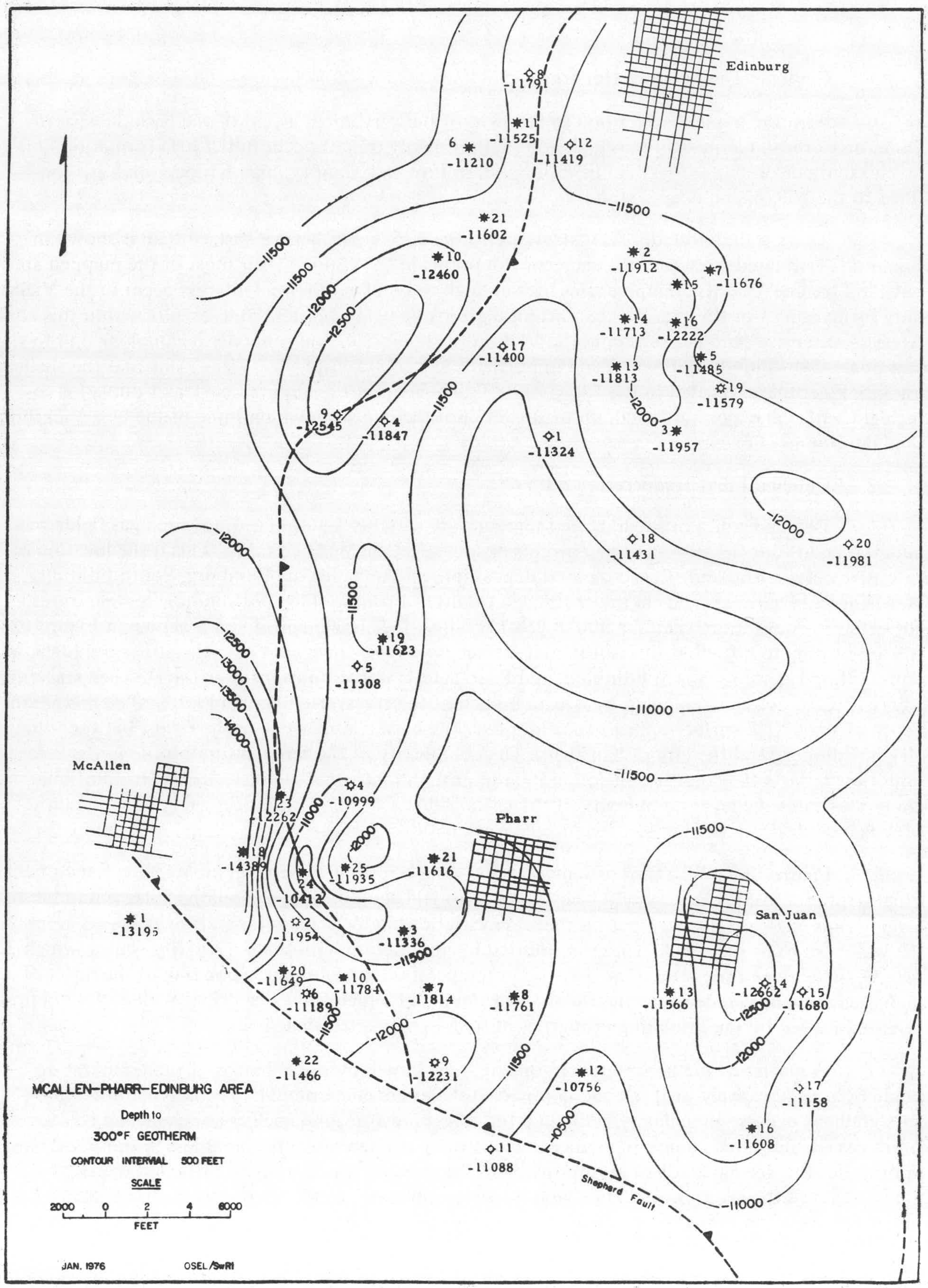


FIGURE 12. McALLEN-PHARR-EDINBURG AREA

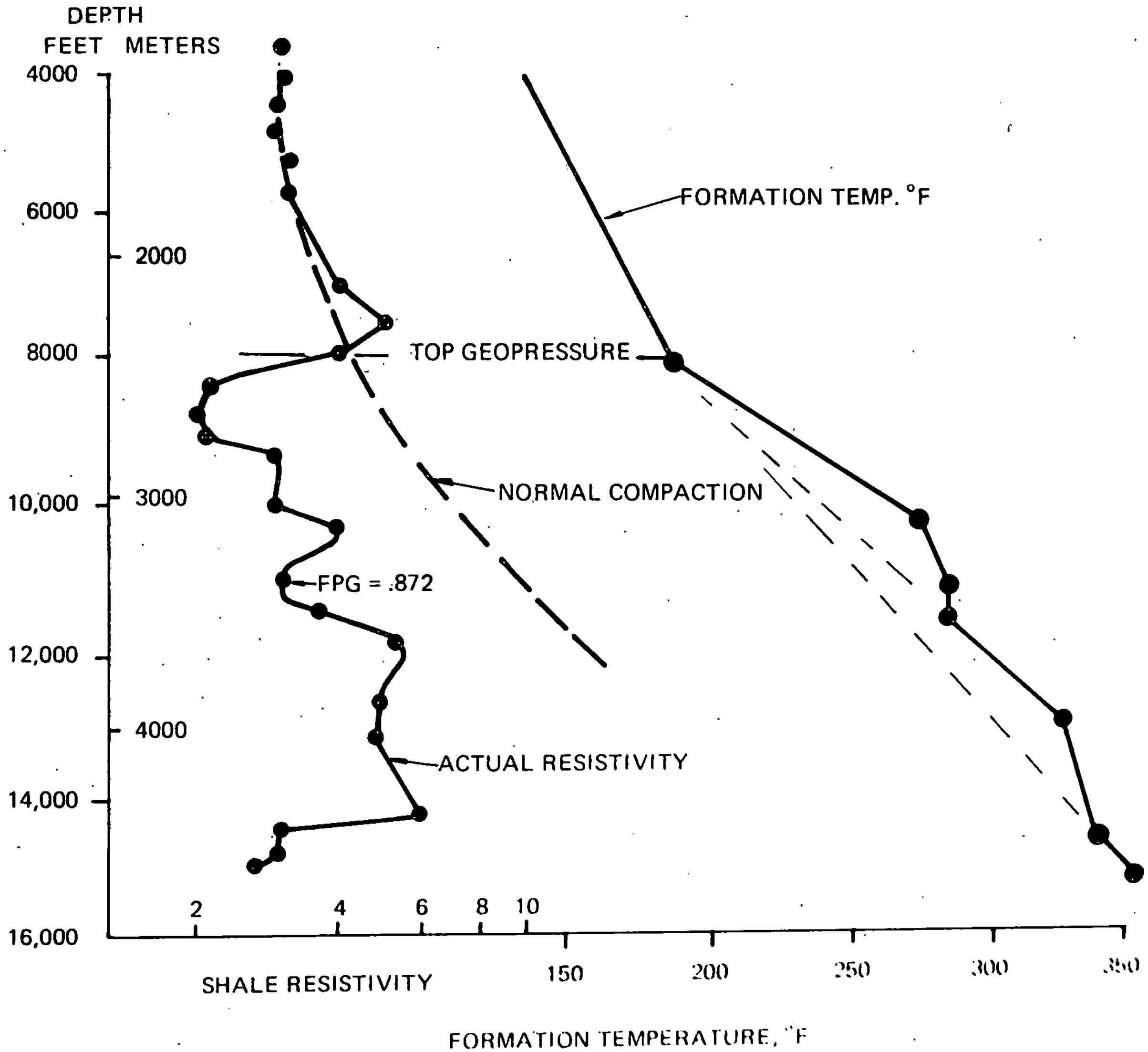


FIGURE 13. FORMATION TEMP (LINEAR SCALE) PLOTTED WITH SHALE RESISTIVITY (LOG SCALE) BOTH VS. DEPTH IN DEEP WELL IN McALLEN RANCH FIELD, HIDALGO CO., TEXAS

The temperature trend in Brooks County closely parallels that in western Hidalgo County. The central Brooks County fields represent Vicksburg production from deposition dominated by the Frio-Vicksburg flexure. The depth of the 300°F geotherm typically ranges from 10,000 to 11,000 ft near the fault, deepening to 12,000 to 13,000 ft near the Kenedy County border.

Temperatures in Kenedy are generally lower than in Hidalgo and Brooks Counties, with the 300°F geotherm ranging from 13,000 ft in Candelaria field to 17,000 ft in Tajos.

D. Reservoir Characteristics

1. Fluid Deliverability

Perhaps the most significant question surrounding exploitation of the geopressure-geothermal resource is the frequency with which suitable reservoirs may be anticipated to occur. This question involves the deliverability of a reservoir for geothermal fluid at adequate flow rates and with maintenance of pressure over relatively long periods of time. Deliverability is of particular significance at the depths necessary to provide temperatures sufficiently high to warrant the equipment investment required to recover useful quantities of heat. While answers to the deliverability question involve the determination of rather complex formation parameters, years of experience in the production of petroleum, particularly in the region of this study, can shed considerable light on the problem.

The fundamental concept upon which exploitation of this resource is based is the continuous production of large volumes of water (tens of thousands of barrels per day per well) from deep, abnormally pressured reservoir rock. Whether or not this is a tractable undertaking depends upon several fundamental reservoir parameters which are well within the province of engineering study.

In order to produce water, a reservoir must have two coincident properties: first, it must have sufficient porosity (void space) to contain the water; and second, it must have sufficient permeability (the ability to flow fluid through the pore space) to allow the water to flow at high rates.

In addition to porosity and permeability, fluid flow from a well drilled into a subsurface reservoir is a function of (1) reservoir pressure; (2) flowing pressure at the well bore; (3) viscosity of the fluid; (4) reservoir thickness; (5) size of the well bore; and (6) size or areal extent of the reservoir.

The absolute permeability of a reservoir is a function of the rock matrix and not of fluid type, provided that only a single fluid is involved. Since all the geopressured fields under study in the south Texas area are gas fields, deliverability determinations have been based on the production of gas. Long experience with a wide range of producing formations has produced mathematical relationships that allow the performance of a gas well to be predicted from the reservoir parameters. Conversely, knowledge of production performance permits reservoir parameters to be inferred. These relationships and their derivation are at the heart of modern reservoir engineering.

The rate of flow of gas from a gas well in a reservoir is given by the following empirical equation

$$Q_b = \frac{19.88\, kh\, (P_e{}^2 - P_w{}^2)}{\mu P b \ln \frac{r_e}{r_w}} \tag{2}$$

where

Q_b –Cu ft gas/day at base pressure P_b
k –Permeability Darcies
h –Formation thickness, ft
P_e –Formation pressure at boundary distance r_e, psi
P_w –Formation pressure flowing, at well, psi
r_e –Radius of reservoir, ft
r_w –Radius of well, ft
μ –Viscosity of the gas.

This expression involves the factor kh, the concept of "permeability X feet." In south Texas, permeability was found to be the critical parameter in determining the producibility of known geopressured formations. Where permeability is low, it can only be compensated by increased formation thickness.

The rate of flow of water from a reservoir is given by a second equation,

$$Q = 7.082 \frac{kh(P_e - P_w)}{\mu \ln \frac{r_e}{r_w}} \qquad (3)$$

where

Q –bbl/day. It involves the same factor kh.

2. Reservoir Parameters

In the following paragraphs, each of the significant reservoir parameters is briefly examined.

a. Reservoir Pressure

The reservoir boundary pressure (P_e in Eqs. 2 and 3) is a function of its depth, and the degree to which it is sealed from its surroundings. Geopressured reservoirs are, by definition, under greater than hydrostatic pressure. In order for abnormal pressures to exist, aquifers must be sealed by faulting, stratigraphy, or both. Geopressure is believed to be a dynamic condition; that is, sealing of such aquifers is relative, with some leakage continually tending to equalize the pressure over geologic time. In general, the pressure due to the weight of overlying rock averages about 1 psi per foot of depth. While reservoirs with fluid pressure gradients greater than 1 psi per foot have been reported, they are not common. South Texas-producing reservoirs all were found to exhibit fluid pressure gradients less than 0.95.

b. Pressure at the Well Bore (Bottom-Hole Flowing Pressure)

As a well is flowed, the pressure near the well bore is reduced. The higher the rate of flow, the lower the well-bore pressure (P_w in Eqs. 2 and 3). However, the minimum flowing pressure is set by the hydrostatic head of the fluid in the pipe and by the friction of the fluid moving up the well. The hydrostatic head depends on the density of the fluid and the height of the column. The possible evolution of gas from produced water will lower the pressure at the bottom of the well, due to the reduction in overall density of the fluid.

Pressure drop in the well bore caused by friction is a function of the diameter of the well and rate at which the fluid moves.

Pressure drop in the formation itself, caused by flowing the well, is known as "drawdown." For a given well (size and depth), drawdown will influence the maximum rate at which the well can be flowed.

c. Viscosity of the Water

The rate of flow of water from a reservoir is an inverse function of viscosity, which in turn depends primarily on the reservoir temperature. In general, water viscosity decreases with temperature, and at 300°F, its viscosity is about 0.2 cp.

d. Thickness

The thickness influences the rate of flow in a straightforward manner: the thicker the producing interval, the greater the potential of the reservoir to produce fluid. The thickness is also a factor in controlling the effective volume of the reservoir, which in turn influences the pressure performance of the reservoir as fluid is withdrawn. A large reservoir will lose pressure more slowly as fluids are withdrawn than will a smaller one.

e. Radius of the Well Bore

A well bore with a large radius will permit fluids to be withdrawn at a higher rate than from a well with a small radius. Hydraulic fracturing has the effect of increasing the effective radius; however, the term appears as a logarithmic one in the deliverability equations (Eqs. 2 and 3), signifying only limited effect due to change of this parameter.

f. Reservoir Area

The areal extent of a reservoir affects the pressure as fluid is withdrawn, and finally determines the producing life. As the pressure is reduced, the rate at which fluid can be withdrawn is also reduced. The pressure in a large reservoir is maintained at a high value longer than pressure in a smaller one.

Neither the well radius nor the size of the reservoir have a profound effect on the initial flow rate, since each affects the flow as a logarithmic function of their ratio. However, in the determination of reservoir life, size is of great importance.

g. Porosity

Porosity, a measure of the relative void space within a rock matrix, is determined by a number of factors including grain size, quantity and type of precipitates, presence of clay, and formation pressure. The effect of pressure is generally to reduce effective pore space. The hydrostatic pressure of fluid in the pore space assists in balancing part of the overburden pressure; if fluid is withdrawn, the formation can be expected to compress by an amount related to the compressibility of water, or approximately 10^{-6} per psi. Compressibility of a rock matrix is not the same for all reservoir rocks, and in addition may vary with the pressure. In abnormally pressured reservoirs, one can expect the compressibility of a reservoir to be greater than in a normally pressured one. As fluid is withdrawn and pressure of the remaining fluid reduced, the pore volume will become smaller and the rate of pore volume change will be reduced. There are few, if any, published results of measurements of the compressibility of geopressured reservoirs, and no such results have been identified for south Texas reservoirs. Knowledge of this parameter is needed before the performance of geopressured reservoirs can be fully assessed.

h. Permeability

The factor most directly affecting the deliverability of a given reservoir is its permeability, or the ability to allow the passage of fluid through the pore space. Both porosity and permeability are functions of rock texture, but permeability is directly affected by the type of porosity in the rock. In sands, high values of porosity almost always signify high permeability because the large pore channels associated with high porosity permit the fluids to pass more easily through the rock. Other factors affecting permeability include "tortuosity," and gas or water saturation. While permeability is not a function of fluid type provided a single fluid is involved, if gas is released from solution, its presence within the pore space will retard the movement of water, and the effective permeability to the flow of water will be reduced. In general, the more gas that is evolved from solution, the lower will be the permeability to the flow of water.

Flowing water through an otherwise undisturbed reservoir may alter the physical properties of the rock and reduce permeability. Flowing a water well can cause clay particles in the matrix to swell and reduce the flow, or may actually cause clays and other solid particles to be released from the matrix itself, altering the porosity and the available flow paths. Chemical content of the formation water may influence the reaction of the water with reservoir rock. The permeability of a reservoir is a complex function of depth, with increased overburden pressure tending to reduce both porosity and potential flow through the pore space. In geopressured formations, the permeability may initially be adequate, but as fluid is withdrawn and the pressure is reduced, the pores may tend to close, reducing permeability. Results of investigations of this effect in geopressured formations have not been reported in the literature and work is needed. The general subject of the direct effect of pressure on permeability has been discussed in detail by Fatt and Davis (1952), McLatchie, *et al.* (1958), Vairogs, *et al.* (1971), Fatt (1953), and Thomas and Ward (1972). In Figure 14 is shown an (unpublished) plot of permeability, measured in the laboratory as a function of confining pressure of a core plug from a geopressured California well. The permeability was reduced from 367 md (unconfined) to less than 4 md at 4000 psi, a reduction of two orders of magnitude.

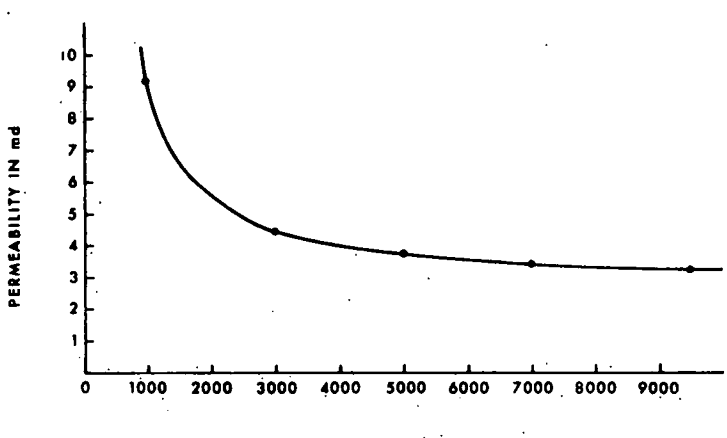


FIGURE 14. REDUCTION IN PERMEABILITY AS A FUNCTION OF CONFINING PRESSURE K_{AIR} = 367 MD

E. Permeability of South Texas Gas Reservoirs

Because of the significance of permeability to the performance of a reservoir, and because the permeability of south Texas petroleum reservoirs generally is known to be low, considerable effort was spent in determining permeability values of the geopressured gas reservoirs in the study region. This turned out to be one of the most significant tasks in the study, and one of the most revealing in terms of the overall assessment of the geothermal potential.

The permeability of a reservoir is normally determined in one of three ways: (1) from core analysis, (2) from behavior of a producing well during flow tests, and (3) from pressure buildup and drawdown tests. Probably the most reliable indication of permeability is obtained from buildup and drawdown tests. Frequently, however, these are not available. Somewhat less accurate but very meaningful determinations can be made from flow tests. Regulations of the Texas Railroad Commission require that completion flow tests and periodic production flow tests be performed and the results filed with the Railroad Commission, where they become matters of public record. For purposes of regional evaluation, they are extremely useful for determining the deliverability of a producing horizon. The results are in the form of an "absolute open-flow potential," calculated from a series of flow tests conducted at different flow rates.

Utilizing Eq. 2 on page 20 for the deliverability of a gas well, calculations of the factor "*kh*" (permeability X thickness) for representative wells from each of the producing fields in the study region were made. A sand-count was then made in each reservoir, and a final calculation of permeability obtained. Permeability values were averaged over a field where appropriate, or separately determined where different producing horizons were involved. These results are summarized in the following paragraphs and in Figures 15 through 22, showing representative permeability values in the fields grouped according to their geographic location, and generally similar geologic settings.

1. Western Hidalgo-Central Brooks County

Six deep gas fields located in western Hidalgo County and eight fields through central Brooks County are located along and to the east of the Frio-Vicksburg flexure, a large major growth fault system that forms the western boundary of geopressure in the study region. Representative permeability values calculated for the six deep fields in this area of Hidalgo County are shown on the map in Figure 15. The eight geopressured fields along the same fault system in central Brooks County are shown in Figure 16. Permeability values in all these fields are consistently less than 2.0 md, ranging from a low of 0.05 md to a high of 1.9 md. These calculated permeability values are confirmed by a complete suite of cores from a well in the McAllen Ranch field in Hidalgo County. The results were provided by the Shell Oil Company and are included in Appendix B. This well, diamond cored continuously from 10,600 to 12,600 ft, showed average core permeabilities in the sands of 0.1 md. There were only 13 samples in the entire suite of cores with permeabilities above 10 md. The highest permeability recorded was 39 md over a 0.5-ft core interval.

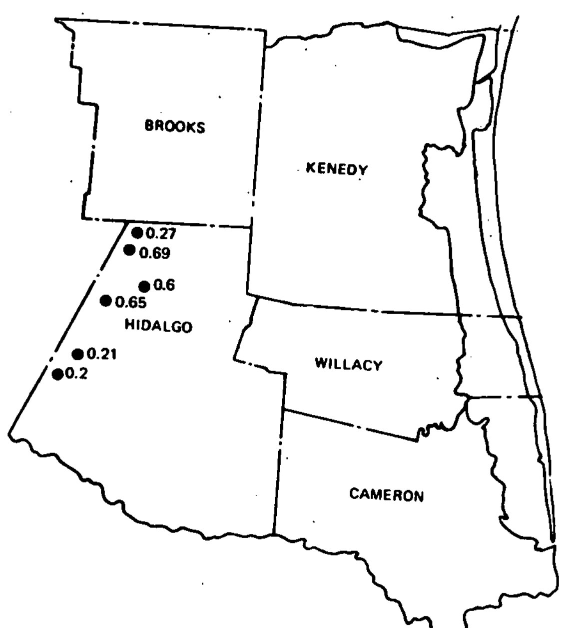


FIGURE 15. REPRESENTATIVE PERMEABILITY, MD VICKSBURG FAULT AREA, HIDALGO CO.

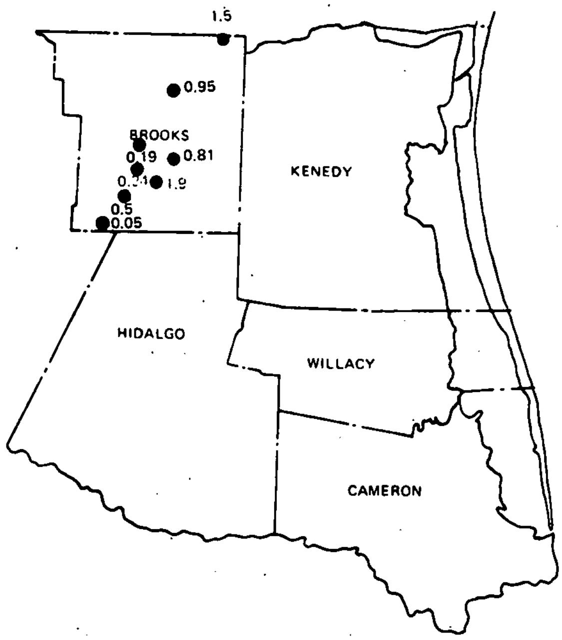


FIGURE 16. REPRESENTATIVE PERMEABILITY, MD
VICKSBURG FAULT AREA, BROOKS CO

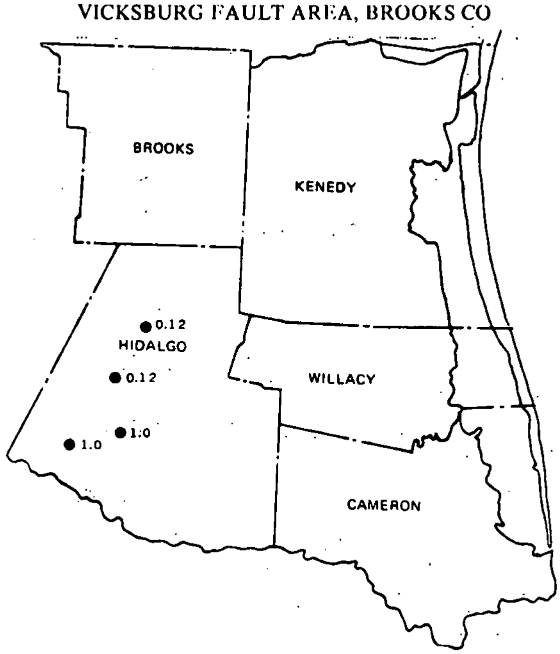


FIGURE 17. REPRESENTATIVE PERMEABILITY, MD
TABASCO FAULT AREA, HIDALGO CO.

2. Hidalgo County-Tabasco Fault Area

Four geopressured gas fields in southwestern Hidalgo County were located along the trend generally defined by the Tabasco fault. Locations of these fields, with representative values of calculated permeability, are shown in Figure 17. Permeability here is also in the range of 1.0 to 0.1 md.

3. Hidalgo County-Lower McAllen Fault

Seven fields in the southeastern part of Hidalgo County lie along the lower part of the major McAllen fault and the nearby Weslaco fault. Permeability values in representative reservoirs in these fields are shown in Figure 18. The highest permeability noted was 2 md, and the lowest 0.5 md.

4. Hidalgo County, Southwestern Kenedy County-Upper McAllen Fault Zone

The continuation of the McAllen fault to the north roughly defines the locations of the five gas fields shown on the map in Figure 19. Representative values of reservoirs in these fields range from 0.9 to 8.0 md.

5. Eastern Brooks County, Northern Kenedy County

Seven fields in the northeastern part of the study region exhibit somewhat similar characteristics and their locations are shown in Figure 20, with representative permeability values. These range from 0.12 to 2.2 md.

6. Cameron County, Willacy County

The four fields making up the geopressured production in Cameron and Willacy Counties are located on the map in Figure 21. Permeability values range from 0.07 md in La Sal Vieja field in Willacy County to 24.0 md in the Riggan field. The latter value was the highest calculated in any field in the study region. Riggan is a shallow Frio field (9400 ft) with a fluid pressure gradient of 0.58, and a temperature of approximately 200°F.

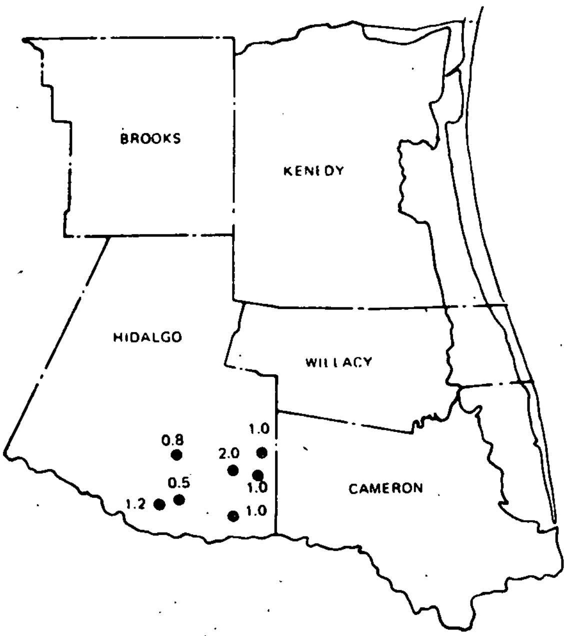


FIGURE 18. REPRESENTATIVE PERMEABILITY, MD
LOWER McALLEN FAULT AREA, HIDALGO CO.

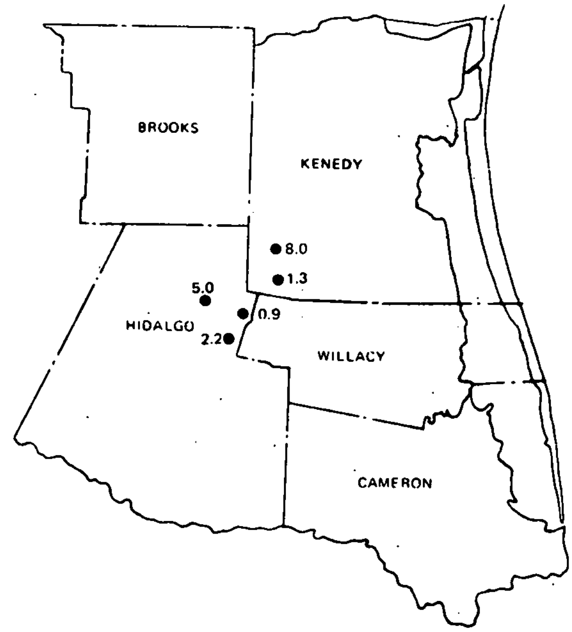


FIGURE 19. REPRESENTATIVE PERMEABILITY, MD
UPPER McALLEN FAULT, HIDALGO-KENEDY COUNTIES

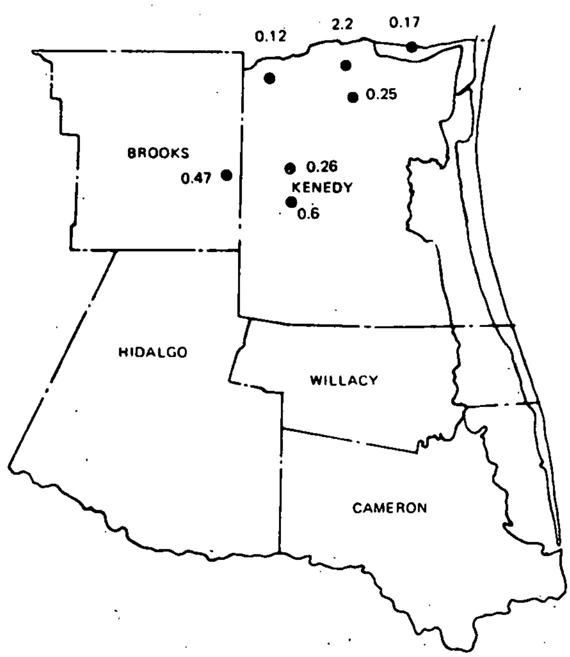


FIGURE 20. REPRESENTATIVE PERMEABILITY, MD
KENEDY-BROOKS COUNTIES

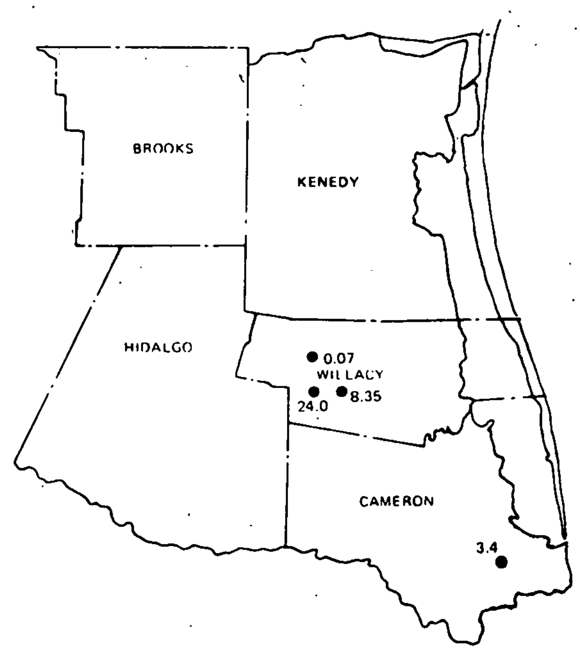


FIGURE 21. REPRESENTATIVE PERMEABILITY, MD
CAMERON-WILLACY COUNTIES

7. Live Oak County

Wilcox gas reservoirs in Live Oak County exhibit effective permeabilities from 0.48 to 8.9 md, and the locations of these fields are shown in Figure 22. The best permeability found in a reservoir with fairly good temperature was located in Live Oak County. The lower Wilcox production in the Tom Lyne field exhibits permeability as high as 8.9 md at 11,500 ft, and coincides with a bottom-hole temperature of approximate 300°F.

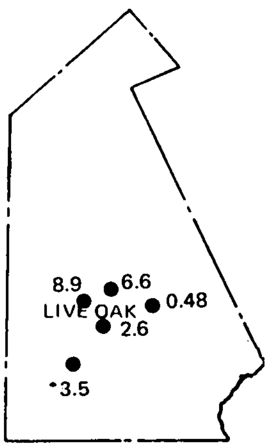


FIGURE 22. REPRESENTATIVE PERMEABILITY, MD LIVE OAK COUNTY

F. Investigation of Depth Effect on Permeability

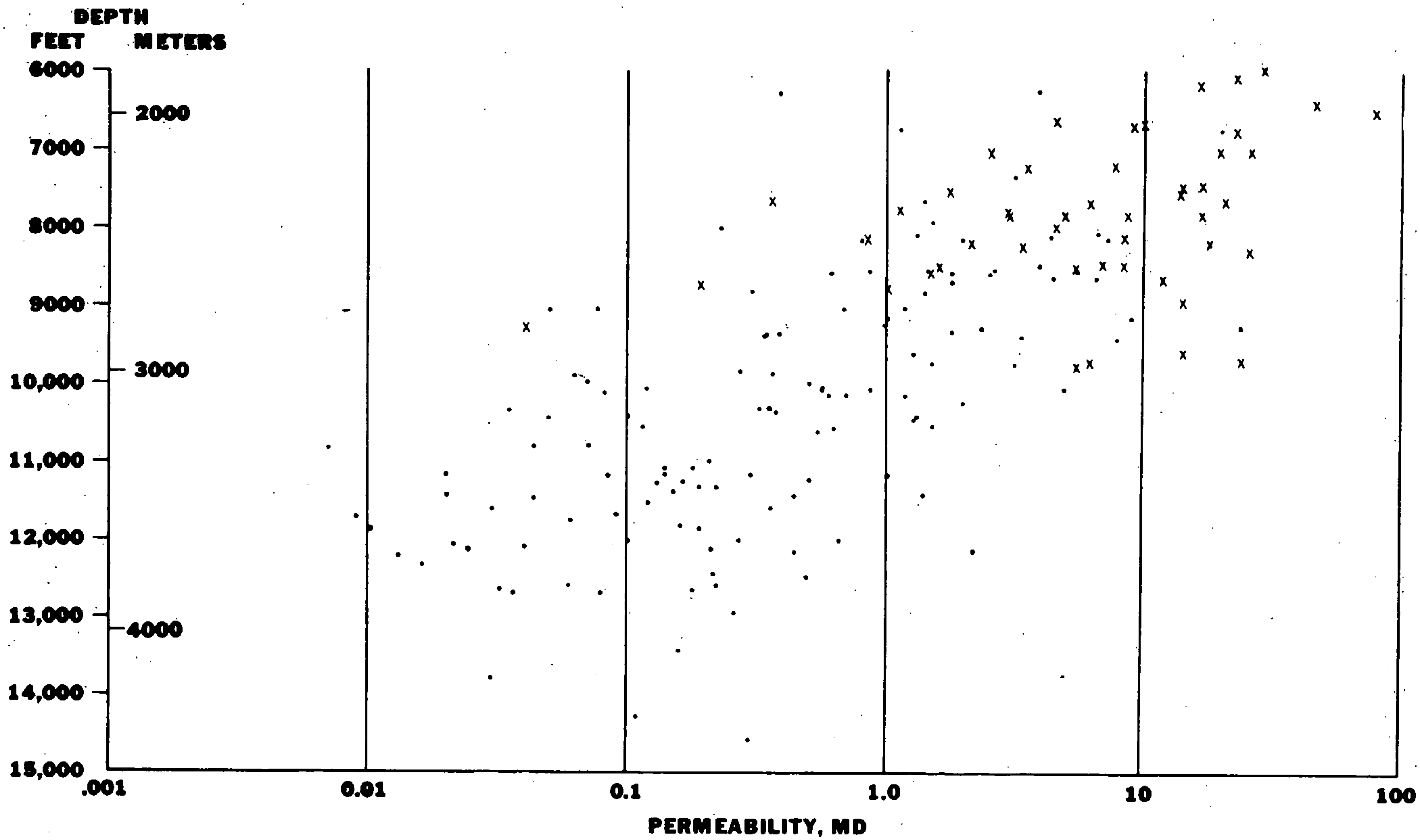
Petroleum engineers are aware that permeability generally decreases with depth, due to the increasing weight of overburden. It has been suggested that the permeability of geopressured formations may be higher than in equivalent normally compacted zones, because the overburden pressure should initially be somewhat offset by the load-bearing effect of the abnormally pressured water. An attempt was made to evaluate this effect, by examining the permeability of a large number of gas wells producing from a variety of reservoirs at all depths, both normally and abnormally pressured. The results of this study are summarized in Figure 23, plot of effective permeability versus depth for more than 100 gas wells throughout the study region. This plot fails to disclose any obvious trend toward either reduced or increased permeability caused by penetrating the geopressured zone. The overwhelming effect displayed is that of reduced permeability with depth, regardless of formation fluid pressure. The trend shown in this figure is particularly disappointing, since in no case are wells with permeability as great as 10 md shown to be coincident with depths at which temperatures as high as 300°F occur. The overwhelming number of deep south Texas reservoirs exhibit effective permeability values of 1.0 md or less.

Results of studies in two fields, one in the south and one in the north of the study region, are shown in Figures 24 and 25. In these figures, permeability of a number of producing horizons in the same fields are plotted versus depth. In Figure 24, wells in the McAllen-Pharr field in Hidalgo County are summarized, and in Figure 25 results of investigation of the Ann-Mag field in northern Brooks County are shown. In both cases, the reduction in permeability with depth appears to amount to roughly one order of magnitude for each 2000 ft of increased depth, in the range from 6,000 to 14,000 ft.

G. Significance of Permeability to Long-Term Water Well Performance

Parmigiano (1973), in the only comprehensive study of geopressured water production known to the authors, has analyzed the aquifer size requirements for production of useful quantities of energy from Gulf Coast formations of this type. In order to investigate the effect of permeability on the performance of south Texas aquifers, calculations of transient and steady-state behavior of such reservoirs under various permeability conditions were performed during this program.

When water is first produced from a subsurface reservoir, there is a transient period during which the well can produce at very high rates of flow. If the well is flowed at a constant maximum rate, the pressure will decline exponentially for a relatively short period of time, after which it will continue to decline linearly until the reservoir is depleted. A well in a reservoir with a permeability of 100 md capable of producing 100,000 bbl water/day for 20 years, would be capable of flowing at a rate in excess of 1 million bbl water/day after one day of production (if casing and tubing were sufficiently



X normally pressured wells • geopressured wells

FIGURE 23. EFFECTIVE PERMEABILITY VS. DEPTH FOR A LARGE NUMBER OF GAS WELLS IN HIDALGO, BROOKS, CAMERON AND KENEDY COUNTIES IN SOUTH TEXAS

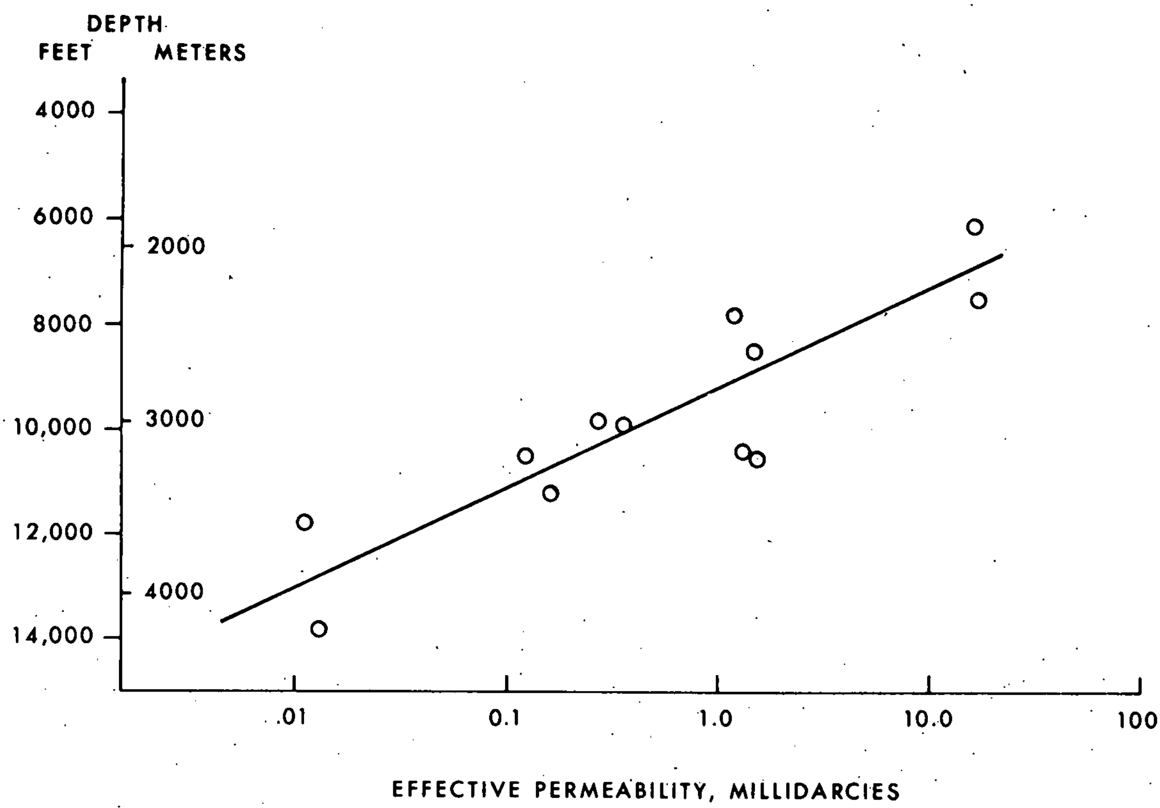


FIGURE 24. VARIATION OF EFFECTIVE PERMEABILITY WITH DEPTH, McALLEN-PHARR AREA

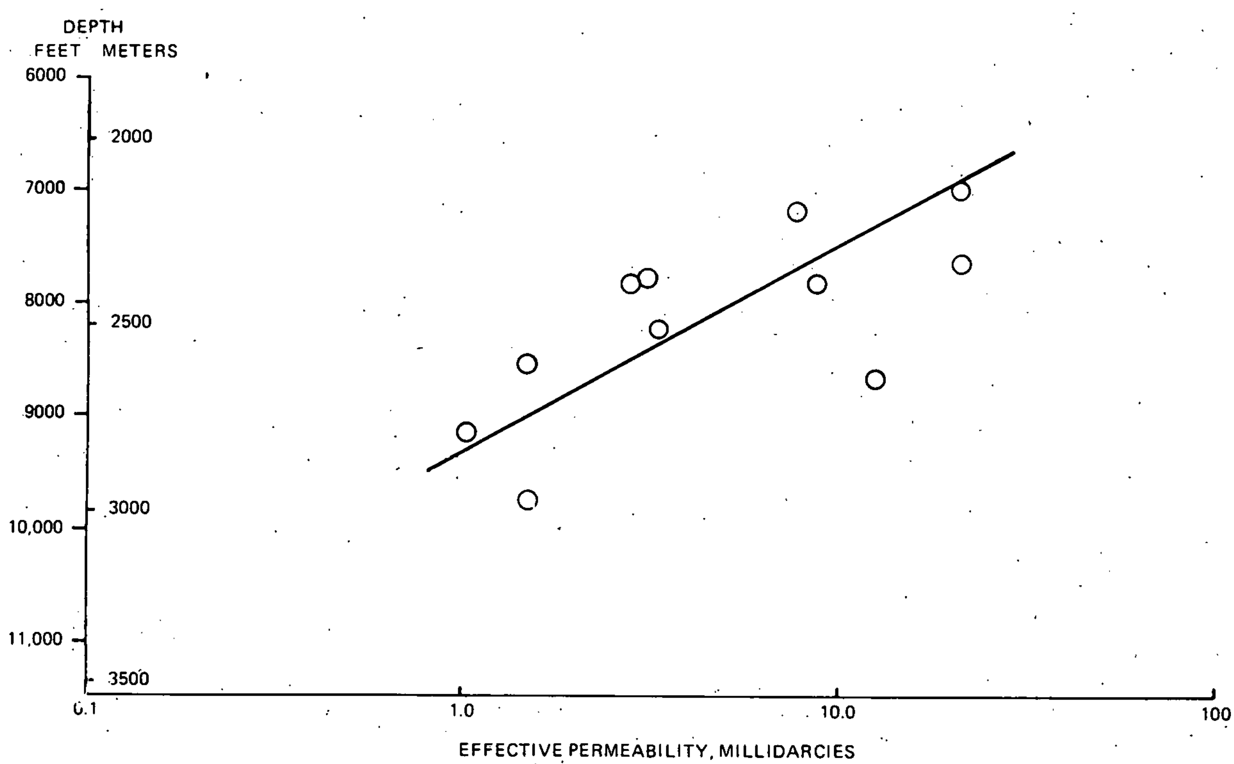


FIGURE 25. VARIATION OF PERMEABILITY WITH DEPTH, ANN-MAG FIELD, NORTHERN BROOKS COUNTY

large). After 100 days, the open-flow potential would still be nearly 800,000 bbl of water/day. Open-flow tests of the producing capability of a well early in its life greatly exceed rates that the well can sustain for a long period, e.g. 20 years.

An examination of data from gas fields in south Texas indicates that the permeability of geopressured reservoirs there is much lower than 100 md, seldom is as high as 10 md, and frequently is less than 1.0 md. Calculations were made to determine how long a well would produce at a rate of 100,000 bbl water/day if the permeability were less than 100 md. The results are shown in Figure 26.

Formation parameters assumed in these calculations are as follows:

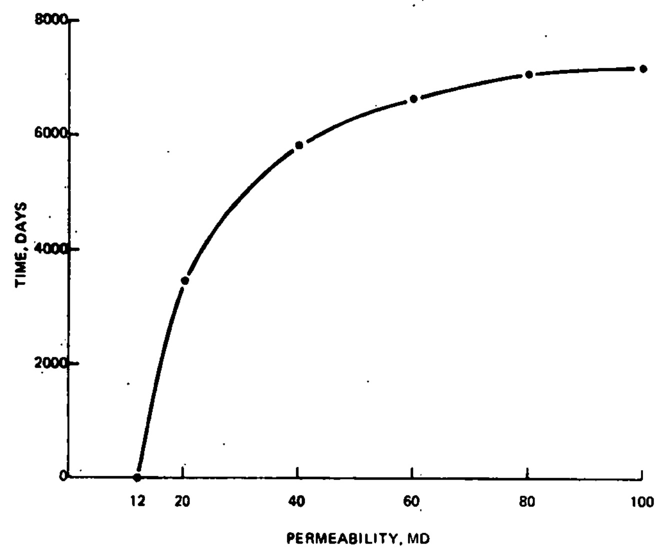


FIGURE 26. FLOWING TIME, DAYS, FOR WHICH A WELL CAN MAINTAIN A FLOWING RATE OF 100,000 BBL WATER PER DAY, VS RESERVOIR PERMEABILITY

Formation thickness	h	= 500 ft
Porosity	ϕ	= 12%
Initial Pressure	P_e	= 10,000 psi
Hydrostatic Pressure	P_{hy}	= 5200 psi
Pressure drop (9-7/8" pipe)	P_f	= 280 psi
Radius of well	r_w	= 0.401 ft
Radius of reservoir	r_e	= 9326 ft
Compressibility	C_e	= 6.23×10^{-5}
Viscosity of water	μ_w	= 0.2 cp
Permeability	k	= variable

Calculations indicate that in such a reservoir if the permeability were less than 12 md, the well would not flow 100,000 bbl water/day. The length of time a well would flow at a rate of 100,000 bbl water/day increases rapidly as the permeability of the reservoir increases as shown in the figure. If the permeability of the reservoir were 100 md, the well would flow for 20 years.

If the reservoir permeability were as little as 1 md, the well would flow approximately 9,000 bbl water/day for 20 years. These calculations are shown in Appendix C.

H. Water Salinity

Reliable data on salinity of connate water from producing horizons in the study region were obtained where possible, and a regional overview of water quality from these data is summarized on the map in Figure 27. The least saline water occurring over a sizable area was found along the Weslaco fault in lower Hidalgo County. Here "fresh" water sands (water salinity of 4000-6000 ppm Cl) occur generally as massive sand units in the basal Frio and upper Vicksburg formations. This is in contrast to local, isolated fresh-water sands that are sometimes identified on well logs in geopressurized zones in many places in the study area. Fresh water is also common, although not general, in Live Oak County.

I. Reports of Well Tests

The results of several drill stem and production tests of unsuccessful gas well completions in the geopressured zones have been located. These give considerable insight into the problems of developing high-volume water wells in these reservoirs.

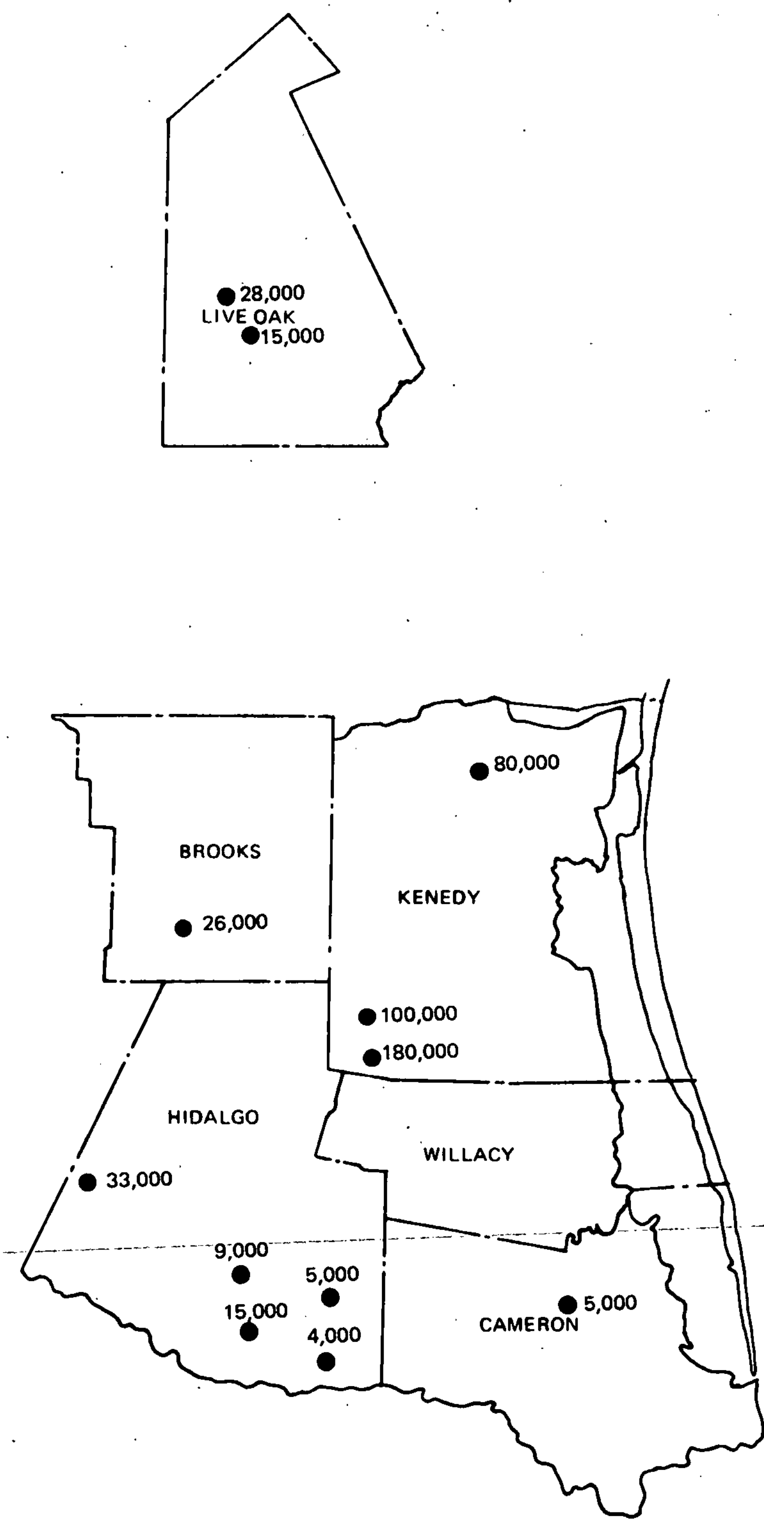


FIGURE 27. CONNATE WATER SALINITY, PPM Cl, REPRESENTATIVE GEOPRESSURED PRODUCING RESERVOIRS IN SOUTH TEXAS

1. Donna Area, Hidalgo County

The most recent of these tests was in the Mercedes-Donna area, near the Donna fault (Lone Star Prod. Co. No. 1 Denzer). The well is typical of the area east of the Donna fault near the Cameron County line, exhibiting low salinity, high-resistivity Frio sands. We believe this well was completed in a water sand, and represents an unwitting test of a geopressured water zone. The log is reproduced in Figure 28.

After several unsuccessful deep completion attempts, the well was perforated (selectively) from 9371-9268, acidized and given a nitrogen pressure treatment. The well flowed gas, nitrogen, and formation water. On a 20/64-inch production choke, the well tested an absolute open-flow potential of 280 mcf gas per day, plus 450 barrels of water (5400 ppm/Cl). This declined to 120 mcf plus 140 barrels of water, and the completion was aborted with a plug. Other perforations at depths from 8994 to 8818 produced similar results and the well was abandoned.

This completion attempt opened a total of 42 ft of perforations in the geopressured zone from which the potential test was made. The 450 barrels of water/day with substantial gas is probably typical of the test results one can expect from water sands in this area. Likewise, the rapid decline can be expected, the probable result of gas released from the water due to the pressure drop in the formation. The relative permeability is such that released gas quickly dominates the flow, blocking further water flow as a result. This reduces the rate at which gas can be released, and the rate of flow of both steadily declines. We believe this sort of performance can be expected in any flow test in the consolidated formations of this region, unless measures are taken to drastically restrict flow rate.

2. Santa Maria Area

A somewhat deeper test in the same general vicinity is reported by Shell in the No. 1 W.H. Drawe in the Santa Maria area, south of the Weslaco field. In this completion test, perforations selectively opened a total of 10 ft between 11,594 and 11,660. The report only indicates that the well "flowed small amount gas and water through 3/8 inch choke," but the flowing tubing pressure dropped from 5000 to 20 lb during the test, indicating the same general condition as in the first test reported above.

3. Mercedes Area

In a third well (J.M. Huber Corporation No. 1 A.M. Miller), similar test results were obtained about 1 mile southwest of the Mercedes field. The log of this well is shown in Figure 29. A total of 27 ft of perforations was opened between 12,873 and 13,083, and the well completed for a test potential of 450 mcf/day plus 350 barrels of water/day. Tubing pressure dropped slowly from 4317 psi to 39 psi. This well was also abandoned.

4. Edinburg Area

A fourth dry hole is of interest because it apparently tested water sands in an area off the south flank of the south Edinburg field in one of the favorable geopressured areas of Hidalgo County, from the standpoint of geopressured sand development. This well (Standard of Texas, No. 1 L.E. German Unit) is located 4 miles southeast of the city of Edinburg. The tests reported open hole drillstem tests of the Reichert sand, a deep Vicksburg sand in the area, and production tests in the Marks & Bond Sands. The deeper test, a 4.5 minute open-hole drill stem test, was run below 5-in.

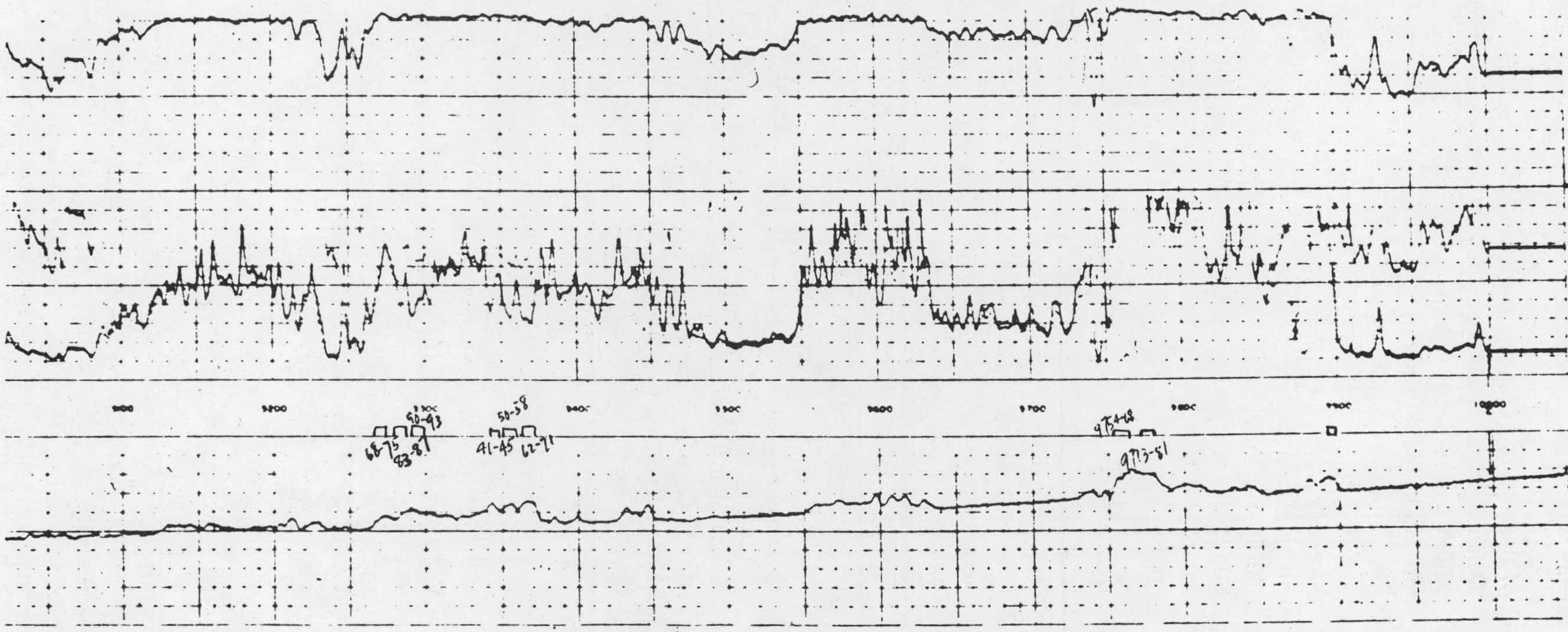


FIGURE 28. SOUTH HIDALGO COUNTY TEST WELL. Highly resistive, fresh water sands are typical of deep Frio in this area. (Lone Star No. 1 Denzer, Donna Area. See text.)

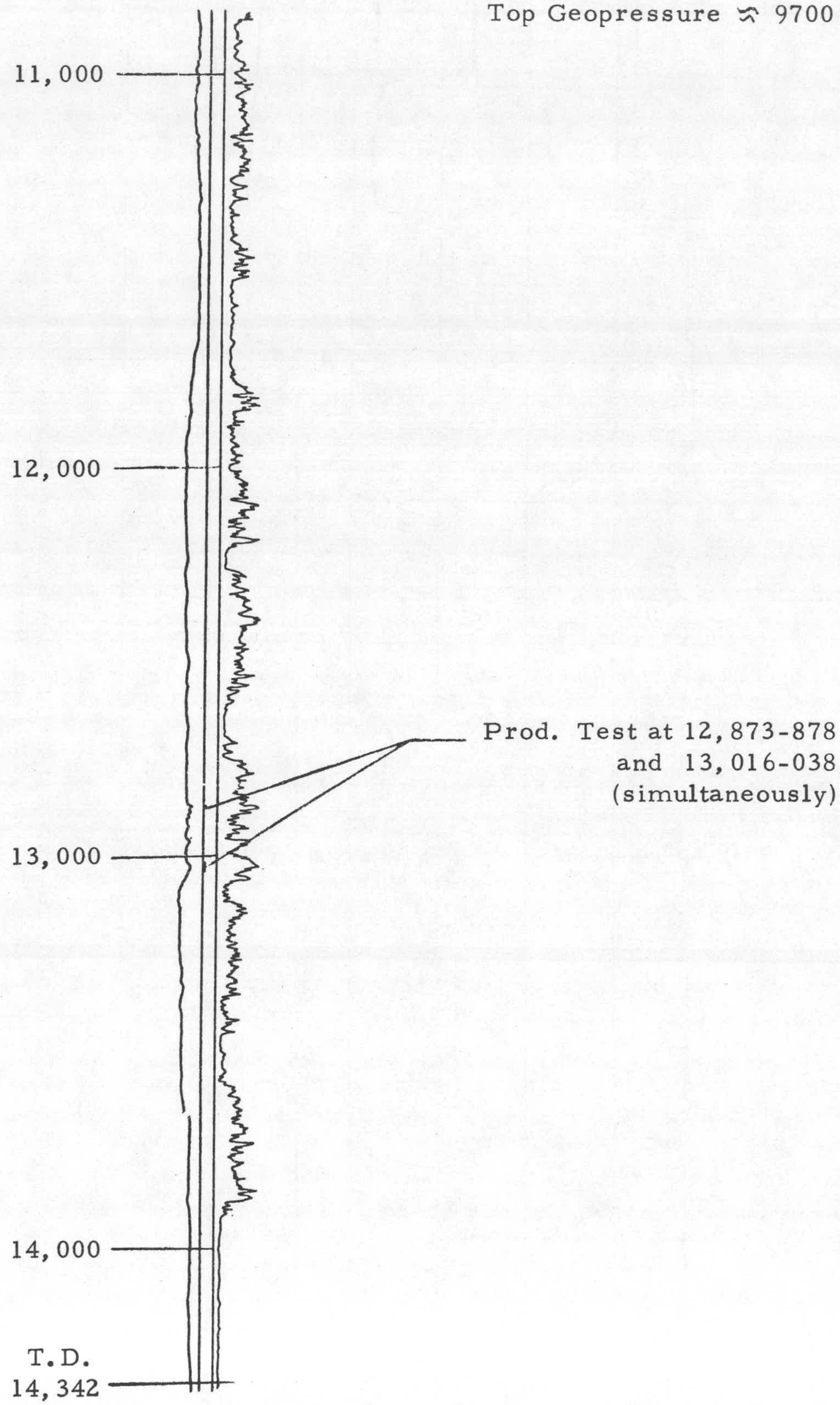


FIGURE 29. J.M. HUBER NO. 1A MILLER, WESLACO AREA
HIDALGO COUNTY, TEXAS

casing from 13,206 to 13,665 ft, through an 8/64-inch choke with full stage water cushion. The test recorded shut-in pressure of 11,275 to 11,445 psi, flowing pressure of 6926 to 7553 psi, and recovered 5400 ft of gas-cut mud. A plug was set at 12,000 ft and a number of production tests attempted through perforations in the Bond and Marks series from 11,598 to 10,977. Each of these tests produced a small amount of water and some gas. Water salinity of recovered water varied from 14,000 ppm to 4,500 ppm in the various sands of these zones.

The normally productive sands are wet in this well. The relative permeability is such that when the sands are water saturated, little or no flow is obtained. The gas is probably released from water solution. This behavior seems to be typical of the Edinburg field. Wells below the gas-water contact will not flow, or will flow only a small amount of water and gas.

5. Southern Brooks County, Encinitas Area

Test results of Vicksburg geopressured sands in southwestern Brooks County have been reported by Coastal States Producing Company, in the No. 1 DeLuna in the East Encinitas field, 8 miles south of the town of Rachal.

A section of the well log of this well is reproduced in Figure 30. It is a typical Vicksburg zone of a type represented by fields such as Kelsey, McAllen Ranch, and Jeffress in Hidalgo County. The well was bottomed in the Vicksburg at 11,377 ft and casing set to bottom. Top of geopressure (not shown in the figure) is between 8700 and 8800 ft.

Production testing in this well began in the deeper zone, through perforations from 10,895 to 11,134. This zone failed to produce fluid, even after bailing dry. The sand is undoubtedly wet, but with effective permeability essentially zero, in spite of the fact that it is an example of excellent deep Vicksburg sand development. These perforations were squeezed.

The well was then perforated in the next higher zone from 10,447 to 10,749 ft. This 300-ft interval flowed a small amount of water in initial tests. After bailing the perforations, the well flowed a small amount of gas and condensate with a flowing tubing pressure of 850 lb. The zone was reperforated from 10,555 to 10,749 ft and given a fracture treatment. The well immediately sanded-up (frac sand). The well was cleaned and swabbed in after which it flowed gas, some water and continued to flow frac sand. The completion was unsuccessful, and the well was squeezed.

Final perforations were made in the upper zone from 9,766 to 79 ft. The well flowed gas, condensate and water on test, with a tubing pressure of 1,275 lb (flowing). The well was squeezed and reperforated from 9,766 to 73 ft, and successfully completed, with AOF potential of 11 million CFGPD and a bottom hole shut-in pressure of 6365 psi. This zone has a calculated kh, from buildup-drawdown tests, of 22.5 md feet (3.2 md).

The tests of the lower zones in this well are very discouraging; although sand development is good, pressure gradient is high, and the equilibrium temperature close to 300°F at a relatively shallow depth, the zone evidently will not produce water.

Other wells in the Encinitas field have produced at depths below 10,000 ft, but only gas, and none with permeability as high as the 9700-ft zone in the DeLuna well. The deepest production recorded in the field, the Texaco No. 36 McGill Bros. was completed in a zone from 10,707 to 10,942 ft. The effective kh of the entire 235-ft zone was less than 1 md-ft.

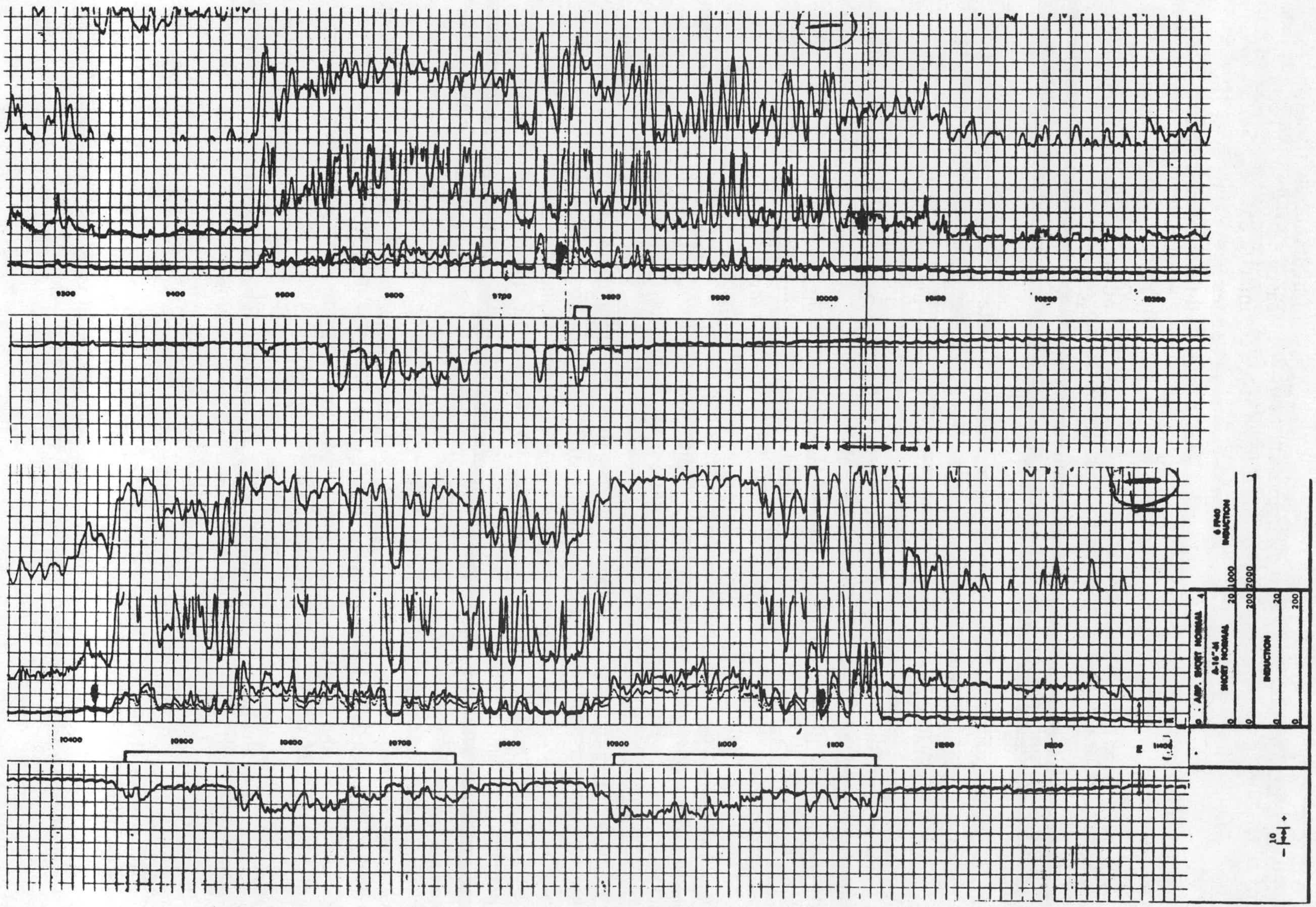


FIGURE 30. SOUTH BROOKS COUNTY WELL IN WHICH DEEP VICKSBURG PRODUCTION TESTS (in zones marked) WERE REPORTED. (Coastal States No. 1 DeLuna, see text)

6. Effect of Fracture Treatment

Another well in the same field gives insight into the effect of hydraulically fracturing low permeability Vicksburg sands. A section of the log of this well, the Coastal States No. 1 Pettus, is shown in Figure 31. Abnormal pressures were encountered at approximately 8500 ft. Recorded bottom hole temperature at 10,908 was 236°F. The well was completed in the zone from 10,213 to 10,422, and on production test, tested 3.4×10^6 CFGPD. The well then received a frac treatment, following which it tested 4.7×10^6 CFGPD.

Calculated effective permeability after fracturing was 0.09 md, an improvement of a factor of 2. This is typical of successful fracture treatments in tight Gulf Coast formations at this depth. Flow rate increase equivalent to a two-fold permeability improvement is about the best that can be expected.

7. Live Oak County, Tom Lyne Area

An inadvertent test of a water-sand was located during the study of Live Oak County. Atlantic Refining Company originally completed the No. 8 T. J. Lyne in 1961. During completion tests, a lower Wilcox sand was perforated from 10,366 to 10,372 ft. The well flowed salt water and gas, and was allowed to clean itself into the pits and continue flowing. On a 1/4-in. choke, the well flowed salt water at the rate of 350 bbl/day, with a bottom-hole flowing pressure of 7300 psi, and bottom-hole shut-in pressure of 7930 psi. Water salinity was 28,000 ppm Cl. The well was eventually squeezed and recompleted at 10,194 to 10,206 ft. Within 1 yr, that zone had also watered out, and the well was plugged back and recompleted in a shallow, normally-pressured sand. Temperature at the 10,000-ft depth is approximately 270°F.

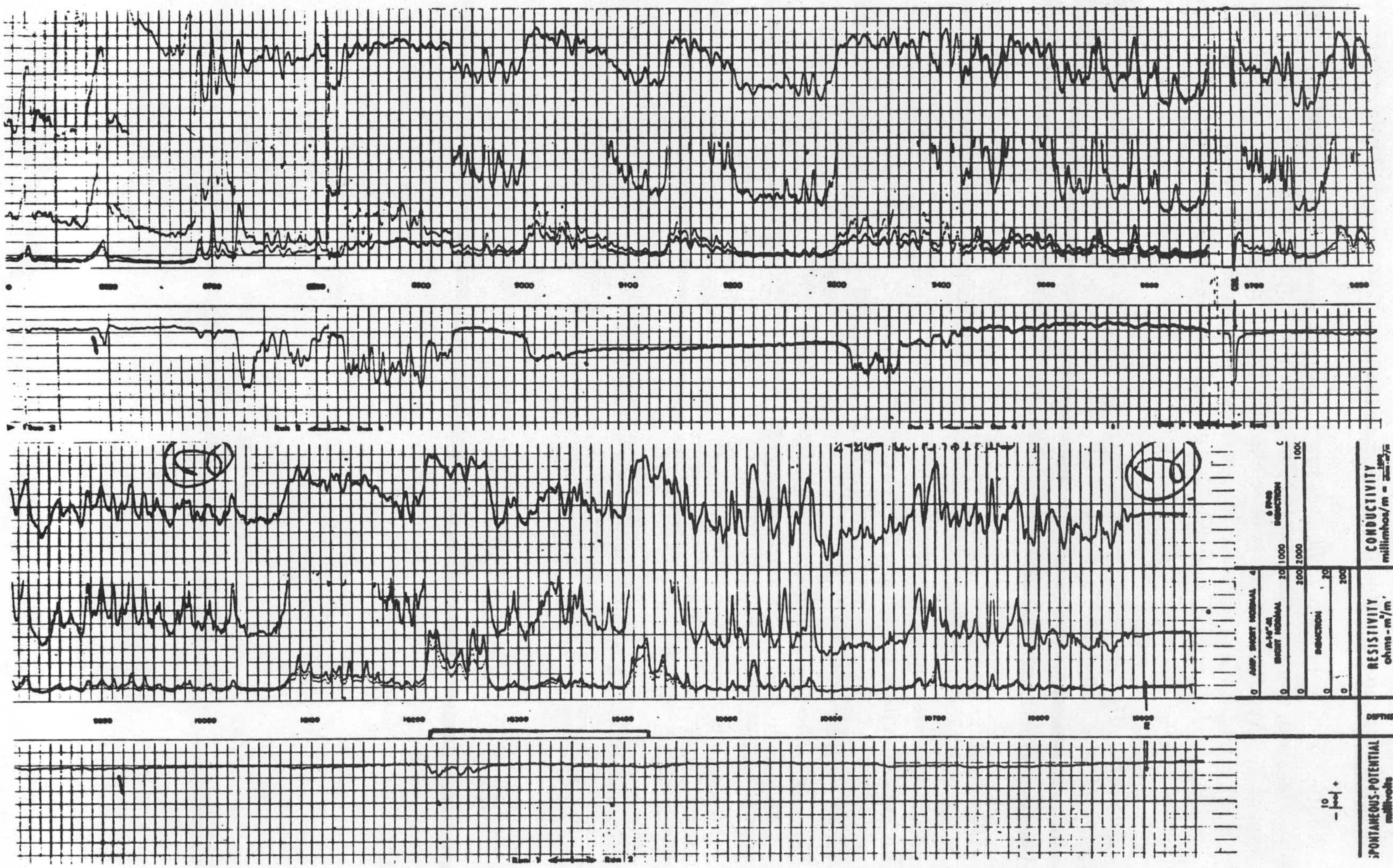


FIGURE 31. SOUTH BROOKS COUNTY VICKSBURG WELL IN WHICH FRAC TREATMENT IS SHOWN TO INCREASE EFFECTIVE PERMEABILITY ABOUT TWO-FOLD. (Coastal States No. 1 Pettus, see text)

IV. GEOLOGY AND ASSESSMENT OF PRODUCING AREAS

On the basis of the reservoir evaluation and a geologic investigation of each field, assessment of the individual producing areas has been made and is summarized in the following paragraphs.

The question of fluid deliverability has been shown to be paramount in considering the south Texas geopressured formations as an energy source. In consideration of this question, the permeability-thickness product, or kh, is the critical parameter in determining initial flow rates, while areal extent is mainly of importance in establishing reservoir life. Considerable effort has been spent in determining effective permeability values throughout the Study Region, and these have been shown to be low. The only compensating factor is formation thickness. The philosophy of this assessment has been to stress the importance of flow rate as compared to reservoir lifetime. If a reservoir will not produce fluid at an adequate rate, the size is immaterial. If adequate flow of fluid at reasonably high temperature can be achieved, the long-term performance can only be determined by extensive test programs. We have attempted to select those areas that represent the best potential for further evaluation, including testing.

A. Brooks County-The Frio-Vicksburg Flexure

The shallowest occurrence of geopressure in the study area was discovered along and to the east of the Frio-Vicksburg flexure which parallels the Gulf Coast just west of the Hidalgo County border, extending diagonally through central Brooks County and beyond. Geopressured reservoirs along this fault system are mainly in Vicksburg sediments of Oligocene Age, immediately underlying the Frio. The term "flexure" refers to the large folds on the downthrown side of the fault. Both the Frio and Vicksburg are greatly thickened to the east of the Frio-Vicksburg flexure.

During the geologic period preceding Vicksburg deposition (Jackson), the seas had transgressed. Vicksburg Seas, encroaching on a slowly subsiding coastal plain, brought huge quantities of argillaceous sediments inland, but to a point not so far advanced as in Jackson times. These sediments were the remnants of vast clastic deposits moved to the sea by the ancestral Rio Grande River. They accumulated as overlapping, irregularly lenticular sedimentary masses, reworked by longshore currents into an extensive system of barrier bars. The weight of these sediments is believed to have caused slumping of the Jackson continental slope, resulting in the Frio-Vicksburg flexure.

In many places along the Texas Gulf Coast, the Vicksburg formation consists primarily of marine shale, which can be traced laterally across upper south Texas into massive deltaic sandstone and shale in the Rio Grande Valley as described by Boyd and Dyer (1965). Nowhere is Vicksburg sand development better than in the Hidalgo-Brooks-Kenedy County region, and is responsible for much of the prolific petroleum production in this area.

Nine separate geopressured gas fields were identified in Brooks County. Without exception, the abnormally pressured production occurs in Basal Frio-Vicksburg or Vicksburg sands. In all but one (Viboras), the sand deposition is directly related to development and thickening along the Frio-Vicksburg flexure. In common with the Vicksburg formation throughout Texas, deposition is primarily shale; most of the sand buildup when it occurs is near the top of the section. On occasion, however, there are isolated sand units deep within the Vicksburg. These must be considered the principal geothermal prospects within Brooks County, since the upper units are at depths too shallow to offer temperatures of interest.

1. South Ann-Mag Field (No. 36 on Figure 2)

Ann-Mag is an old, normally pressured oil field on the Brooks-Kleberg county line. A relatively new field extension to the south, known as Ann-Mag South, is in Brooks County. Production is generally from lower Frio sands, with some production from abnormally pressured zones in the upper Vicksburg. Top of geopressure is generally coincident with the top of the Vicksburg at approximately 9000 ft. Control in the field to 10,000 ft is fair, but deeper control is lacking. Formation temperature at the deepest horizon penetrated, is approximately 250°F at 10,500 ft. Sand development in the Vicksburg below this depth is unknown. The effective permeability of the principal geopressured producing sand is less than 1 md at 9750 ft. Structurally, the upper Vicksburg is largely undisturbed by faulting, as shown in the structure map in Figure 32. The lack of well control makes assessment of the high temperature zones impossible, but the low permeability in the producing sand is discouraging.

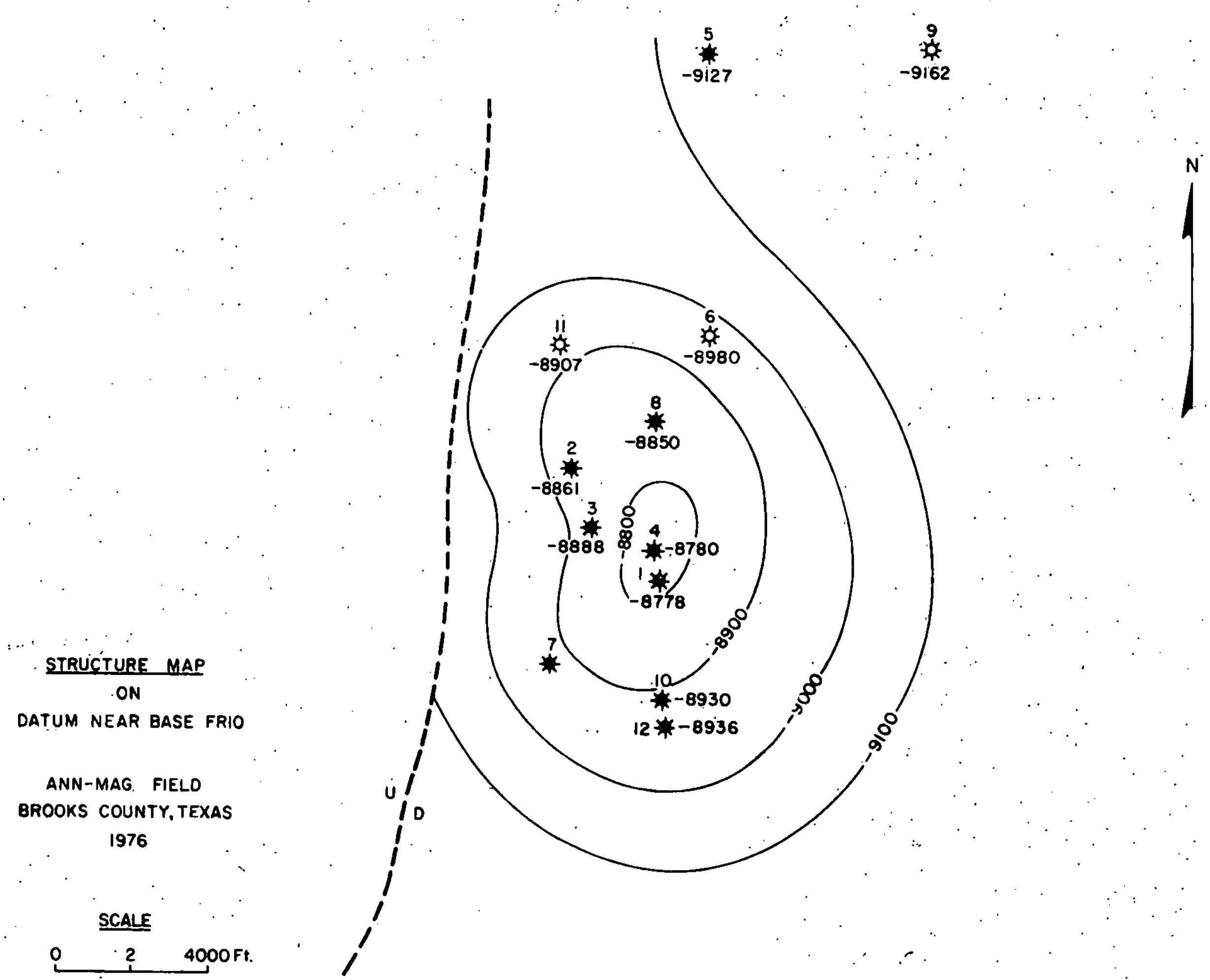


FIGURE 32. STRUCTURE MAP ON DATUM NEAR BASE FRIO–ANN-MAG FIELD, BROOKS COUNTY, TEXAS

2. Viboras Field (No. 33 on Figure 2)

Viboras is a normally pressured gas and oil field near the Kenedy County border in east central Brooks County. The field, like Ann-Mag, normally produces from Frio sands above the top of geopressure. The most favorable geothermal prospect in this area is in the southeast extension of

Viboras field, across a large fault to the east. Frio-Vicksburg and Vicksburg sands are highly developed on the downthrown side (east) of this fault. Below the lower-Frio mapping datum in Figure 33, Well No. 18 on the map (arrow, lower right) shows over 850 ft of relatively clean, massive sands and clean sand stringers to about −12,200 ft. The well has produced from a zone at 12,105 to 12,119 with an initial potential of 7.3 MMcf gas per day. Calculated effective permeability in this producing zone is approximately 0.5 md. The remainder of the well to total depth at 13,500 ft encountered only shale. Temperatures in the well-developed sands range from approximately 220° to 310°F. Unfortunately, there is no other control on this section available. Wells Nos. 14 and 25 are not deep wells, but correlation is good on the mapping datum at the top of the zone. Based on this sketchy information, the zone immediately to the east of this fault can be considered a good prospect for the production of water at temperatures in the range of 250°F.

One of the significant questions about geothermal production from abnormally pressured zones is the ability of extensive vertical sections to produce fluid simultaneously. If several hundred feet of section can be successfully produced, the generally low permeability may be somewhat compensated. S. E. Viboras is a good area in which to attempt to flow a long section of low permeability sand over a considerable depth interval.

The potentially productive section in this zone is shown in the log section in Figure 34.

3. Kelsey-Encinitas Area (Nos. 28 and 29 on Figure 2)

Kelsey is a large, old oil field shared by Brooks, Starr, and Hidalgo Counties with major production occurring at shallow depths. A minor branch of the Frio-Vicksburg fault cuts the eastern edge of the field, providing some deeper sand buildup in the Vicksburg at depths below 8000 ft. The deep horizons of the Encinitas field are on the same trend along the same fault. A structure map on a datum in the Textularia Warreni zone (Vicksburg) is shown in Figure 35. Geothermal possibilities on this trend are in a series of relatively clean Vicksburg sands from the top of geopressure at approximately 8,300 to about 10,000 ft. Available temperatures at these depths vary from about 200° to 275°F, but permeability is less than 1 md in the single productive gas sand. Although geopressure occurs at a shallow depth and the temperature gradient is relatively high, overall sand development is only fair. With no favorable reservoir parameters uncovered, Kelsey and Encinitas fields cannot be considered to hold good geothermal potential.

4. La Encantada Field

This field is just to the northeast of Encinitas and there is some evidence that the principal aquifer is continuous. Sand development in the Vicksburg is only fair and permeability is low. The field produces from thin sand stringers that undoubtedly represent sand lensing. There is little to recommend this area other than a reasonably high-temperature gradient.

5. Scott and Hopper Field (Map No. 31)

This field lies along a main branch of the Frio-Vicksburg fault in central Brooks County, with excellent sand buildup immediately adjacent to the fault, although unfortunately the best sands are under normal pressure. The only known deep Vicksburg sand occurs to the east at 10,500 ft. Wells have not explored this zone near the fault. There is inadequate control at depth to adequately assess the geothermal potential, but if the sand build-up continues to sufficient depth to thicken the 10,000-ft sand, it could be an interesting prospect. The depth of the 300°F geothermal surface is at approximately 12,000 ft, and low priority can be given to deep exploration here.

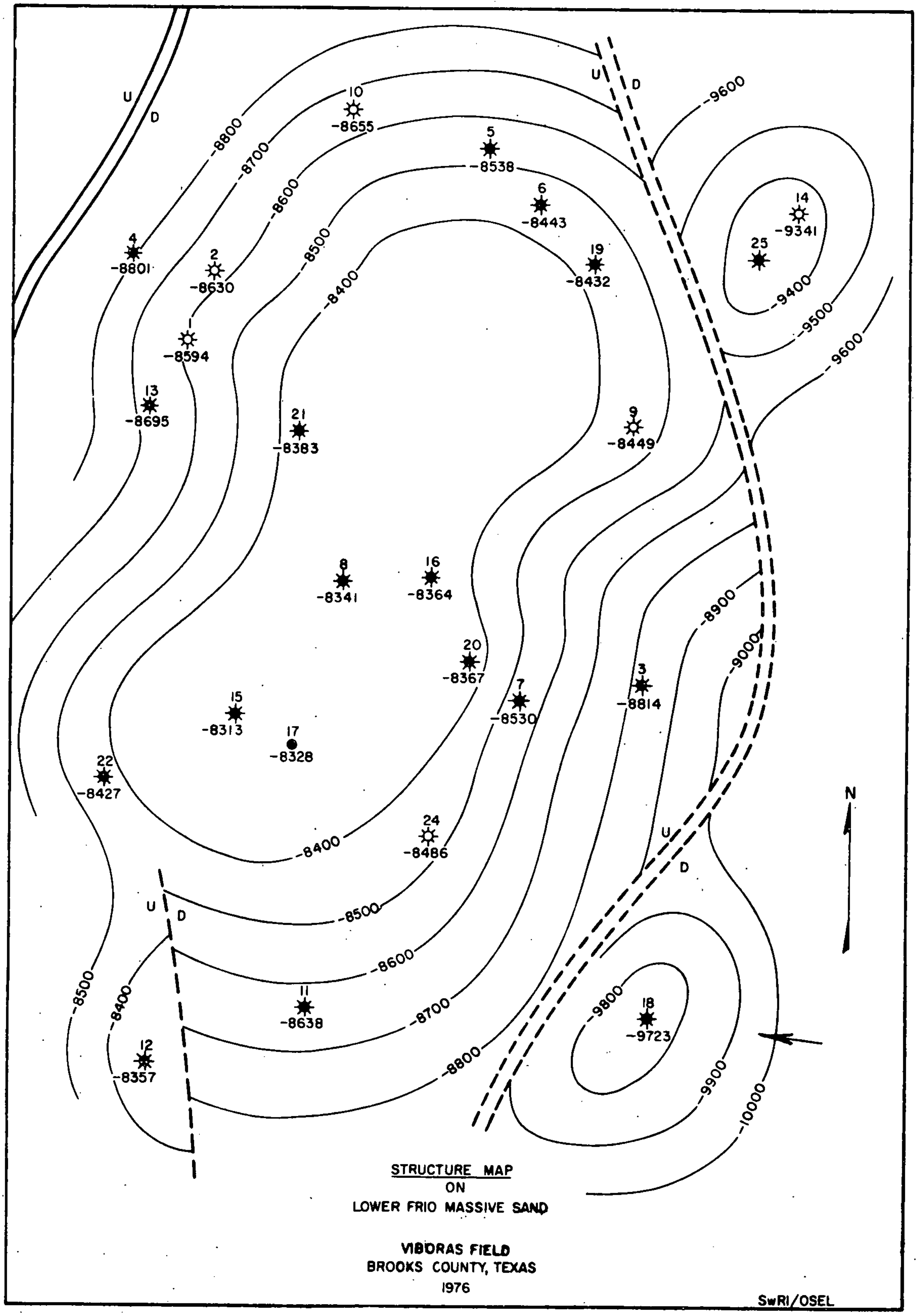


FIGURE 33. STRUCTURE MAP ON LOWER FRIO MASSIVE SAND VIBORAS FIELD, BROOKS COUNTY, TEXAS

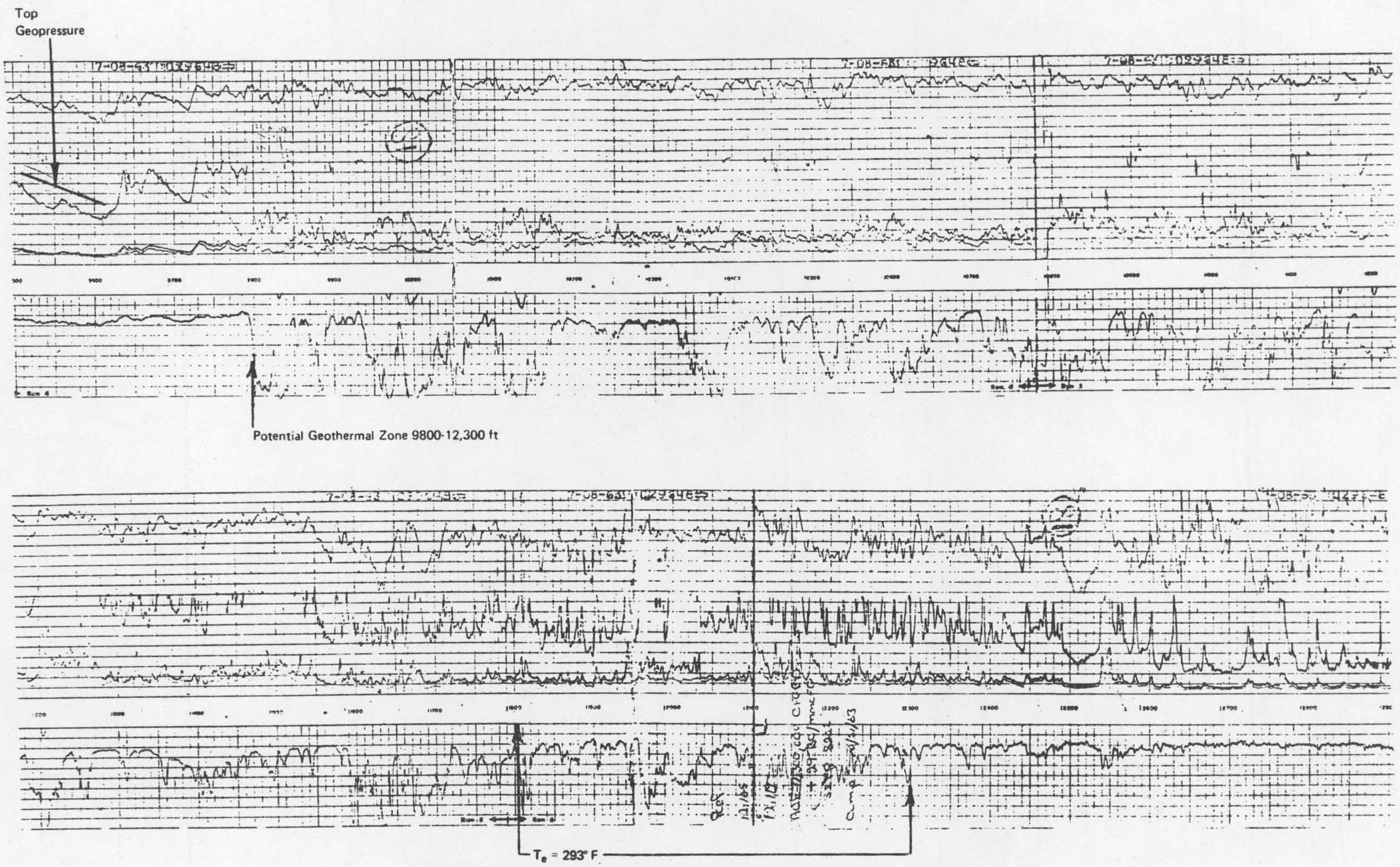


FIGURE 34. POTENTIAL GEOTHERMAL SANDS IN FRIO-VICKSBURG AND VICKSBURG SANDS, S.E. VIBORAS FIELD, BROOKS COUNTY, TEXAS
Equilibrium Temperature at 11805 ft = 293°F (Humble #37 Kleberg)

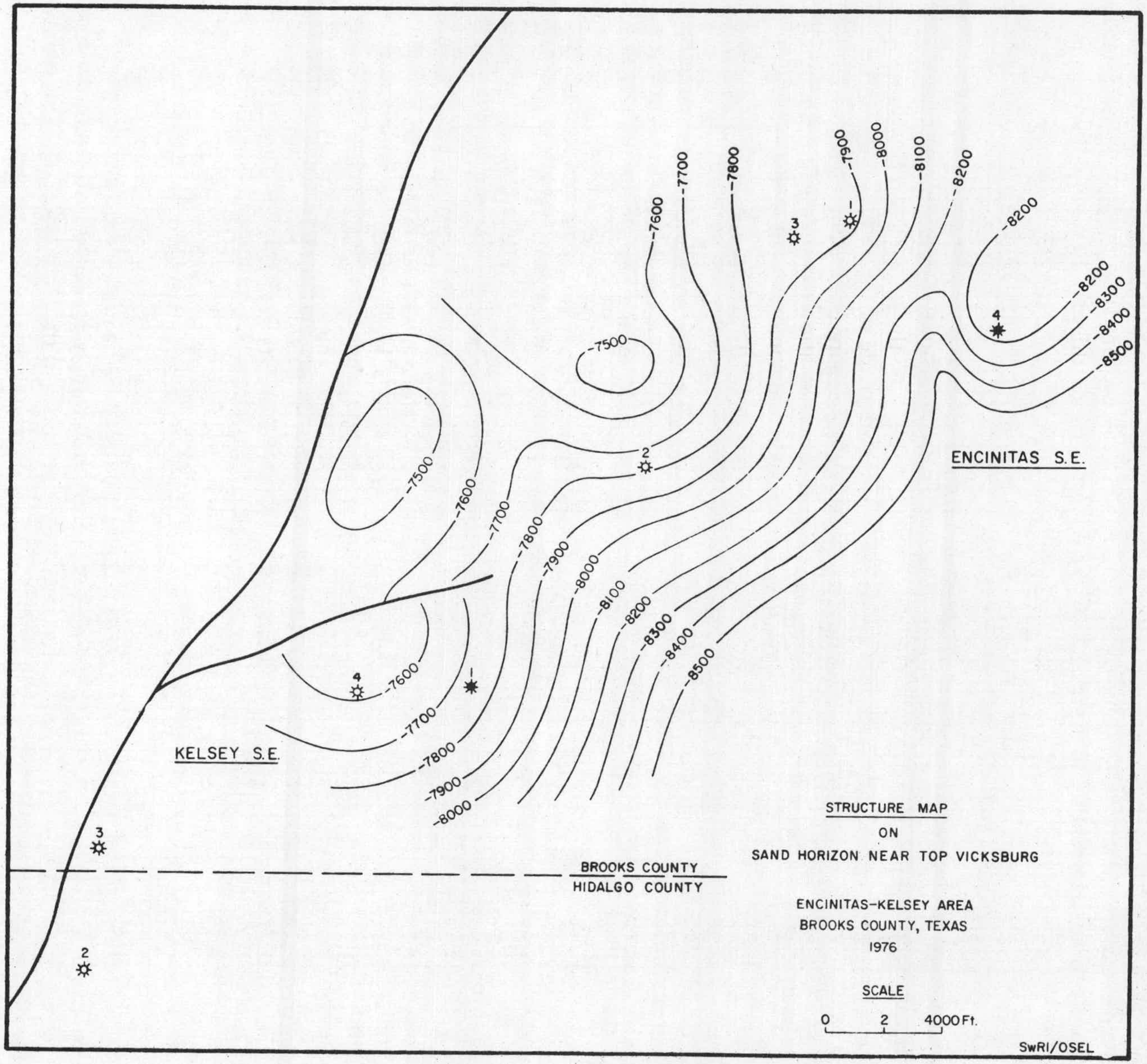


FIGURE 35. STRUCTURE MAP ON SAND HORIZON NEAR TOP VICKSBURG–ENCINITAS–KELSEY AREA, BROOKS COUNTY, TEXAS

6. Skipper-Cage Ranch-Alta Mesa Area (Map Nos. 32, 34, 35)

Related structurally to Scott and Hopper and La Encantada fields and producing from generally shallow sands, these fields all have some production history from a common Vicksburg zone showing relatively good sand development at depths ranging from 9,400 to 10,500 ft. One of the best of these is shown on the log section in Figure 36 from the Skipper field. Although these sands are unusually clean for Vicksburg sands, permeability calculations from production tests indicate effective permeability of 1 md or less. We do not consider this area to represent an attractive prospect.

7. Summary of Brooks County Investigation

All of the identified geopressured production in Brooks County lies to the east of the Frio-Vicksburg flexure and ranges from the base of the Frio through the Vicksburg formation. Several of the fields exhibit fair sand buildup on the downthrown side of the various faults in the region. The temperature gradient, particularly near the Frio-Vicksburg fault, is high but the depths to which exploration has reached are modest and there is little indication of potential production of water at temperatures as high as 300°F. Faulting is somewhat less complex than in many parts of Hidalgo County, and the continuity of aquifers less disturbed by such faulting. However, the sands are often lenticular with small, single-well reservoirs the rule. We consider the best possibility to be in the southeast Viboras area near the Kenedy county line, where a test of methane production from water at 250°F or so could be accomplished at moderate depth from excellent Frio-Vicksburg sands. Testing of an extended vertical interval of low permeability needs to be attempted, and this is a promising place to do so.

B. Kenedy County

Sediments thicken basinward across the study region from west to east. Thus, Kenedy County is in an area of greatly thickened Frio and Vicksburg deposition, particularly near the coast. In most locations, the top of the geopressured zone is coincident, or nearly so, with the top of the Vicksburg. This point occurs at greater depth in Kenedy County than in Brooks County, but the temperature gradient in Kenedy County is lower. Production from Vicksburg sands is not so common in Kenedy as in Brooks County, although the deepest production (15,000 ft) in the south Texas study region occurs in Vicksburg sand in El Paistle field, to the south of the Nueces county line. Temperatures as high as 300°F occur only in the Vicksburg and deeper sediments. A total of eight geopressured gas fields were located in the county.

1. Candelaria Field

Candelaria is in west central Kenedy County, to the east of a major extension of the McAllen fault. Most of its production history has been from normally pressured Frio sands, but two wells have produced gas from a geopressured sand that is probably in the Vicksburg. Many of the shallow Frio wells exhibit high permeability, but both geopressured producers show permeability less than 1 md.

The geopressured section in Candelaria includes the lower part of the Frio, and the Vicksburg formation. Both the Frio and Vicksburg sections contain sands of considerable thickness, individual units often measuring as much as 50 to 100 ft. However, correlations between the two Candelaria geopressured producing wells and dry holes in the area are extremely tenuous in the geopressured zone, suggesting sand lensing. Continuity of these sands over a broad areal extent, such as

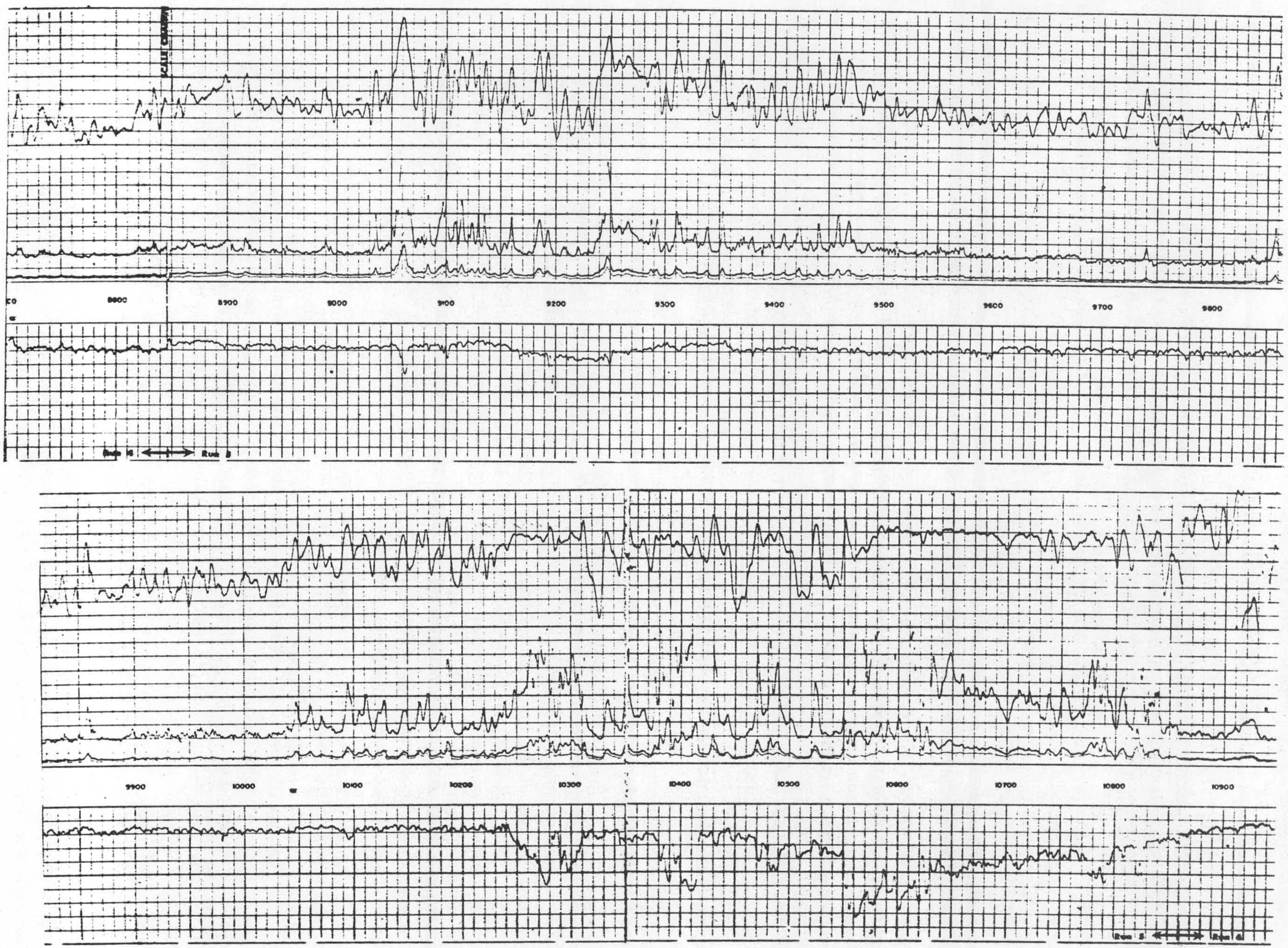


FIGURE 36. DEEP VICKSBURG SAND DEVELOPMENT TYPICAL OF CENTRAL BROOKS COUNTY, TEXAS
Approximately 250 ft of Clean Sand between 10,250 and 10,800 ft. (Humble #11 Skipper, Skipper Field)

would be favorable for the containment and potential extraction of large quantities of water, appears unlikely.

Structure maps constructed on the top of the 8500-ft sand unit in the Frio and another on the probable top of the Vicksburg appear as Figures 37 and 38. From the available control, faults within the field are few in number, and small in displacement. The large fault displayed on the western side of the field was not encountered in the wells studied, but was projected from the work of others. The down-to-the-coast fault to the southeast of the field was only mildly defined by the Humble C. M. Armstrong No. 20 and No. 22 (designated as wells No. 3 and No. 7 in Figures 37 and 38). No evidence was found to indicate that prominent cross-faults isolate this area to the northeast or the southwest. Individual sand units in the Vicksburg are not readily correlatable from the Candelaria area to Mifflin, El Paistle, or Sarita fields to the northeast, but the good sand buildup in Candelaria thickens in that direction.

Numerous well-developed Vicksburg sands to depths as great as 17,000 ft have been logged, and in the absence of test information, production from zones of this type cannot be ruled out. Eventual testing of such deep sands in Candelaria, and to the east and northeast of Candelaria, may be warranted.

On the negative side, however, is the unfavorable reservoir information from shallower gas-producing sands, with Candelaria geopressured wells exhibiting very low (less than 1 md) permeability at depths of only 10,000 to 12,000 ft. The temperature gradient is low with the 300°F geotherm at approximately 13,000 ft, and the sands are probably lenticular. For these reasons, Candelaria rates only "fair" as a geothermal prospect.

2. Rita Southeast

The southeast extension of the shallow Rita field, immediately to the northwest of Candelaria, is apparently separated from Candelaria by stratigraphy. Correlation to Candelaria field is difficult, indicating the lenticular nature of the individual sand units. Overall Vicksburg sand development, however, remains good, but the limited deep control in the field prevents any serious assessment. The permeability in the producing sand at 12,800 ft is low. We consider, from a geothermal standpoint, that this field is in the same trend as Candelaria and any lack of continuity of the aquifers is due to sand lensing. For geothermal purposes, this field can be grouped with Candelaria El Paistle, Sarita East, and Baffin Bay.

3. El Paistle, Sarita East, and Baffin Bay

These three deep fields in north central Kenedy County continue the trend toward thick, well-developed Vicksburg sands that extends northward from the Candelaria field. The deepest recorded production is in El Paistle field where the Humble No. 7 Kenedy was completed in a thick zone from 15,057 to 16,805 ft with an initial potential of 2.4 MMcf gas per day. Effective permeability of this long interval is extremely low and discourages any prospects of deeper production. There are a number of well-developed sands at shallower depths in all three of these fields, with the best sands apparently occurring in Sarita. Production in Sarita has been from zones as deep as 14,500 ft. A type log from E. Sarita is shown in Figure 39.

The top of the geopressured zone in El Paistle is at approximately 11,200 ft in the Vicksburg. Well-developed sands occur in intervals from 12,400 to 13,400 and from 14,200 to

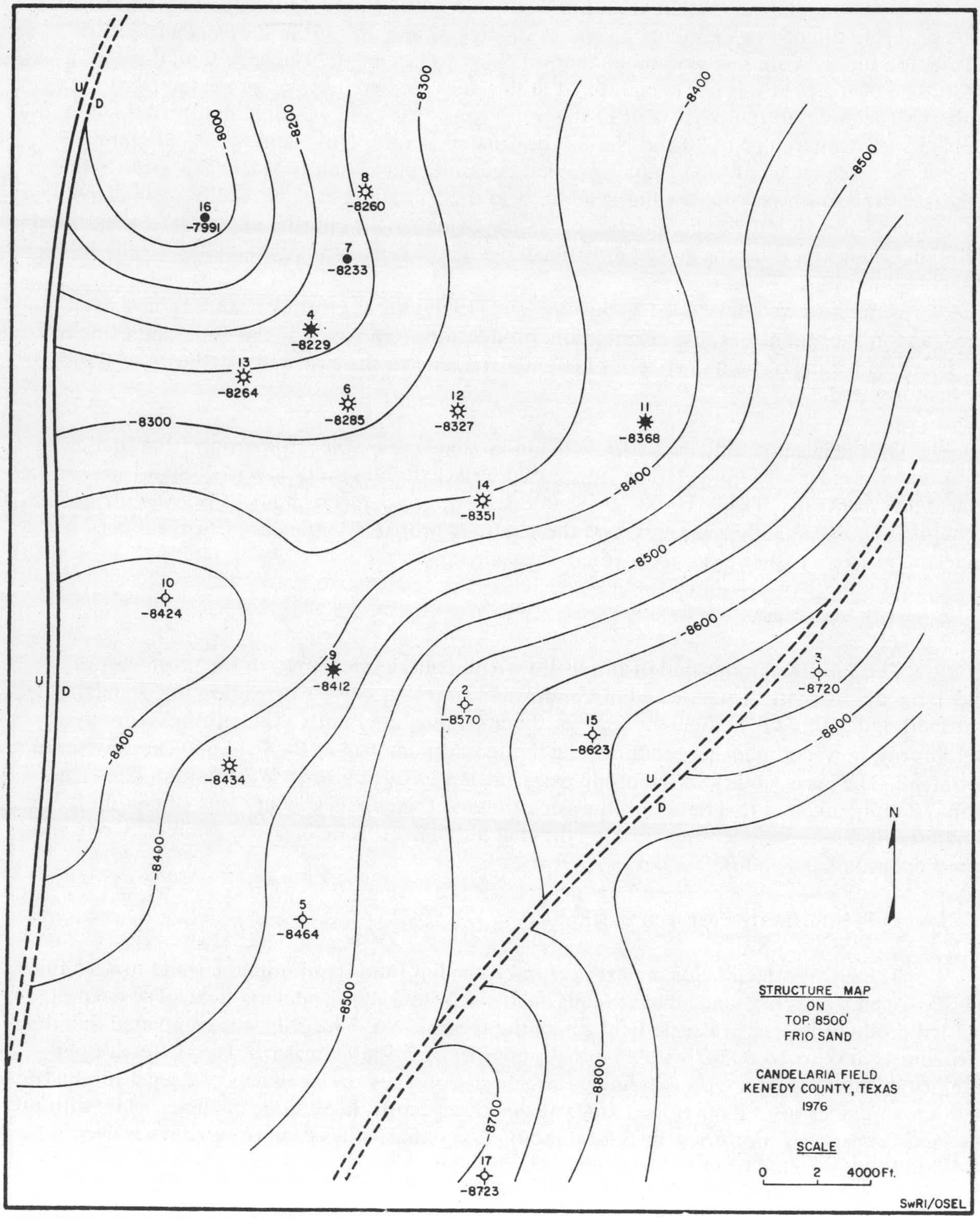


FIGURE 37. STRUCTURE MAP ON TOP 8500 FT FRIO SAND CANDELARIA FIELD, KENEDY COUNTY, TEXAS

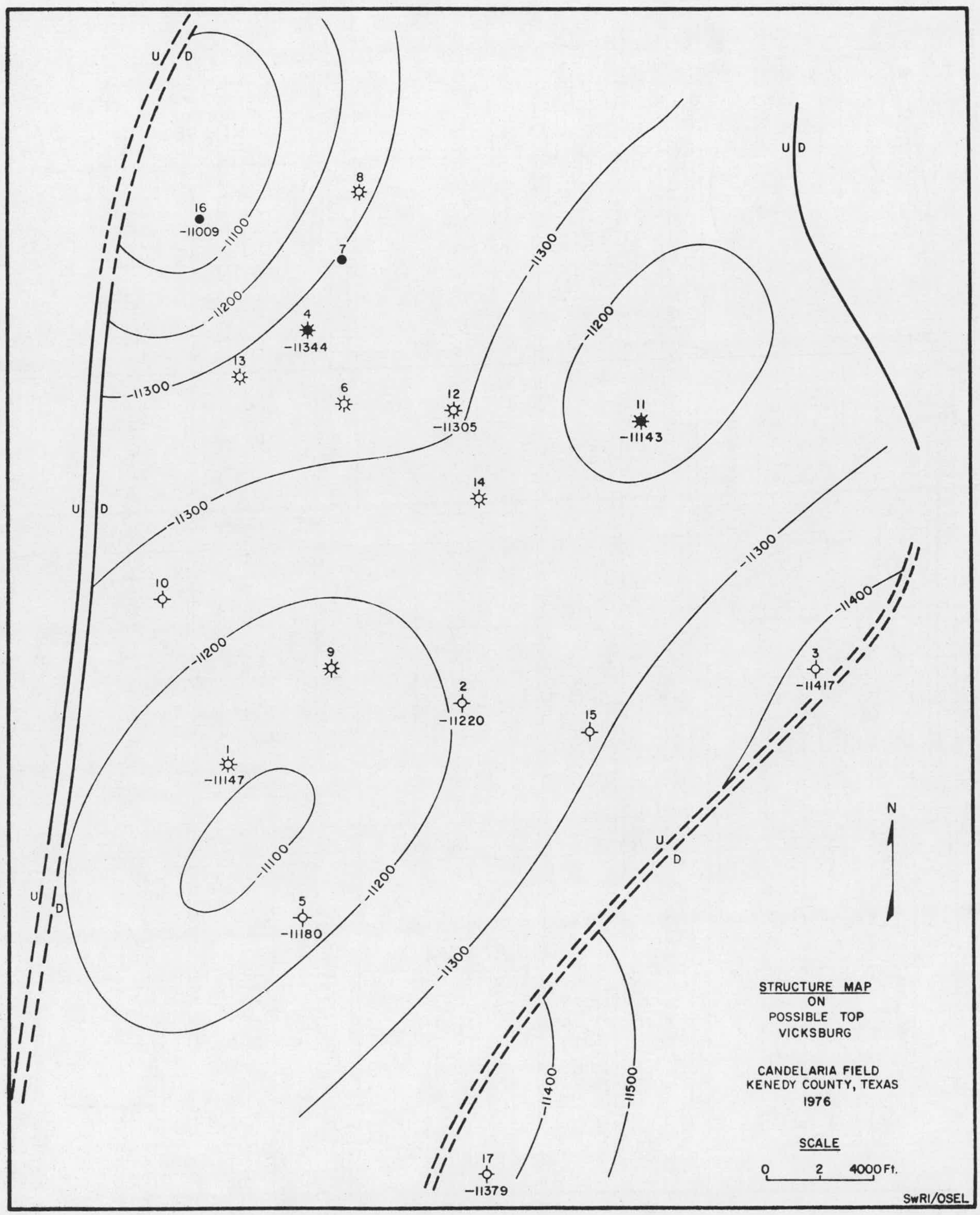


FIGURE 38. STRUCTURE MAP ON POSSIBLE TOP VICKSBURG–
CANDELARIA FIELD, KENEDY COUNTY, TEXAS

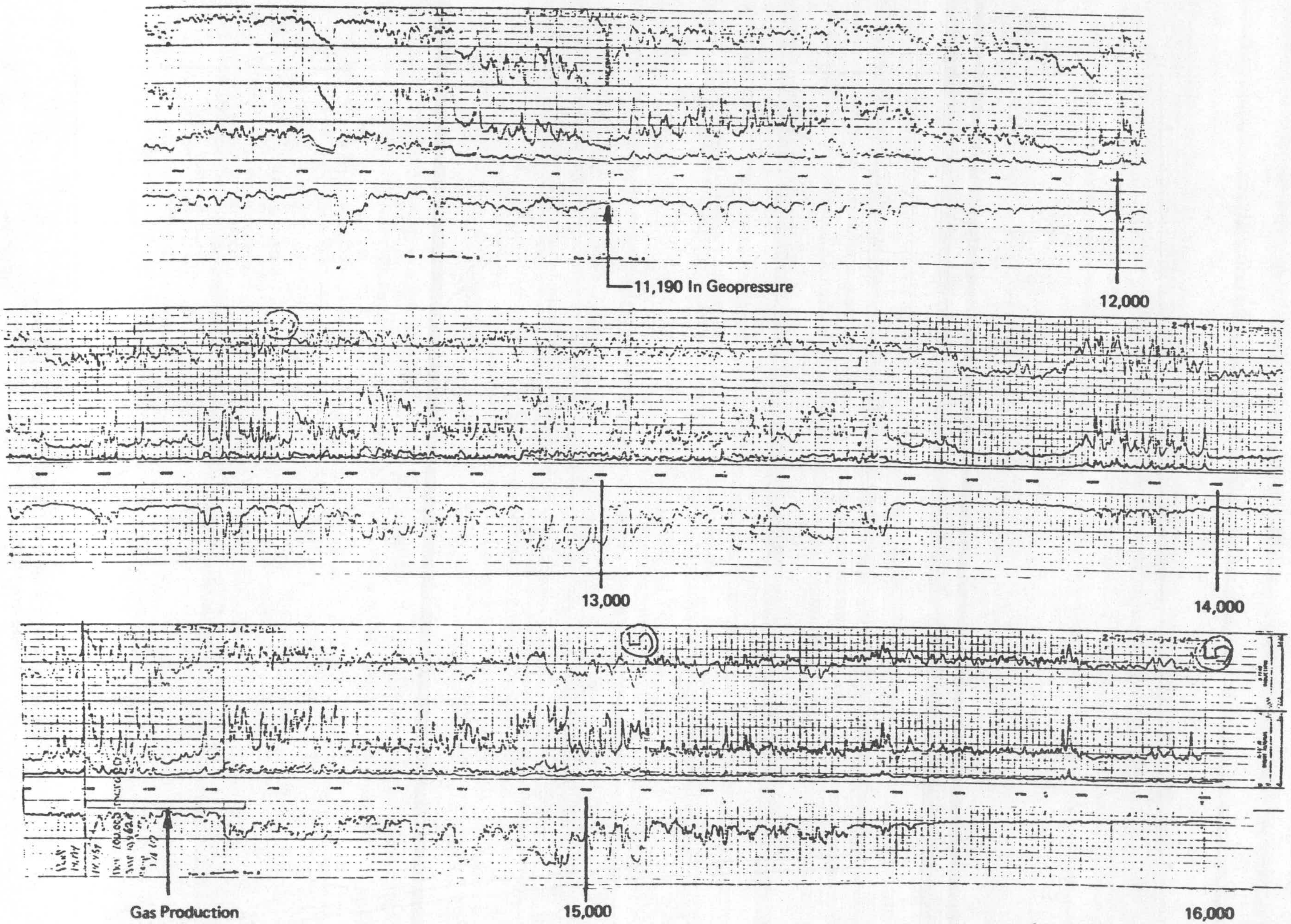


FIGURE 39. LOG SECTION OF GEOPRESSURED SEDIMENTS PENETRATED IN SARITA FIELD, KENEDY COUNTY, TEXAS. Top of Geopressure 10,950 ft; Recorded BHT = 300° at 16,000 ft (Humble #13 East "B")

15,200 ft with reasonable possibility of producing fluid. There is a total of nearly 1000 ft of good, well-developed sand between the top of geopressure and 16,000 ft.

Baffin Bay continues the same trend, with less well-developed Vicksburg sands and lower permeability. The best prospect in the northern part of Kenedy County is probably in the Sarita area. However, the temperature gradient is relatively low with the 300°F geotherm located at approximately 14,000 ft. Correlation of the individual sand units between fields is not possible, and it is likely that lenticular sands and limited aquifer size are the rule. The general area is, however, worthy of further consideration, because of the sands at depth in the Vicksburg.

4. Sorillo

The geopressured production in Sorillo field is in a south extension of an old, shallow field in the northwest corner of Kenedy County. The single well geopressured producer has nothing to recommend the area as a geothermal prospect. The well produces from a thin Vicksburg stringer at 11,600 ft and there is no further sand development indicated to the total well depth of 13,500 ft. The top of geopressure is located at approximately 10,000 ft and the geothermal gradient is low. The depth of the 300°F geotherm is at approximately 14,000 ft.

5. Tordilla-Stillman Area

Two geopressured producing fields were located in the southwestern corner of Kenedy County near the Hidalgo County border. Both produce from lower Frio Sands near the top of geopressure, and while permeability is as high as 8.0 md, there is no indication that Vicksburg prospects are good. The 300°F geotherm is at approximately 13,000 ft in this area.

6. Summary of Kenedy County Investigation

The best geothermal prospects in Kenedy County occur in a diagonal belt from the Candelaria field area northeast to El Paistle and Sarita. Particularly on the downthrown side of the large faults, Vicksburg sand development is good in many of the wells investigated. Correlation between sand units is extremely tenuous, however, and the probability of small, lenticular aquifers of limited extent is high. The best prospect appears to be in the Sarita field area, although no favorable reservoir information was uncovered. Permeability is low as is the geothermal gradient. But deep Vicksburg sands are present, and adequate testing should be accomplished. The deliverability of water sands at great depth is unknown.

C. Hidalgo County

Twenty of the forty-seven geopressured fields identified during the study were located in Hidalgo County. These fields may be grouped with the three major fault systems under whose influence their structures developed. Six of the fields, located near the western boundary of Hidalgo County, are similar to fields in central Brooks County, along the Frio-Vicksburg flexure. Four fields slightly to the east produce from sediments controlled by the Tabasco fault. The remainder are roughly oriented along the huge McAllen-Alazan fault system, which extends from southern Hidalgo County through Kenedy County and beyond.

The four easternmost fields, although listed with those on the McAllen fault, are actually the result of a fourth system, not usually considered a major flexure, known locally as the Weslaco fault. It should be understood that these categories are only broadly defined. Each major fault system is composed of almost countless branches, and unnamed transverse faults are commonplace.

The trend as one moves from north to south into Hidalgo County is one of increased fault-trapping in the south, with small individual fault blocks the rule. To the north, in Kenedy and Brooks Counties, the trend is toward less complex faulting with increasingly frequent sand lensing.

1. Western Hidalgo County

The Frio-Vicksburg flexure, to the west of the Hidalgo county line, has been described previously in this report in connection with Brooks County. That general description applies to western Hidalgo County, with gradual thickening of Vicksburg sediments to the south. Sand development in the region generally shows improvement over that in Brooks County, but faulting becomes more complex. Six geopressured fields were identified along this trend. They are: (1) South Kelsey, (2) McMoran, (3) McAllen Ranch, (4) Arrowhead, (5) McCook, and (6) Jeffress. These fields all produce from Vicksburg sediments and the geopressured production occurs at depths as great as 14,000 ft. Producing zones in each of the fields are typical, with small individual reservoirs and fault closure the rule. Even within the two largest fields, McAllen Ranch and Jeffress, it is difficult to obtain correlation between more than two wells in the same productive zone. Faulting increases in complexity with depth. The region can be typified by discussion of these two major fields.

a. Jeffress Field

Jeffress is a large prolific gas field in west central Hidalgo County with the highest geothermal gradient in the county. Geopressured zones can be identified at depths as shallow as 6000 ft, but the average top of geopressure lies between 7000 and 8000 ft. Current gas production is from isolated sand elements from 6,000 to 13,500 ft in depth, separated by complex faulting and typical of barrier-bar deposition and lensing. Abnormal pressures increase rather gradually with depth, from approximately the top of the Vicksburg formation. Intermediate casing is normally set near 7000 ft, and usually a second intermediate string must be set at depths between 9,500 and 10,000 ft. At a depth of 10,000 ft, the pressure gradient is typically above 0.9. Faulting becomes more complex below the blanket sand known as the Vicksburg "S" sand. Below the Vicksburg "T" sand, correlation between individual units becomes extremely tenuous.

These two sand bodies, the "S" and the "T," are shown on the type-log in Figure 40. They are generally well developed, and thicken appreciably on the downthrown side of the several faults that cut the field. These faults are shown in the two structure maps in Figures 41 and 42, which also show the increased faulting with even moderate increases in depth. We consider these two sands to be of interest and worthy of testing, because the depths are moderate, testing should be simple, and the likelihood of producing water saturated with dissolved gas is excellent. Although the temperatures at this depth are not high, they exceed 250°F in the Vicksburg "T" sand.

A number of outstanding questions can best be approached by testing geopressured sands at depths and under conditions as moderate as possible. These include experience with gas production from water solution, experience with corrosion and scale problems with south Texas geothermal fluids, and attempts to produce multiple sand sections at different depths in the same well. Jeffress' shallow Vicksburg sands are likely to be continuous, and successful operation of a well here would add a great deal to the background of knowledge on the subject of geopressured water production.

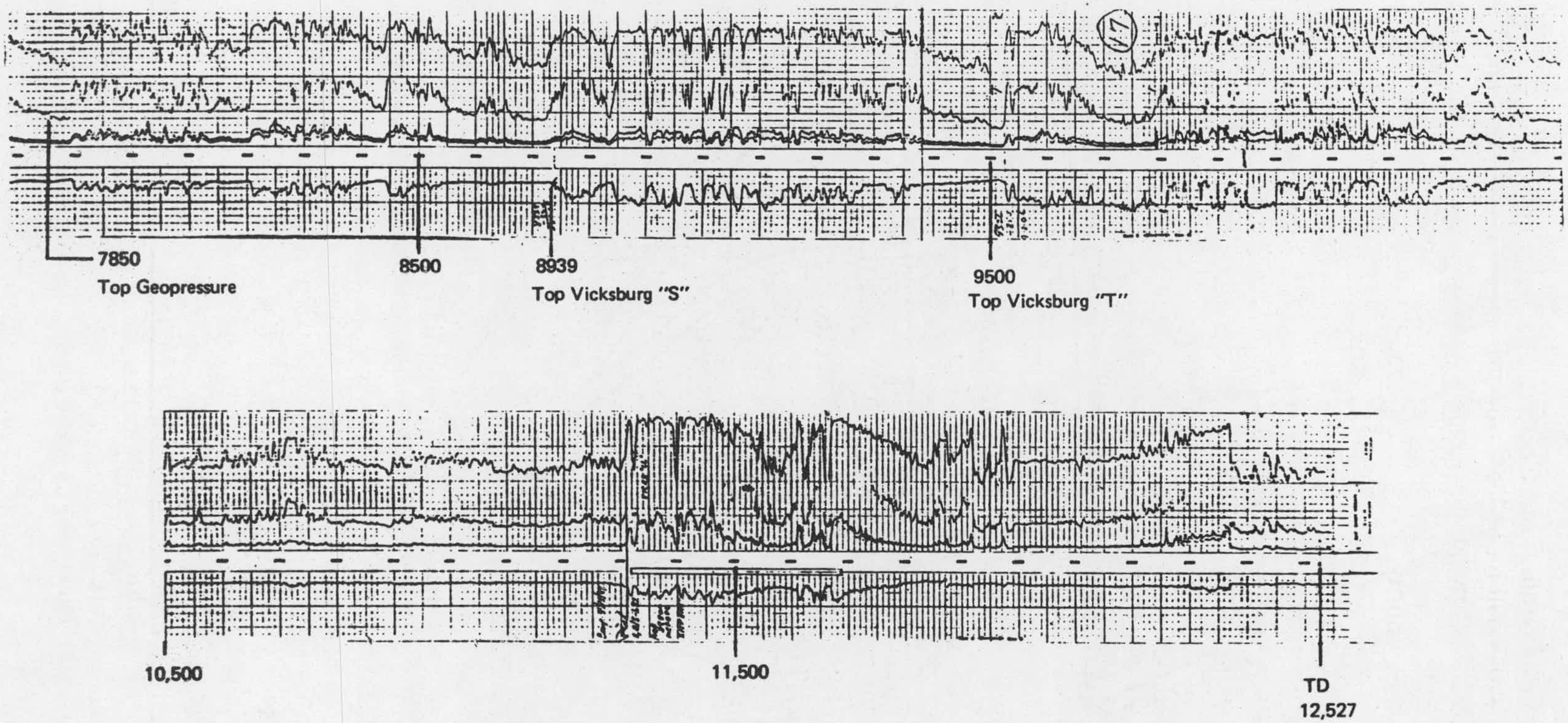


FIGURE 40. TYPE-LOG, JEFFRESS FIELD, HIDALGO CO., TEXAS SHOWING TWO LARGE VICKSBURG BLANKET SANDS, "S" AND "T." (COASTAL NO. 1 JEFFRESS)

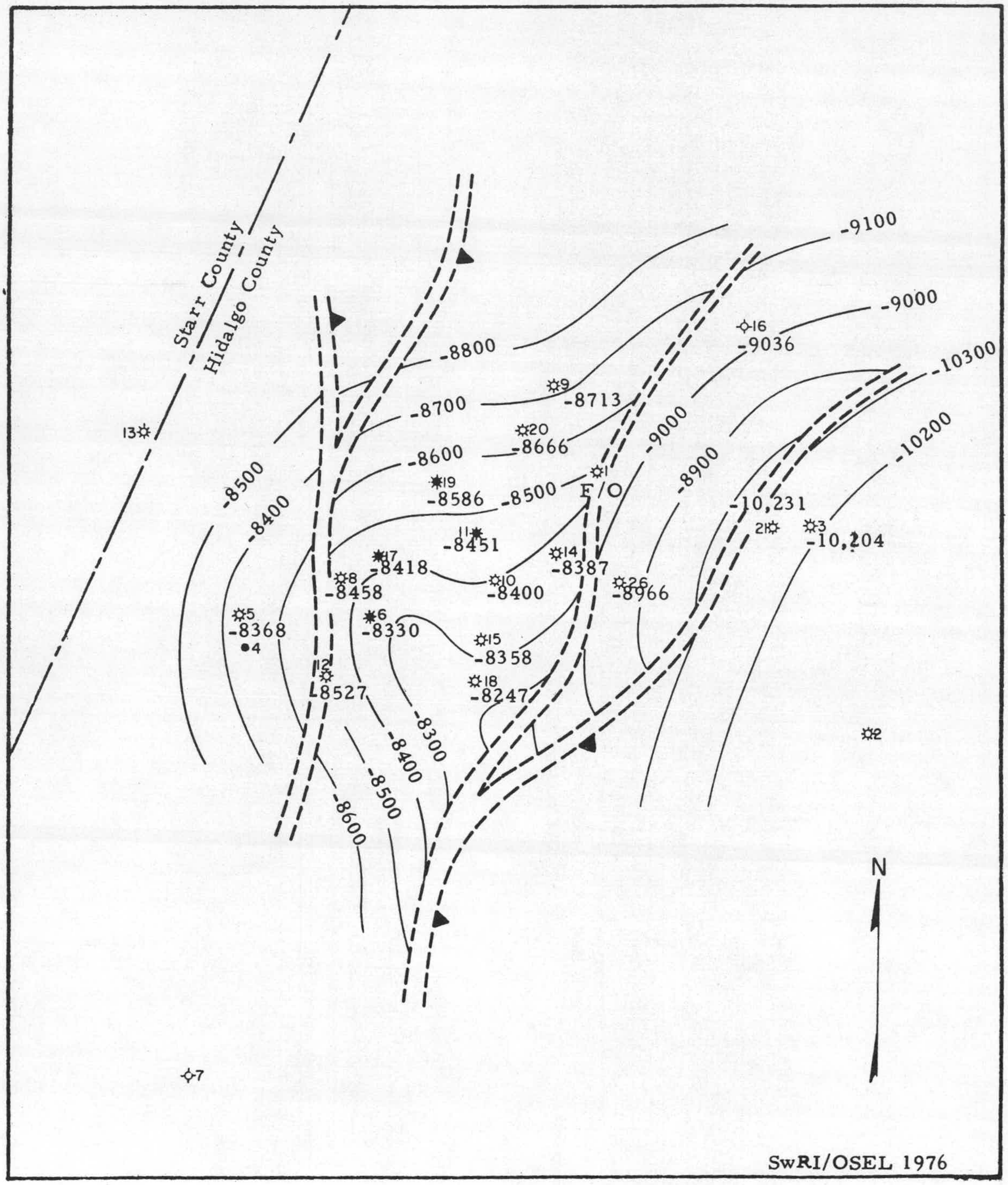


FIGURE 41. STRUCTURE VICKSBURG "S" SAND, JEFFRESS FIELD, HIDALGO COUNTY, TEXAS

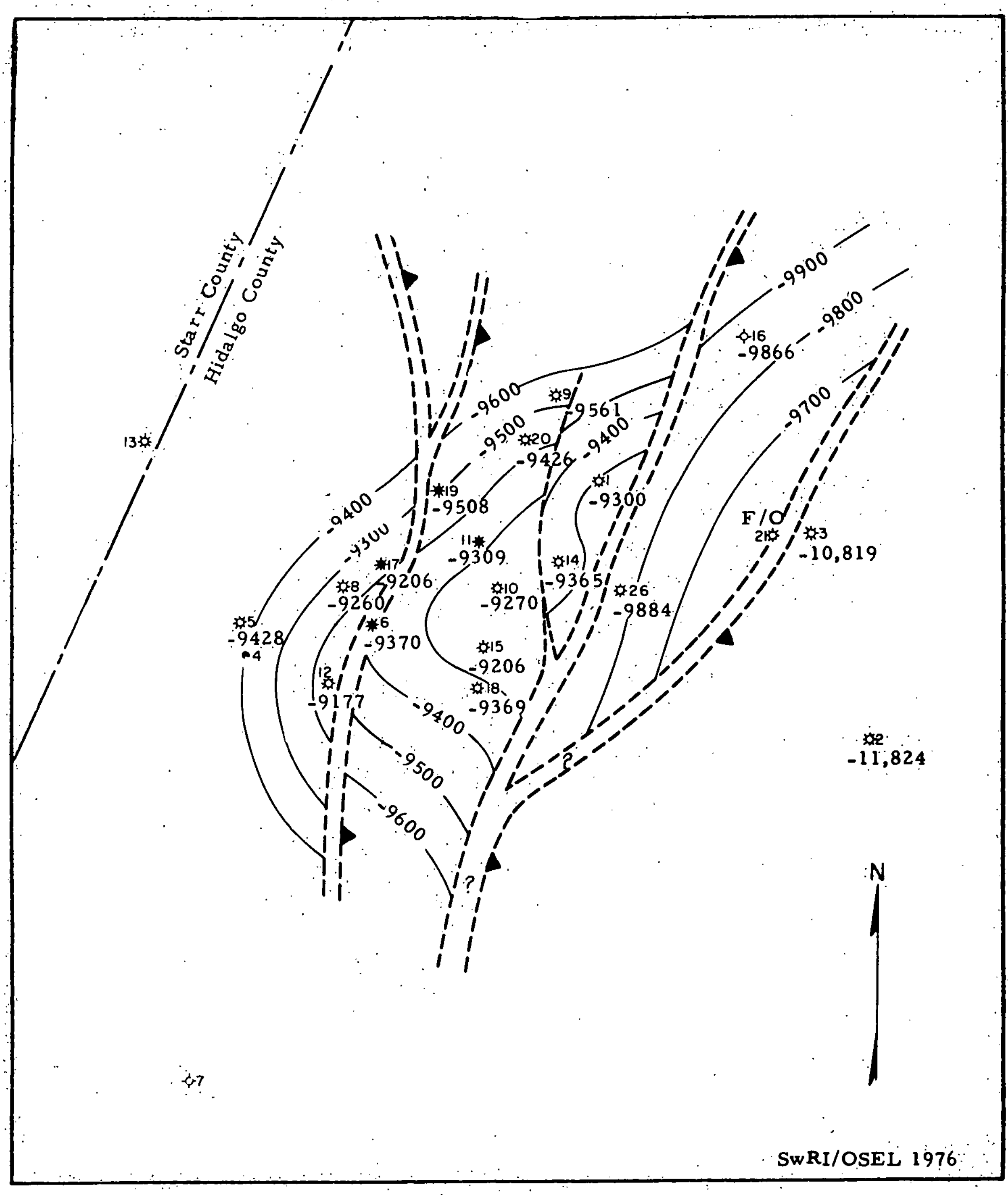


FIGURE 42. STRUCTURE VICKSBURG "T" SAND, JEFFERESS FIELD, HIDALGO COUNTY, TEXAS

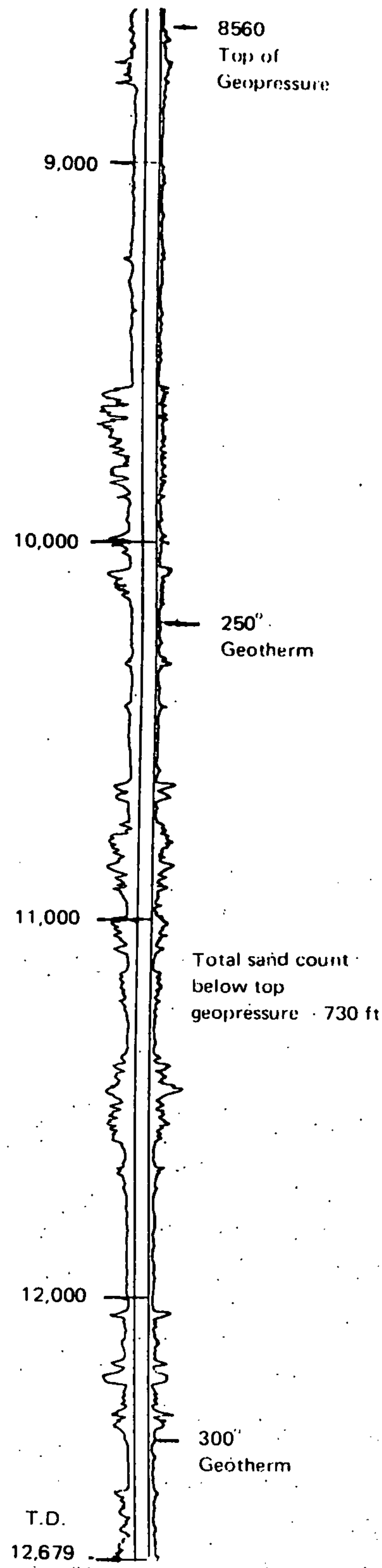


FIGURE 43. LOG OF GEOPRESSURED SEDIMENTS, McALLEN RANCH FIELD, HIDALGO COUNTY TEXAS

The possibility of deep water production in Jeffress is doubtful; reservoir properties at depth are poor and the sands discontinuous.

b. McAllen Ranch

McAllen Ranch is a large Vicksburg gas field east and north of Jeffress. It is typical of three smaller adjacent fields (south Kelsey, McMoran and Arrowhead). Structurally, McAllen Ranch field is dominated by two faults, one of which is responsible for most of the sand development in the field, the other cutting the field production into two components. Wells produce gas and condensate at depths ranging from 10,000 to 14,000 ft. Deep Vicksburg sands are numerous, and the geothermal gradient is high. The depth of the 300°F geotherm is approximately 12,000 ft. However, the permeability is very low, and production of water at high flow rates extremely doubtful. A type-log of McAllen Ranch is shown in Figure 43, and structure maps on two consistent Vicksburg sands are shown in Figures 44 and 45. Deeper sands are much more elusive and correlation difficult.

In spite of its size and relatively high temperature gradient, the less well-developed upper zones make McAllen Ranch not as attractive as Jeffress for a shallow test, and the lack of encouraging reservoir parameters at depth give neither field a good chance for high-temperature production.

2. Tabasco Fault Area

Four relatively unimportant fields, from the geothermal standpoint, are grouped along the Tabasco fault, a minor system in the southwestern part of Hidalgo County. These fields are, by map number, (7) Monte Christo;

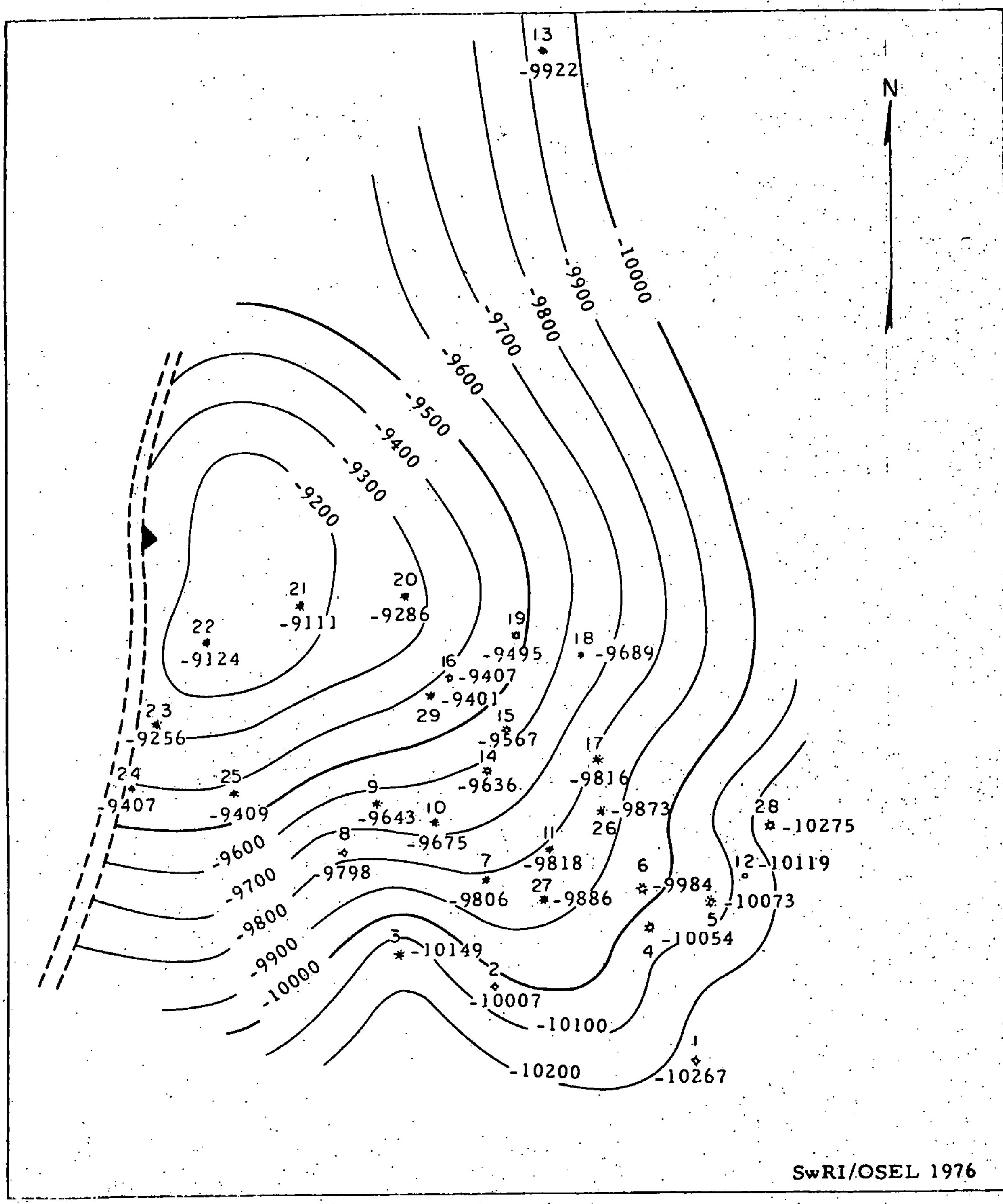


FIGURE 44. STRUCTURE TOP VICKSBURG "L" SAND, McALLEN RANCH, HIDALGO COUNTY, TEXAS

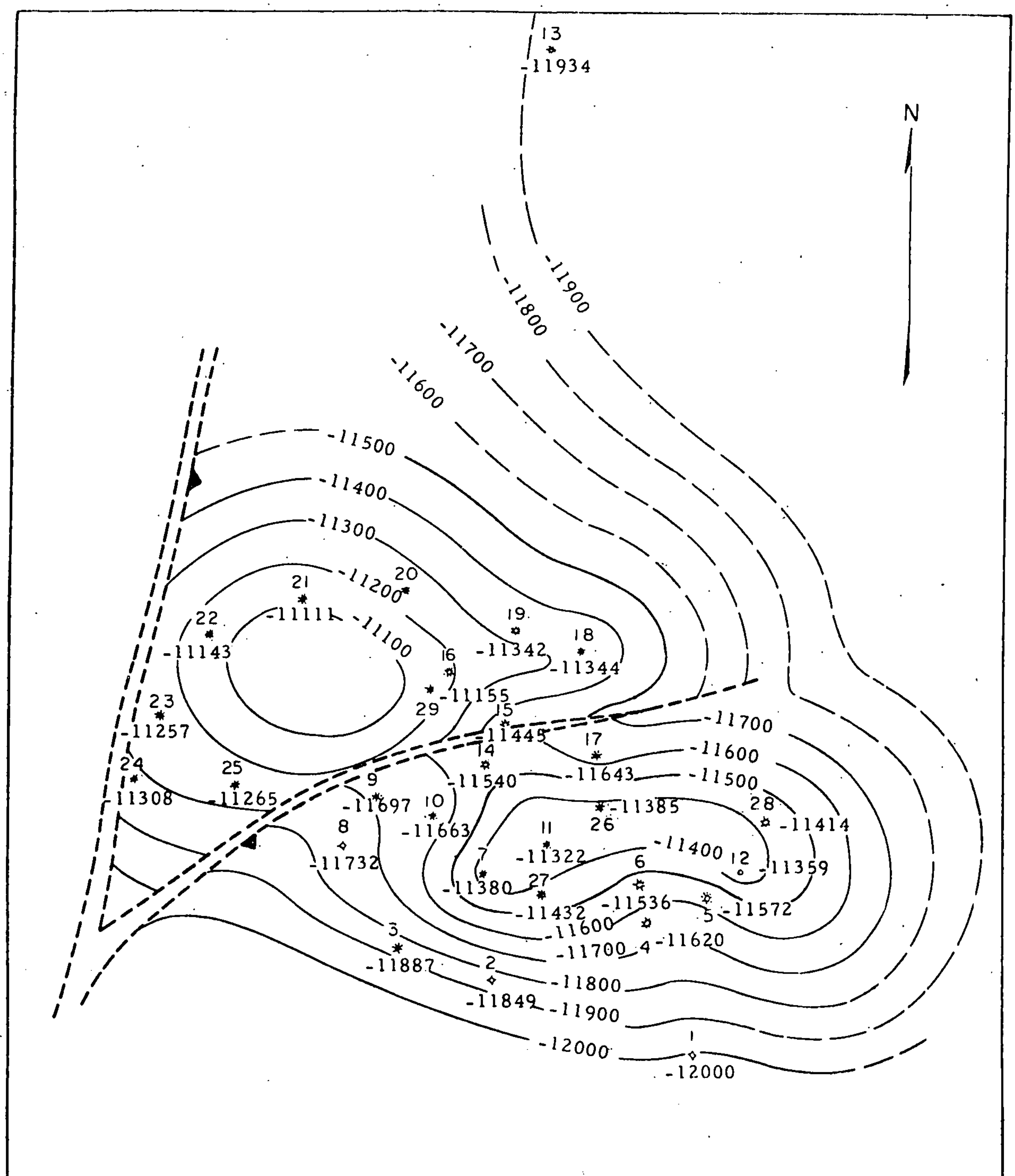


FIGURE 45. STRUCTURE TOP VICKSBURG "S" SAND, McALLEN RANCH, HIDALGO COUNTY, TEXAS

(8) Foy; (9) Oblate; (10) Santellana. The largest of these is Monte Christo, producing from lower Frio and upper Vicksburg sands ranging in depth from 6000 to below 11,000 ft. Top of geopressure is at approximately 8600 ft. Sand development below 11,000 ft is poor. In the deepest test in the area (Shell No. 5 Hamman Ranch), some shaley sand of generally poor quality and limited extent was located between 16,400 and 16,900 ft. Temperature at this depth is 350°F or more. The best sand development is from 9,000 to 10,000 ft, but this sand is known to have low permeability.

The remainder of the fields are not significant, each containing one or at the most two wells producing from small abnormally pressured reservoirs. Sand buildup along the Tabasco fault has apparently been restricted to shallow sediments. A deep test in the Foy area discloses virtually no sand at all from 6,000 to 12,000 ft. Although the temperature gradient is good here, reservoir prospects are poor. We do not consider the Tabasco fault area to offer attractive testing possibilities at this stage.

3. The McAllen Fault-Lower Hidalgo County

The McAllen fault, dividing the county to the east of center, is one of the largest growth fault systems on the lower Gulf Coast. It has been active throughout the geologic history of the area and was probably caused by structural weakness in the basement rather than by simple slumping. According to Collins (1967), the earliest indication of the fault is the steep westward (reverse) dip of the lower Frio beds in the McAllen field, indicating thickening into the fault. Each successive bed was deposited contemporaneously with fault movement and therefore thickens into the downthrown side, away from the basin. The tremendous amount of deposition associated with the Rio Grande embayment, coincident with the activity of this huge fault system, created enormous reservoir possibilities for both petroleum (which it has produced prolifically) and for geothermal fluid all along its length. The large McAllen-Pharr field area, with numerous separate producing reservoirs, and the Edinburg field just to the north, are situated on this thickened deposition.

The Weslaco fault, a minor system to the east is largely responsible for Frio and upper Vicksburg sand development in four other fields nearby. These fields in the Weslaco-Mercedes area are of interest because they contain the least saline water of any fields studied.

a. McAllen, Pharr, and S. Edinburg Fields (13, 14, 12)

A promising area for the occurrence of continuous geopressured reservoirs of broad areal extent is in the vicinity of the McAllen-Pharr and the south Edinburg gas fields. These fields are situated between two north-south trending fault systems, the McAllen fault and the Donna fault. The sedimentation and structure of the area were controlled primarily by the massive McAllen growth fault to the west of the fields but in part by the relatively stable area created to the east by the Donna fault. The east-west trending Shepherd fault, with several thousand feet of throw, limits the fields on the south. A type-log of McAllen-Pharr is shown in Figure 46.

Gas and gas condensates have been produced from more than a dozen Frio-Vicksburg sands between the depths of 5,800 and 13,700 ft. In the upper portion of the geopressured section (Hansen Sand), the production occurs in a large stratigraphic trap; deeper production is from small fault blocks, with the beds dipping generally away from the basin. Of principal interest in this study are the lower Frio-Vicksburg sands of the Marks and Bond series and below, where the temperatures are in the range of 300°F and higher. The Marks and Bond series alone contain as much as 800 ft of sand, with some individual sand beds more than 100 ft in thickness. According to Collins, most of the faults do not disrupt the continuity of the aquifers because the thickness of the sands is greater

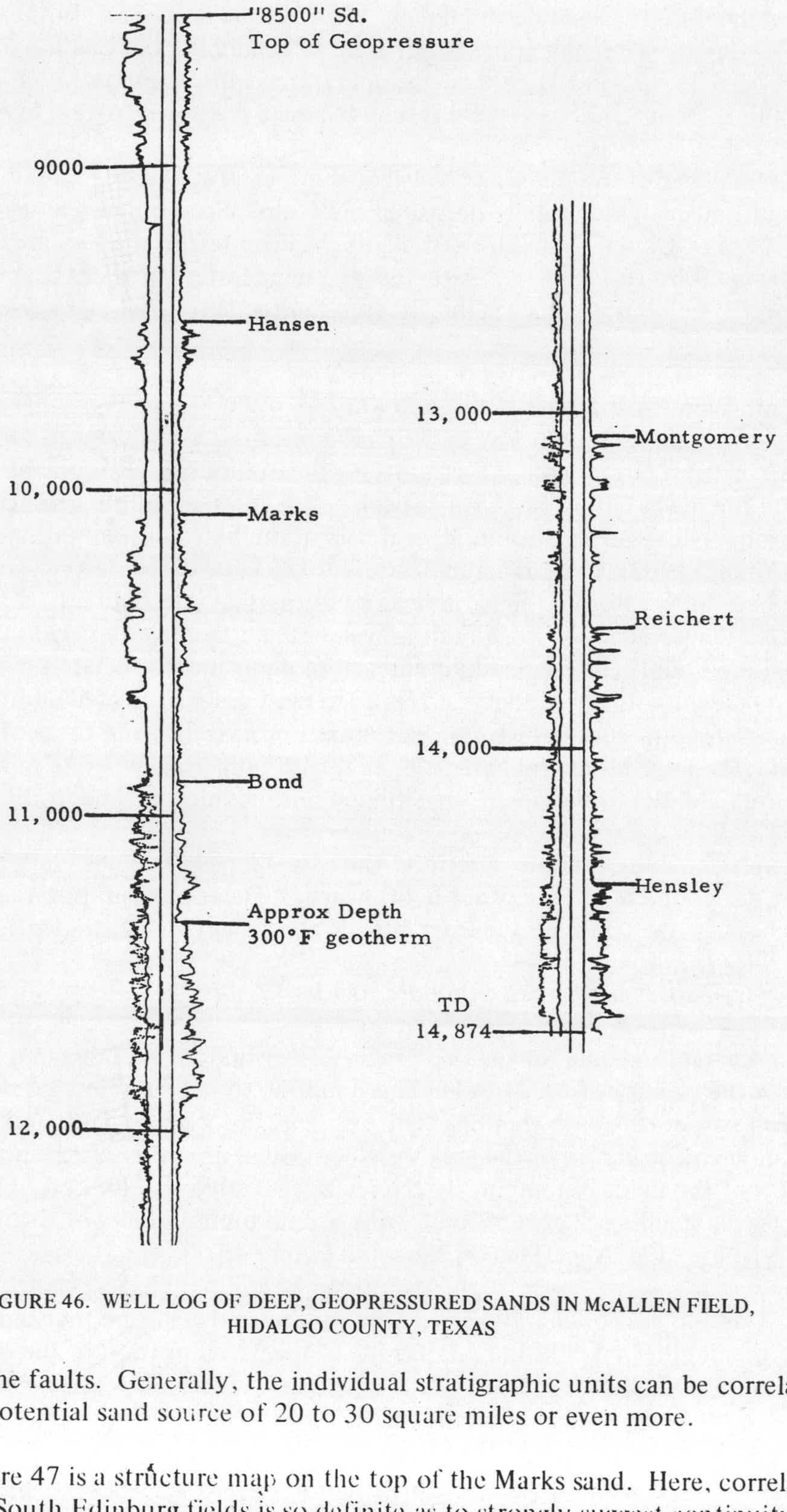


FIGURE 46. WELL LOG OF DEEP, GEOPRESSURED SANDS IN McALLEN FIELD, HIDALGO COUNTY, TEXAS

than the throw of the faults. Generally, the individual stratigraphic units can be correlated between fields suggesting a potential sand source of 20 to 30 square miles or even more.

Figure 47 is a structure map on the top of the Marks sand. Here, correlation between McAllen-Pharr and South Edinburg fields is so definite as to strongly suggest continuity over the area between, even though direct control is limited.

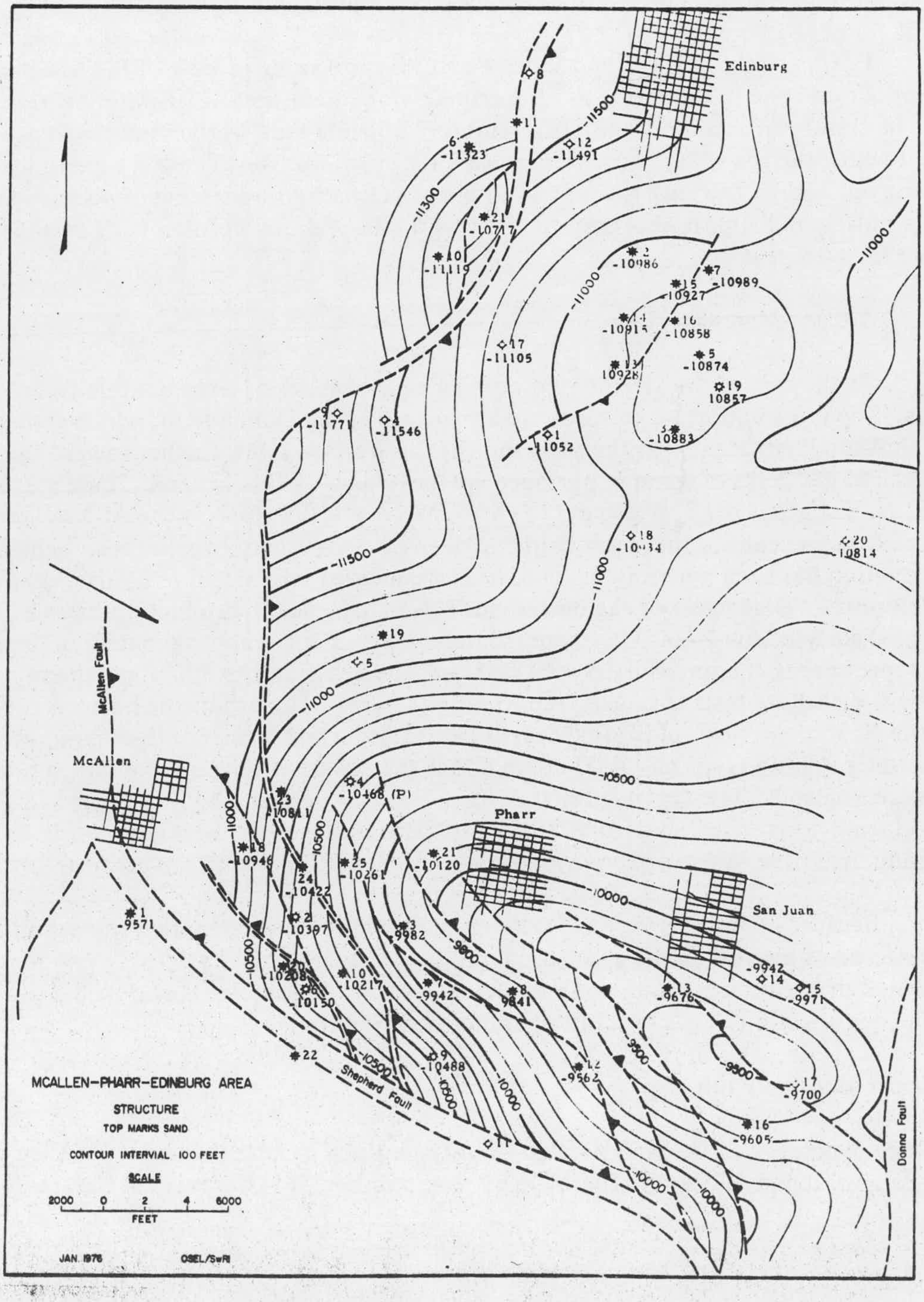


FIGURE 47. STRUCTURE TOP MARKS SAND
McALLEN-PHARR-EDINBURG AREA

Several tests in the McAllen-Edinburg area might be profitable to pursue. First, the thickening of sediments into the McAllen fault, to the west of the producing fields, is known to yield sand intervals of great vertical extent. For example, the 8500-ft (Frio) sand itself is nearly 1400 ft thick at McAllen, and the Marks-Bond series thickens from 540 ft at Pharr to 1200 ft at a distance of one mile from the McAllen fault. These sands, below the gas-water contact, have not been adequately tested, and this is an excellent place to do so. Gas content, permeability, and the ability to successfully flow a long interval of water-bearing sand all need confirmation.

Testing of the Marks-Bond series seems less promising in view of the low permeability in the gas-production zone in that horizon. Nevertheless, adequate testing of water-bearing strata off-structure has not been accomplished. It is remotely possible that, as the sand thickens into the McAllen fault below the gas-water content, permeability may improve. There is a great deal of experience arrayed against this suggestion, but no proof. Off-structure testing of deep, high-temperature sands would appear necessary to test this thesis, and the McAllen fault area is perhaps the best place to attempt it.

b. Weslaco-Mercedes Area

To the east of the McAllen-Edinburg area lie a series of large but relatively local growth faults. The most important of these are known as (1) the Donna fault, which geologically isolates the McAllen-Pharr area from the east, and (2) the Weslaco fault, further toward the coast. Four geopressured gas fields of some importance are located along this system. These are, by map number, (17) N. Weslaco; (18) S. Weslaco; (19) S. W. Mercedes; (20) Mercedes. All are characterized by massive fresh water sands in the lower Frio and deep into the Vicksburg, in those wells in which the latter formation has been penetrated. The fields are located on a structural "high" known as the "Weslaco uplift." The largest of the deep fields is North Weslaco. Production there is from the Frio at depths slightly below 10,000 ft where the pressure gradient is approximately 0.75 psi/ft, the top of geopressure is at approximately 9500 ft, and the depth of the 300°F geotherm near 13,000 ft. Few Vicksburg tests have been reported in the area. The producing horizon correlates well across the N. Weslaco field, indicating only minor faulting and large, continuous aquifers. The low connate water salinity (typically 4,000 ppm Cl) is the lowest of any area for which reliable water data were available. The type-log for the North Weslaco field is shown in Figure 48. The principal producing horizon is indicated at 10,200 ft. This is one of the best gas wells in the field. The 15-ft productive zone has an effective kh value of 17 md-ft, or an average permeability of 1.16 md.

Because of the massive sand development and the low connate water salinity, this area would appear to be of interest to the geothermal program. However, the relatively low temperature gradient and lack of encouraging reservoir parameters restrict the usefulness of possible tests in this region, to the identification of gas in solution at moderate depths.

4. Upper McAllen Fault

Three geopressured fields in Hidalgo County lie along or near the upper McAllen fault which extends into Kenedy County. These are by map number, (11) Cerda; (15) LaJara; (16) Hargill.

a. Cerda

Cerda is a small geopressured field of isolated extent producing from thin Frio-Vicksburg sand elements from 10,000 to 12,000 ft. Permeability in the discovery well was over 5 md, but offset wells failed to find the producing sand and only two additional wells have produced,

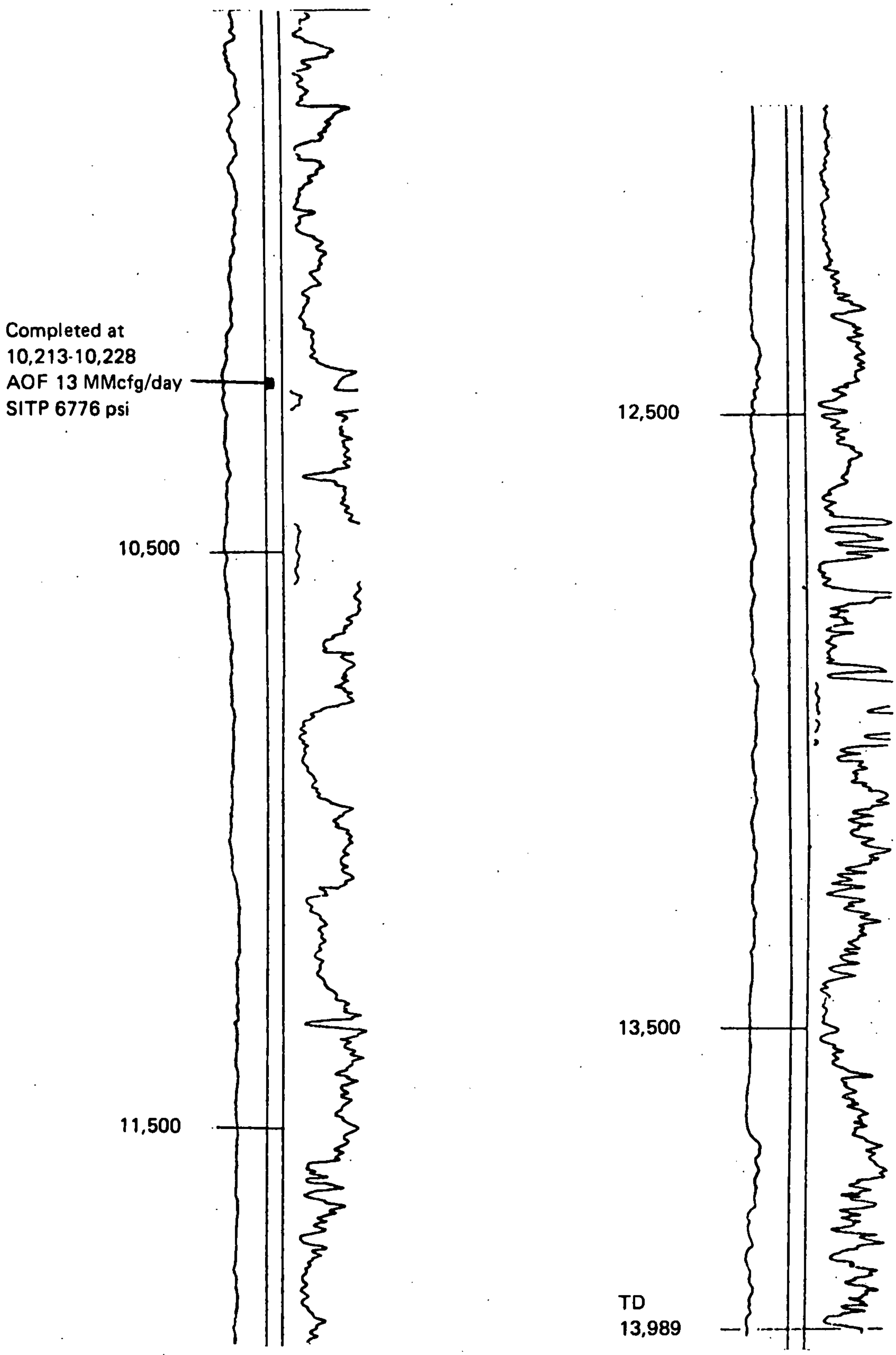


FIGURE 48. TYPE LOG, N. WESLACO FIELD SHOWING MASSIVE DEEP FRIO-VICKSBURG FRESH WATER SANDS TO 14,000 FT (NORTH PUMP NO. 2 HARRIS)

each at separate depths from separate thin sand stringers. The total sand development in the area is poor, the single good gas producer undoubtedly producing from a small sand lens of unusual quality. A number of dry holes in the region give fair control to the area, but the lack of deep Vicksburg sands leaves scant hope for profitable testing.

b. Hargill-LaJara Area

Both these two fields (Nos. 15 and 16 in Figure 3) produce from Lower Frio sands of good quality but limited extent near the top of geopressure at approximately 11,000 ft. A 14,000-ft test in LaJara logged isolated, well-developed sand elements in the Vicksburg to total depth, but the temperature gradient is only moderate. In the face of generally unfavorable reservoir information, the area has little to recommend it for geothermal interest.

D. Live Oak County

Geopressure is common in the deeper horizons of south and south central Live Oak County, and has been identified in six producing gas fields in the Wilcox formation. These fields are all to the east of the Mirando-Gohlke fault, a major growth fault system which, like other major fault systems in south Texas, parallels the coast. Historically, it is along the downthrown side of this system that much of the regional Wilcox petroleum production has been located. Live Oak County, in this regard, may be considered typical of nearby counties along the fault, including Zapata, Webb, Duval, McMullen, Bee, Goliad, and Victoria.

The south Texas Wilcox sands are of Eocene age, and consist of shallow marine and continental facies, ranging from coarse to fine grained, heterogenous, crossbedded and interbedded with silts, clays, peat and lignite. Deposition evidently took place in flood plains in nearshore marine waters, lakes, swamps, embayments, and a wide flat coastal plain traversed by shifting streams, aggrading, degrading, and flooding in much the same depositional environment that prevails along the Gulf Coast today.

During early Wilcox time, the seas were retreating; then fluctuated with slow subsidence of the coastal plains during middle Wilcox; and finally were encroaching in the final period of Wilcox time. The sands toward the outcrop are of different age than the downdip beds; thus, regionally the sand members are not correlatable on dip as time units. In localized areas, and on strike for considerable distances, the sand and shale zones are generally characteristic and electric log correlations can be made with comparative ease.

Structurally, the Wilcox reservoirs in south Texas are characterized by low relief, elongated anticlines associated with normal down-to-the-coast faulting. Usually the structures which close against a fault are on the upthrown block but frequently the structures seem to have been developed simultaneously with the faulting, and the formation dips into the fault on both the upthrown and downthrown blocks.

Northeast of Lavaca County the Wilcox has larger structures which appear to be less dependent on faulting. The lower members of the formation here are often productive, whereas to the southwest, in the region of our interest, the upper members are predominantly more productive. Toward the Rio Grande Valley, the structures are generally fewer in number with less faulting. The predominantly marine facies also tend to cause the formation to be less permeable.

The type of deposition leads to a high degree of heterogenity of the sands, the characteristics of which often vary considerably from field to field and even within the same reservoir. Accurate prediction of reservoir performance is difficult because of the varying porosity, permeability, and the number of small and larger faults. These features act as barriers or partial barriers to the broad areal movement of hydrocarbons or water. For these reasons Wilcox sands, like Vicksburg sands, must be considered to have many drawbacks as geothermal producers. Nevertheless, in south Texas the temperature gradient to the Wilcox is high, and where reservoir conditions are favorable, production of fluid at temperatures higher than 350°F is a possibility.

1. Individual Fields in Live Oak County

The locations of the six geopressured fields identified in Live Oak County were shown on the map in Figure 2. All are in close proximity to each other, although structurally isolated. They are (47) Tom Lyne; (44) East Tom Lyne; (45) Kitty Burns; (42) Katz-Slick; (43) Clay West; and (46) Mikeska. Five of these fields are shown on the structure map on the top of the Wilcox in Figure 49. Mikeska is located off the map to the east.

A cross section of the Katz-Slick field, on the section marked "AA," is shown in Figure 50. The severe faulting which is no doubt the controlling factor in geopressure in the field is clearly evident.

Good sand development is general in the area of these fields. Permeability, although spotty, is frequently very good for sands at these depths. The highest permeability values in any reservoirs with equivalent temperatures in the study region were located here, ranging to a high of 8.8 md at 11,500 ft.

The best prospect for a relatively large geopressured aquifer in the Live Oak-producing area is south of the principal fault in the Katz-Slick field, along the line of the fault to the northeast (arrow in Figure 50). Two log sections, one from Well No. 3 and one from Dry Hole No. 8, are shown in Figure 51. Good sand development throughout the Wilcox section holds as one proceeds down the anticline (off-structure), and gives evidence of continuing to do so to the east. The deep Wilcox sand at 14,000 ft in Well No. 8 is at a temperature near 375°F, and we select it as the most favorable high temperature water producing prospect in the entire Study Region.

Well No. 1 adds control to the south, and indicates good sand development continuing in the 10,000 and 12,000-ft sands. This well was too shallow to penetrate the 14,000-ft sand, however,

Other prospects, which lack sufficient control to establish credibility, exist between other major faults in the area, particularly off-structure to the southwest and northeast of Clay West and Kitty Burns.

The most pressing question at this time is whether or not commercially viable sources of geothermal fluid exist in south Texas, and if so, whether or not such fluid contains methane. It is likely that the abundance of methane in the earth declines with temperature, above some critical point. A source of 375°F or hotter water should be tested soon, and verification of gas saturation obtained. In most of south Texas, the prospect of producing 375°F water is poor, but in Live Oak County, the possibility of successfully testing such a zone is good.

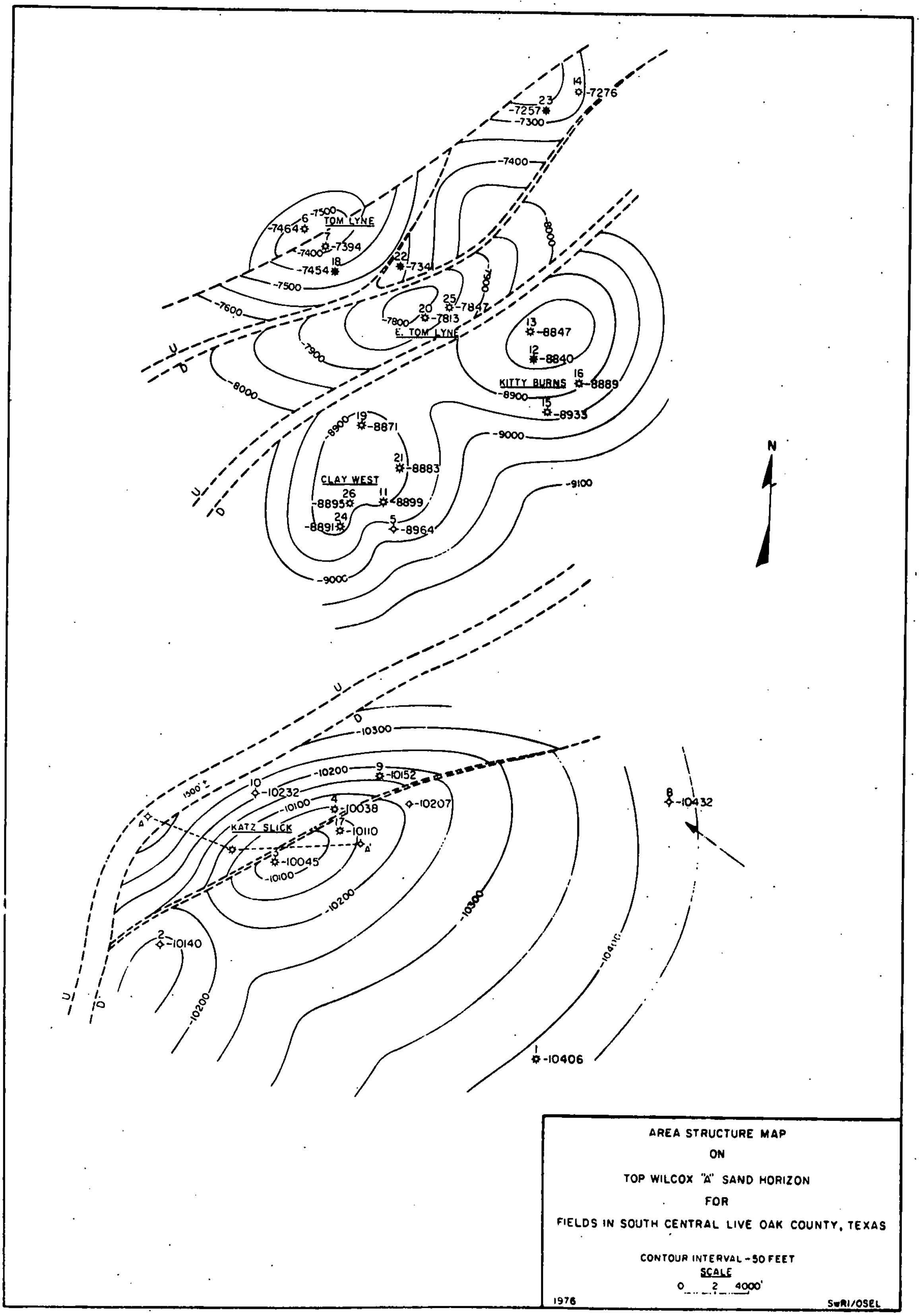
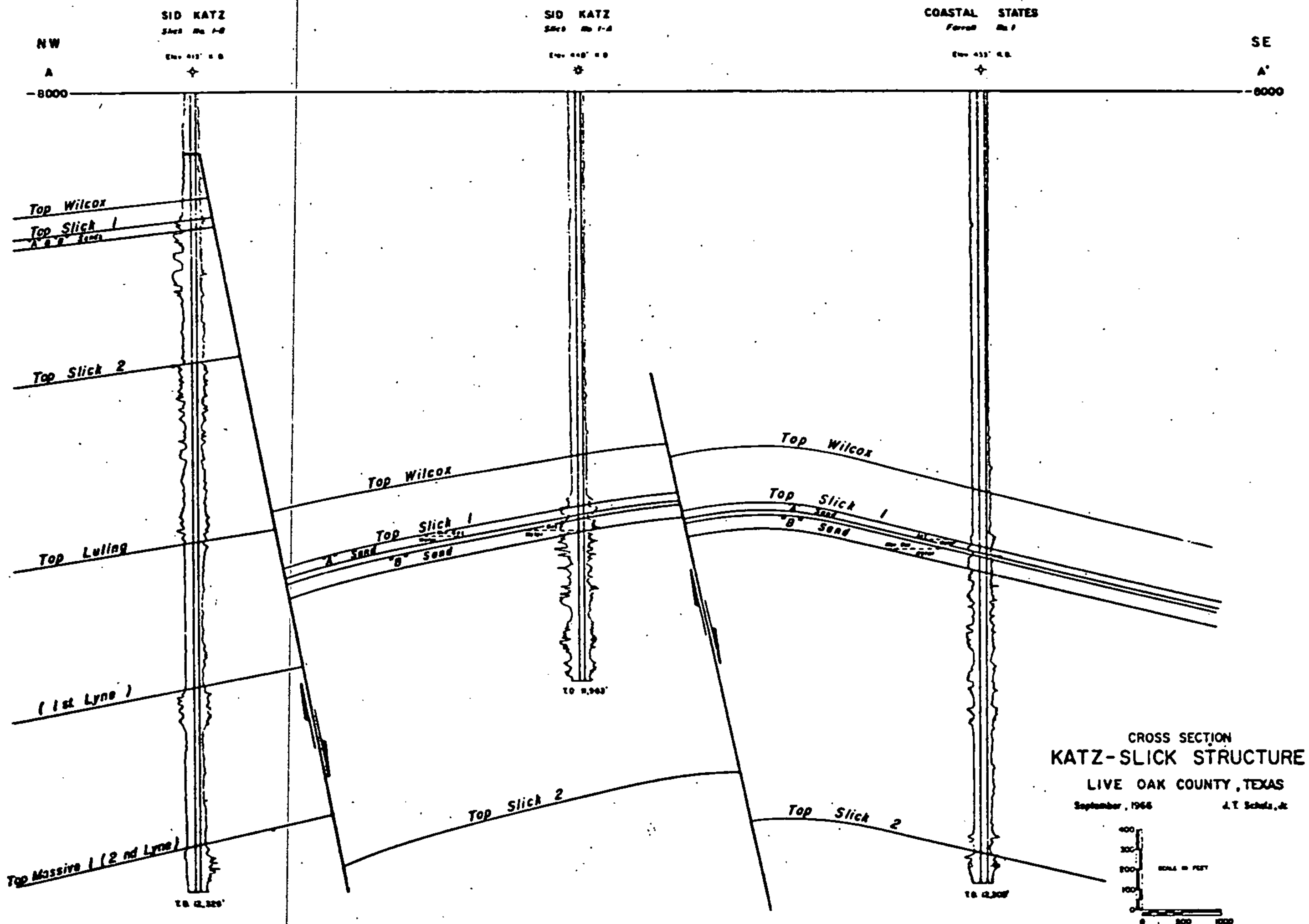


FIGURE 49. AREA STRUCTURE MAP ON TOP WILCOX "A" SAND HORIZON FOR FIELDS IN SOUTH CENTRAL LIVE OAK COUNTY, TEXAS



After Shultz, from "Typical Oil and Gas Fields in South Texas," 1967 (used by permission of Corpus Christi Geological Society).

FIGURE 50. CROSS SECTION KATZ-SLICK STRUCTURE, LIVE OAK COUNTY, TEXAS

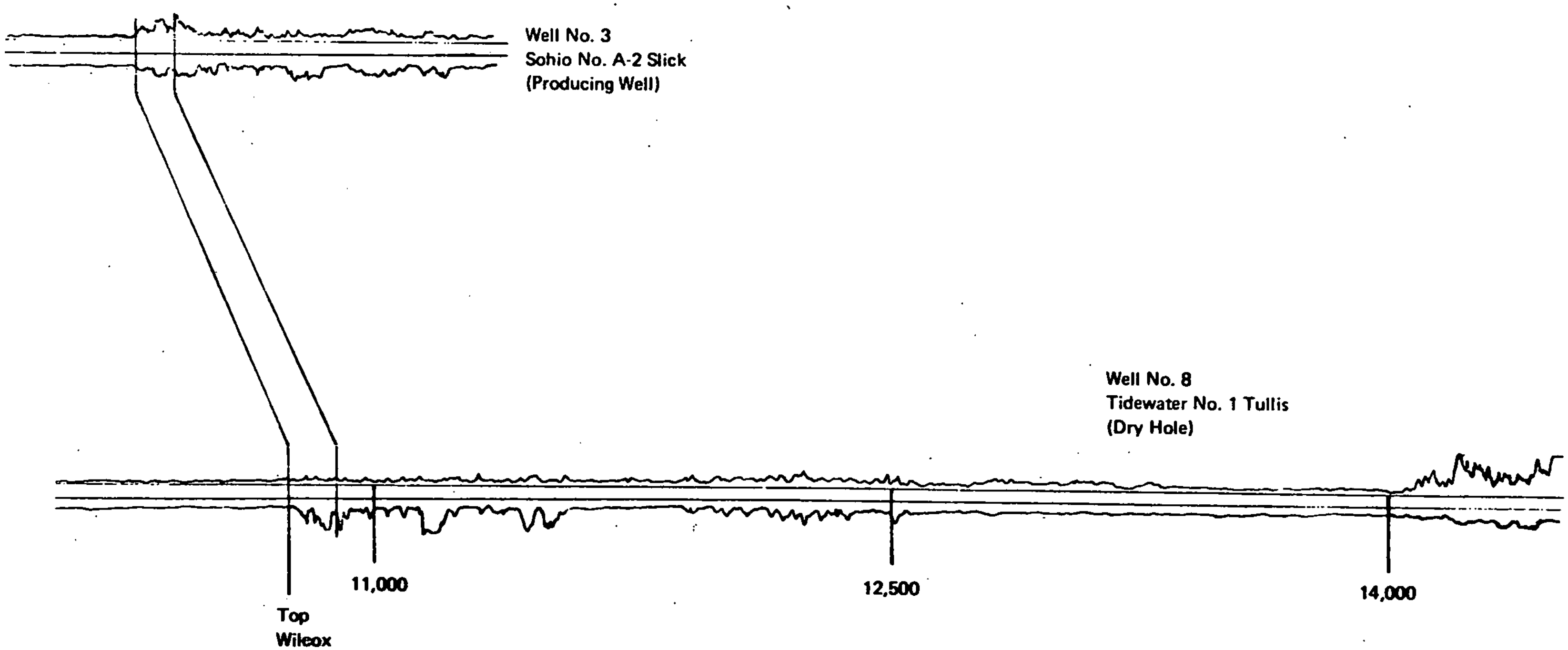


FIGURE 51. DEEP WILCOX DEVELOPMENT OFF-STRUCTURE, (WELL NO. 8) TO NORTHEAST KATZ-SLICK FIELD. LIVE OAK CO., TEXAS

2. Nonelectric Uses of Geothermal Fluid

Live Oak County is in one of the favorable areas for uranium production in the Southwest. The active development of the resource in Texas is presently restricted to Live Oak and adjacent Karnes Counties, and the location of the Live Oak uranium deposits is roughly coincident with the Wilcox geothermal prospects. The available hot water may complement the leach-production of the underground uranium ore. There are severe problems in considering such activity, but the possibility is at least worth consideration.

E. Cameron County

Cameron County has been notoriously disappointing to exploration geologists. Only a handful of producing fields have been successfully completed, and the only geopressured production identified is in the San Martin field in the extreme southeastern corner of the county, where the Skelly No. 1 Gatewood recorded an initial fluid pressure gradient of 0.58 at 9400 ft (Miocene). No deeper production has been discovered in the county, although a number of deep exploration wells have been drilled. Lack of significant sand deposition in the Frio shale is commonly cited as the reason for the failure to discover good petroleum prospects.

On the basis of production experience, the geothermal potential in Cameron County cannot be accurately assessed. Locations of three deep wildcats, spaced diagonally across the county, can be seen in Figure 3, shown earlier in this report. Examination of these wells gives some insight into the matter. The deepest of the three, in the approximate center of the county (Chevron No. 1 Rodriguez) reached a total depth of 18,500 ft. Below the top of geopressure at 12,000 ft, the few sands encountered are poorly developed and show little promise. One zone, from approximately 16,000 to 17,000 ft, showed fresh water sands (calculated R_w = 5,000 ppm Cl), with total sand thickness of about 200 ft. Less well-developed sands from approximately 17,600 ft to total depth may add as much as 100 additional total net feet. The maximum temperature recorded was less than 350°F. We do not consider Cameron County to offer good geothermal possibilities.

F. Willacy County

Willacy County, the site of several large shallow fields, has limited deep production, with abnormal pressures identified in three fields in the west central part of the county. Niles and Riggan fields report wells with small abnormal pressure gradients at depths from 9,000 to 10,000 ft. La Sal Vieja is a Frio field with production from slightly below 10,000 ft and an initial fluid pressure gradient of approximately 0.8. The temperature at this depth is only about 200°F. There is no deeper production experience on which to base assessment of potential high-temperature reservoirs in the County. The average permeability in the 10,000-ft zone in La Sal Vieja is less than 1.0 md, and the depth of the 300°F (150°C) geotherm is approximately 14,000 ft. The highest permeability (24.0 md) of any geopressured producing zone in the study region, however, was in the 9400-ft sand in Riggan field.

V. CONCLUSIONS AND RECOMMENDATIONS

The study of south Texas gas fields has produced a number of general conclusions about the region that apply to its geothermal potential. These are discussed in the following paragraphs. In addition, a well-developed assessment methodology has emerged which is applicable to broad areas of the Gulf Coast. Certain specific recommendations are also made with regard to geothermal development in the south Texas region.

A. Summary of Results

1. Depth and Occurrence of Geopressure

Geopressure is evidently a general feature of deeper sediments throughout the study region, and occurs locally at relatively uniform depths. In Live Oak County, geopressured gas production is restricted to the Wilcox formation, east of the large Mirando-Gohlke fault. Abnormal pressures are encountered there at depths generally near 9000 ft.

In the lower south Texas study area, the shallowest occurrence of geopressure is along the Frio-Vicksburg flexure, roughly coincident with the western Hidalgo County border and the southeastern half of Brooks County. Here, as in most places in lower south Texas, abnormal pressures are the province of the Vicksburg formation; the top of geopressure is frequently approximately coincident with the top of the Vicksburg. A notable exception is in the massive Frio delta near McAllen in Hidalgo County, where Frio deposition and active subsidence along the McAllen fault system were contemporaneous, and Frio sands occur to depths at least as great as 14,000 ft. The top of geopressure there is in the middle Frio.

The occurrence of abnormal pressure occurs at gradually increasing depth to the east; through central Cameron, eastern Willacy, and extreme eastern Kenedy Counties, geopressured Frio sediments occur to unknown depths. Where the Frio is greatly thickened near the coast, marine shale predominates, and sand buildup is generally poor.

2. Temperature Regime

In Live Oak County, temperatures above 300°F are restricted to Wilcox and deeper sediments. In the lower study region, temperatures of interest occur mainly in the Vicksburg formation and below. The geothermal gradient is highest in the west, generally declining to the east. Based on a limited number of control points, a 375°F-geothermal surface was found to range from a depth of 14,000 ft in southwestern Live Oak County to 22,000 ft in eastern Kenedy County.

3. Reservoir Parameters

Examination of gas fields in the study region disclosed that the question of the deliverability of potential productive reservoirs is paramount, and that the critical parameter is formation permeability. Permeability of producing reservoirs throughout the region is indicated to be an inverse function of depth, and no effective permeability values as great as 10 md have been identified at depths which are associated with 300°F or higher temperatures.

In two widely separated fields, each with a large number of separate producing horizons, the Ann-Mag field in the extreme north of Brooks County and McAllen-Pharr in the extreme south of Hidalgo County, permeability is shown to be highly dependent on depth, with a reduction of approximately one order of magnitude in permeability for each 2000 ft of increased depth over the range of 6,000 to 14,000 ft.

The average permeability of lower south Texas gas fields at depths of 10,000 to 12,000 ft is 1 md or less. In Live Oak County, the average permeability at this depth is somewhat higher but less uniform. The highest permeability value located in any reservoir with 300°F or higher temperature was 8.8 md at 11,500 ft in the East Tom Lyne (Wilcox) field, in Live Oak County.

Deep production throughout the lower south Texas study area has been largely confined to the Vicksburg formation, with the exception of the deep Frio delta in the McAllen-Edinburg area. Permeability values in the Oligocene are apparently primarily a function of depth rather than formation age. Frio sediments in the McAllen field are notably comparable in permeability to Vicksburg sediments at the same depth in northern Brooks and Kenedy Counties, even though the Frio sands are generally better developed.

B. Conclusions

Production of water from reservoirs similar to the south Texas gas reservoirs unquestionably cannot approach flow rates of 100,000 bbl/day for sustained periods of time. While both Frio and Vicksburg formations include vertical intervals containing more than 500 ft of sand, the permeability is too low to achieve high rates of flow.

Simultaneous production of extended intervals of sands at widely varying depths has not yet been attempted, and will be a prime requisite to successful exploitation of the geopressure-geothermal resource in south Texas.

Based on a minimum useful permeability of 1.0 md, water production at a temperature of 300°F is likely to represent an upper limit in south Texas reservoirs, with somewhat higher temperatures possible in Live Oak County.

Geopressure seems likely to originate in lenticular or highly faulted sand units deep in the Vicksburg, over most of the south Texas study region. Diffusion upward, particularly leakage along fault planes, tends to equalize the pressure over geologic time, resulting in the development of abnormal pressures in upper, larger sands which have become sealed during later periods. Thus high pressure aquifers of large extent may occur mainly near the top of the geopressured zone. Reservoirs such as the McAllen "8500" (Frio) sand, and the Vicksburg "S" or "T" sands in Jeffress field, relatively shallow and at unimpressive temperature, are likely to represent the best high-volume water prospects, with methane production as the principal goal.

High-temperature production (>300°F) is most likely to be successful in Live Oak County because of the higher temperature gradient at depth, and the higher permeability of local deep Wilcox sands near the Mirando-Gohlke fault.

C. Recommendations

Specifically, the recommendations resulting from the study are as follows:

(1) Plans for implementation and demonstration of power plants based on south Texas geopressured water production should not be pursued. The low temperatures available indicate no

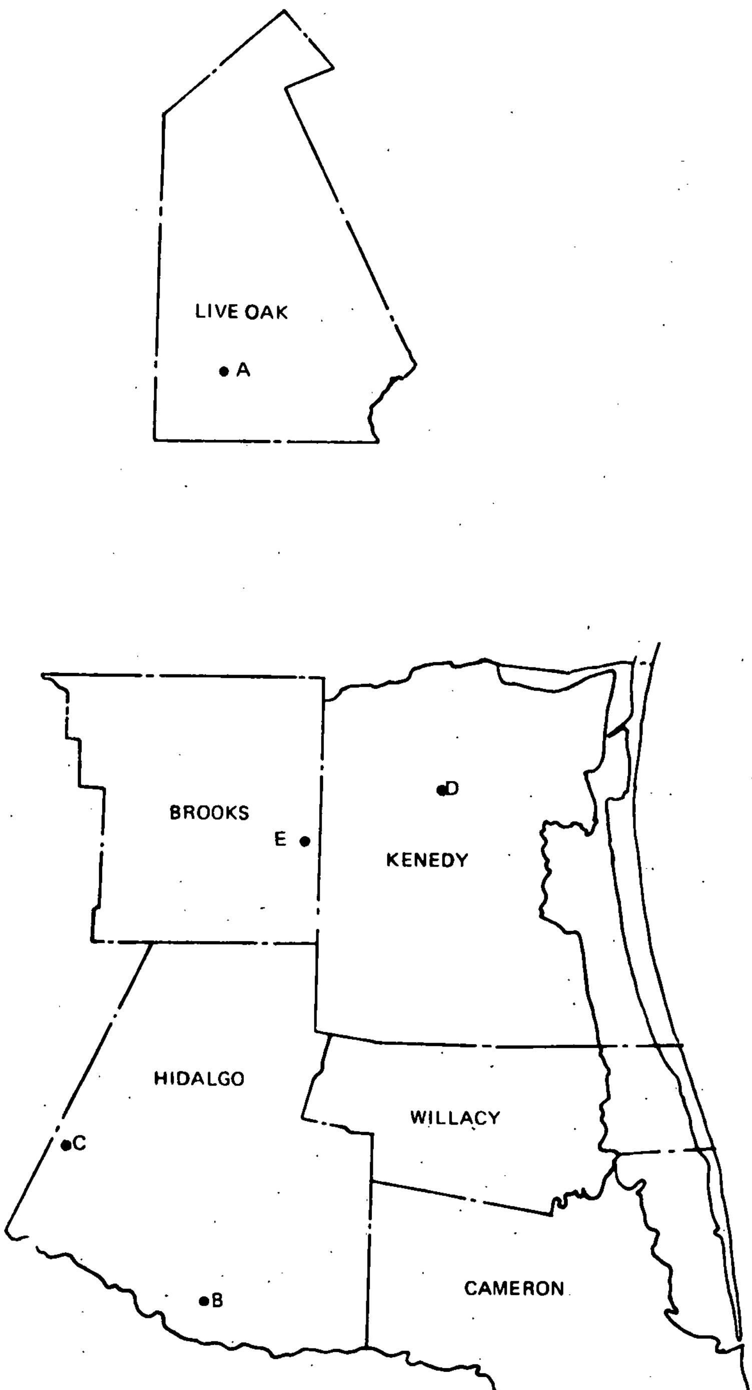


FIGURE 52. AREAS RECOMMENDED FOR FURTHER EVALUATION AND TESTING. (A) KATZ-SLICK AREA, LIVE OAK COUNTY; (B) McALLEN FAULT AREA, HIDALGO COUNTY; (C) JEFFRESS AREA, HIDALGO COUNTY; (D) CANDELARIA-SARITA AREA, KENEDY COUNTY; (E) VIBORAS AREA, BROOKS COUNTY

economic success in exploitation of the available thermal energy for power purposes, until technology is greatly advanced in the use of low-temperature working fluids. Promising approaches to the latter should continue to receive support.

(2) In Texas, further assessment efforts at this time should be confined to a detailed search for permeable formations at depth. Generally speaking, Texas Gulf Coast reservoirs at depths below 10,000 ft with permeability greater than 10 md are rare, whether geopressured or not.

(3) Limited testing of certain selected areas in south Texas may be warranted, assuming useful information is acquired from tests now pending in Louisiana. These locations are marked on the map in Figure 52.

a. Live Oak County. Flow tests to determine gas content at temperatures above 350°F are desirable, and Live Oak County appears to offer the greatest chance of success. A zone at 14,000 ft in the deep Wilcox, to the northeast of the Katz-Slick field, shows promise. A considerable body of professional opinion suggests there may be no gas at temperatures of 375°F. This fact should be established as quickly as possible.

b McAllen Fault Area. Enormous sand deposition occurs in the area immediately to the west of the McAllen field, adjacent to the McAllen fault. Here geopressured sands thousands of feet thick occur at every potential geothermal horizon and these should be explored from the top of geopressure to great depth. While there are few encouraging reservoir parameters in the producing field, it is possible that permeability may improve off-structure; if so, the tremendous thickness of the potentially productive section here could represent a favorable prospect.

c. Western Hidalgo County. In the Jeffress field area, blanket Vicksburg sands (the "S" and "T" sands) occur at depths between 8,000 and 10,500 ft, and are apparently continuous over a reasonably large area. The depth is moderate, and the temperature gradient is the highest in Hidalgo County, with temperatures approaching 300°F at 10,000 ft. This is a promising place to attempt to produce a long vertical interval of low permeability sand, with a good chance of producing gas-saturated water.

d. Northern Kenedy County. East of Candelaria field, Vicksburg sands at depths as great as 17,000 ft have been logged. North of Candelaria, in El Paistle and E. Sarita Fields, Vicksburg sands produce gas to depths below 15,000 ft. Knowledge of the capability of these very deep south Texas sands to produce water is needed. The area should be more thoroughly evaluated, and these very deep sands explored and eventually tested.

e. Eastern Brooks County. The S.E. Viboras area, near the Kenedy-Brooks county line, lies along a large fault that separates it from the main Viboras field. Frio-Vicksburg sand buildup along the fault is excellent. Although control is limited, the aquifer, containing nearly 1000 ft of sand from 9,800 to 12,300 ft, appears continuous off-structure along the fault to the north. Production of methane-saturated water from a long interval of clean, low permeability sand could be attempted here at relatively low cost. The temperature ranges from 220° to 275°F over the section.

(4) Barring revolutionary developments in thermodynamics and heat engine design, the most favorable prospect for Gulf Coast geothermal water is in its direct, nonelectric uses. Suggestions for such use should continue to receive cautious evaluation. The application of hot water to leach-mining of Live Oak County uranium ore represents one such possibility.

BIBLIOGRAPHY

Am. Assn. of Petroleum Geologists, "Geothermal Gradient Maps of the United States," AAPG Geothermal Survey Committee, 1971.

Amyx, Bass & Whiting, **Reservoir Engineering**, McGraw Hill, New York, 1960.

Bebout, D. G., "Subsurface Techniques for Locating and Evaluating Geopressured Geothermal Reservoirs Along the Texas Gulf Coast," Proc. Second Geopressured-Geothermal Energy Conf., Austin, Texas, Feb. 23-25, 1976.

Boyd, D. R. and Dyer, B. F.,"Frio Barrier Bar System of South Texas," *Trans. Gulf Coast Assn. Geol. Soc.*, **XIV**, pp 309-322, 1965.

Collins, J. W., "The Geology of the McAllen-Pharr Field Area, Hidalgo Co., Tex." *Trans. Gulf Coast Assn. Geol. Soc.*, **XVIII**, 1968.

Dickinson, G. (February 1953): "Geologic Aspects of Abnormal Reservoir Pressures in Gulf Coast Louisiana," Bull. AAPG 37, pp 410-432.

Dowdle, W. L. and Cobb, W. M., "Static Formation Temperature From Well Logs," *J. Pet. Tech.*, **XXVII**, November 1975.

Fatt, I., "The Effect of Overburden Pressure on Relative Permeability," *Trans.*, AIME, **198**, pp 325-326, 1953.

Fatt, I. and Davis, T. H., "The Reduction in Permeability With Overburden Pressure," *Trans.*, AIME, **195**, p 329, 1952.

Holt, B. and Bergman, J., "Investment and Operating Costs of Binary Cycle Geothermal Power Plants," *NSF Geothermal Conf. Proc.*, 1974.

Hottman, C. E. and Johnson, R. K., "Estimation of Formation Pressures from Log-Derived Shale Properties," *J. Pet. Tech.* 234:6, pp 717-722, 1965.

Hottman, C. E., "Method for Producing a Source of Energy From an Over-Pressured Formation," U.S. Patent No. 3,258,069, June 1966.

Jones, P. H., "Hydrodynamics of Geopressure in the Northern Gulf of Mexico Basin," *J. Pet. Tech.*, pp 803-810, July 1969.

Joyner, H. D., "Correlation of E. Log Indicated Reservoir Temperature With Actual Reservoir Temperature," *J. Pet. Tech.*, **XXVII**, February 1975.

Lewis, C. R. and Rose, S.C., "A Theory Relating High Temperatures and Overpressures," Soc. Pet. Eng., AIME, SPE 2564 Preprint, 8 p., 1969.

BIBLIOGRAPHY (Cont'd)

Matthews, C. S. and Russell, D. G., *Pressure Buildup and Flow Tests in Wells,* Monograph Series, 1:48, Soc. Pet. Eng., AIME, Dallas, 1967.

McLatchie, L. S., Hemstock, R. A., and Young, J. W., "Effective Compressibility of Reservoir Rocks and Its Effects on Permeability," *Trans.,* AIME, 213, pp 386-388, 1958.

Nichols, E. A., "Geothermal Gradients in Mid-Continent and Gulf Coast Oil Fields," TP 2114, Petroleum Technology, 44-49, November 1946.

Osoba, J. S., Swanson, R. K., Oetking, P., and Hagens, R. C., "Production of Water from Geopressured-Geothermal Reservoirs in South Texas," presented at Second Geopressure-Geothermal Energy Conf., Austin, Texas, 23-25 February 1976 (Southwest Res. Inst., San Antonio, 1976).

Parmigiano, J. M., "Geohydraulic Energy from Geopressured Aquifers," Thesis, Dept. of Petr. Engr., Louisiana State University, 1973.

Schoeppel, R. J. and Gilarranz, S., "Use of Well Log Temperatures to Evaluate Regional Geothermal Gradients," *J. Pet. Tech.,* 667-673, June 1966.

Schultz, J. T., Jr., "Katz-Slick Field," *in Typical Oil & Gas Fields of South Texas,* Corpus Christi Geol. Soc. Pub., Corpus Christi, Texas, 1967.

Thomas, R. D. and Ward, D. C., "Effect of Overburden Pressure and Water Saturation on Gas Permeability of Tight Sandstone Cores," *J. Pet. Tech.,* April 1972.

Vairogs, J., Hearn, C. L., Dareing, D. W. and Rhoades, V. W., "Effect of Rock Stress on Gas Production From Low-Permeability Reservoirs," *J. Pet. Tech.,* pp 1161-1167, September 1971.

Wallace, R. H., "Abnormal Pressures and Potential Geothermal Resources in the Rio Grande Embayment of Texas," *Proc. Sec. Symp. on Abnormal Surface Pressure,* pp 86-116, Baton Rouge, La., Louisiana State University.

Wilson, John S., *et al.,* Dow Chemical Company, "A Study of a Phase "O" Plan for Production of Electrical Power From U.S. Gulf Coast Geopressured Geothermal Waters," *Proc. Sec. Geopressure-Geothermal Energy Conf.,* **IV**, February 23-25, 1976.

APPENDIX A

Fields with Production Depths Deeper than 7000 Feet by County
South Texas Study Area

THE COUNTIES REQUESTED ARE HIDALGO

THE MINIMUM, MAXIMUM DEPTH REQUESTED IS ALL

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
ALAMOSANDERS	HIDALGO	APR64	7220
ALAMO	HIDALGO	MAR71	8065
ARROWHEAD	HIDALGO	NOV67	11942
BEAURLINEEAST	HIDALGO	SEP63	7591
CANO-MEXICO	HIDALGO	SEP57	7628
CAPISALLO	HIDALGO	NOV71	8039
CASAS	HIDALGO	MAY65	7031
CASASNORTH	HIDALGO	DEC65	7290
CASASSOUTH	HIDALGO	FEB70	8744
CERDA	HIDALGO	DEC62	9005
CERDA	HIDALGO	JAN63	10074
CERDA	HIDALGO	SEP63	11552
CHIHUAHUA	HIDALGO	AUG55	8336
DONNAHANSEN	HIDALGO	JUL53	9478
DONNA	HIDALGO	DEC65	7150
EDINBURG	HIDALGO	JAN49	7563
EDINBURG	HIDALGO	AUG71	8993
EDINBURG	HIDALGO	MAY71	9955
EDINBURG	HIDALGO	MAR65	10761
EDINBURG	HIDALGO	OCT64	11522
EDINBURGEAST	HIDALGO	MAY65	7716
EDINBURGEAST	HIDALGO	JUN52	8248
EDINBURGSOUTH	HIDALGO	DEC65	11104
ELSASOUTH	HIDALGO	JUN71	7170
ELSASOUTH	HIDALGO	JAN61	8588
ELSASOUTH	HIDALGO	NOV55	9774
FLORES	HIDALGO	NOV70	8154
HARGILL	HIDALGO	FEB56	10035
HARGILL	HIDALGO	NOV54	11241
HEIDELBERG	HIDALGO	DEC70	8706
HIDALGO	HIDALGO	FEB68	7530
INDIOSWEST	HIDALGO	MAY66	7413
JAVELINA	HIDALGO	OCT56	11174
JAVELINA	HIDALGO	OCT59	9800
JAVELINA	HIDALGO	OCT68	10257
JEFFRESS	HIDALGO	DEC68	8690
JEFFRESS	HIDALGO	SEP69	9696
JEFFRESS	HIDALGO	APR69	11318
JEFFRESS	HIDALGO	OCT70	12335
JEFFRESSEAST	HIDALGO	JAN71	12430
KELSEYEAST	HIDALGO	SEP59	11972
KLUMP	HIDALGO	FEB53	9754
LABLANCA	HIDALGO	OCT36	8195
LABLANCA	HIDALGO	JAN71	7839
LABLANCA	HIDALGO	JAN69	7450

LABLANCA	HIDALGO	JAN64	8060
LABLANCA	HIDALGO	JAN64	9415
LABLANCA	HIDALGO	JAN64	10082
LACOMA	HIDALGO	JUL59	9308
LAJARA	HIDALGO	JAN62	9950
LAJARA	HIDALGO	FEB54	10064
LAREFORMA	HIDALGO	FEB68	7110
LACY	HID-CAMER	DEC46	7983
LACY	HIDALGO	JUL49	7156
LANDA	HIDALGO	JAN60	7980
LANDA	HIDALGO	DEC53	8253
LOSINDIOS	HIDALGO	JUL47	8447
LOSINDIOS	HIDALGO	SEP47	7113
LOSINDIOS	HIDALGO	OCT60	10091
LOSINDIOSWEST	HIDALGO	JUN70	7070
LOSTORRITOS	HIDALGO	JAN51	8510
LOSTORRITOS	HIDALGO	JAN69	7394
LOSTORRITOSNOR	HIDALGO	FEB56	8150
MCALLEN	HIDALGO	OCT38	7065
MCALLEN	HIDALGO	OCT38	8108
MCALLEN	HIDALGO	OCT38	10090
MCALLEN	HIDALGO	APR65	11464
MCALLEN	HIDALGO	AUG65	9560
MCALLENSOUTH	HIDALGO	JUL65	7432
MCALLENSOUTH	HIDALGO	JUL65	8423
MCALLENSOUTH	HIDALGO	OCT63	9852
MCALLENSOUTH	HIDALGO	MAR64	10239
MCALLENWEST	HIDALGO	FEB60	7052
MCALLENWEST	HIDALGO	AUG67	8256
MCALLENRANCH	HIDALGO	AUG67	9230
MCALLENRANCH	HIDALGO	NOV64	10117
MCALLENRANCH	HIDALGO	APR61	11086
MCALLENRANCH	HIDALGO	MAR66	13876
MCALLENRANCH	HIDALGO	SEP63	12356
MCCOOKEAST	HIDALGO	APR70	12181
MCMORAN	HIDALGO	FEB69	8235
MCMORAN	HIDALGO	JUN69	9272
MERCEDES	HIDALGO	APR35	7405
MERCEDES	HIDALGO	JUL61	8083
MERCEDES	HIDALGO	NOV59	10144
MERCEDESSW	HIDALGO	MAR67	9239
MERCEDESSW	HIDALGO	JUL66	10594
MISSIONWEST	HIDALGO	MAR55	7108
MISSIONWEST	HIDALGO	JUN55	8258
MONTECHRISTO	HIDALGO	MAR60	7266
MONTECHRISTO	HIDALGO	JUN53	8478
MONTECHRISTO	HIDALGO	AUG67	10064
MONTECHRISTO	HIDALGO	DEC60	11283
MONTECHRISTOE	HIDALGO	DEC63	9669
MONTECHRISTON	HIDALGO	JAN54	8326
MONTECHRISTON	HIDALGO	JUL64	9418
MONTECHRISTOS	HIDALGO	JUN61	7796
MONTECHRISTOS	HIDALGO	AUG60	8426
MONTECHRISTOS	HIDALGO	APR61	10518

OBLATE	HIDALGO	OCT50	7390
OBLATE	HIDALGO	FEB61	11317
PENITAS	HIDALGO	SEP67	7934
PENITAS	HIDALGO	AUG59	8276
PHARR	HIDALGO	JUL49	9370
PHARR	HIDALGO	JUL49	8657
PHARR	HIDALGO	JUL49	10650
PHARR	HIDALGO	AUG65	13766
PHARR	HIDALGO	AUG63	11875
PROGRESSO	HIDALGO	MAY61	8548
RETAMA	HIDALGO	FEB57	7769
RICO	HIDALGO	JAN63	7120
SALDELREY	HIDALGO	MAY55	8178
SALDELREYWEST	HIDALGO	JUN60	8138
SALDELREYWEST	HIDALGO	AUG57	9189
SANCARLOS	HIDALGO	DEC64	7284
SANCARLOS	HIDALGO	DEC53	8790
SANMANUEL	HIDALGO	MAY62	7598
SANMANUEL	HIDALGO	MAY61	8266
SANRAMON	HIDALGO	JUL57	8433
SANRAMON	HIDALGO	JUL61	11005
SANSALVADOR	HIDALGO	OCT64	7224
SANSALVADOR	HIDALGO	MAY47	8104
SANSALVADOR	HIDALGO	FEB70	9153
SANSALVADOR	HIDALGO	FEB70	10360
SANTAANITA	HIDALGO	NOV62	9380
SANTAANITA	HIDALGO	NOV62	11624
SANTAFESOUTH	HID-BRO	NOV49	7722
SANTAFESOUTH	HIDALGO	AUG66	7185
SANTAMARIA	HIDALGO	DEC59	8339
SANTELLANA	HIDALGO	FEB70	7006
SANTELLANA	HIDALGO	NOV70	8012
SCHMIDT	HIDALGO	APR63	8572
SHARY	HIDALGO	JUL52	8172
SHARY	HIDALGO	DEC56	7217
SHEPHERD	HIDALGO	SEP56	7019
SHEPHERDS	HIDALGO	AUG62	7012
TABASCO	HIDALGO	JUN55	7935
TABASCO	HIDALGO	APR56	8114
TABASCONORTH	HIDALGO	AUG60	7790
TEXANGARDENS	HIDALGO	SEP63	7394
TEXANGARDENS	HIDALGO	JUN63	8020
TEXANGARDENS	HIDALGO	FEB64	9262
TODOSSANTOS	HIDALGO	DEC64	10686
WESLACONORTH	HIDALGO	APR59	8299
WESLACONORTH	HIDALGO	MAY60	9056
WESLACONORTH	HIDALGO	MAY59	10242
WESLACOSOUTH	HIDALGO	AUG63	7532
WESLACOSOUTH	HIDALGO	FEB45	8090
WESLACOSOUTH	HIDALGO	OCT62	9020
WHITTED	HIDALGO	FEB60	7113

THE COUNTIES REQUESTED ARE HIDALGO

THE MINIMUM,MAXIMUM DEPTH REQUESTED IS 10000,20000

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
ARROWHEAD	HIDALGO	NOV67	11942
CERDA	HIDALGO	JAN63	10074
CERDA	HIDALGO	SEP63	11552
EDINBURG	HIDALGO	MAR65	10761
EDINBURG	HIDALGO	OCT64	11522
EDINBURGSOUTH	HIDALGO	DEC65	11104
HARGILL	HIDALGO	FEB56	10035
HARGILL	HIDALGO	NOV54	11241
JAVELINA	HIDALGO	OCT56	11174
JAVELINA	HIDALGO	OCT68	10257
JEFFRESS	HIDALGO	APR69	11318
JEFFRESS	HIDALGO	OCT70	12335
JEFFRESSEAST	HIDALGO	JAN71	12430
KELSEYEAST	HIDALGO	SEP59	11972
LABLANCA	HIDALGO	JAN64	10082
LAJARA	HIDALGO	FEB54	10064
LOSINDIOS	HIDALGO	OCT60	10091
MCALLEN	HIDALGO	OCT38	10090
MCALLEN	HIDALGO	APR65	11464
MCALLENSOUTH	HIDALGO	MAR64	10239
MCALLENRANCH	HIDALGO	NOV64	10117
MCALLENRANCH	HIDALGO	APR61	11086
MCALLENRANCH	HIDALGO	MAR66	13876
MCALLENRANCH	HIDALGO	SEP63	12356
MCCOOKEAST	HIDALGO	APR70	12181
MERCEDES	HIDALGO	NOV59	10144
MERCEDESSW	HIDALGO	JUL66	10594
MONTECHRISTO	HIDALGO	AUG67	10064
MONTECHRISTO	HIDALGO	DEC60	11283
MONTECHRISTOS	HIDALGO	APR61	10518
OBLATE	HIDALGO	FEB61	11317
PHARR	HIDALGO	JUL49	10650
PHARR	HIDALGO	AUG65	13766
PHARR	HIDALGO	AUG63	11875
SANRAMON	HIDALGO	JUL61	11005
SANSALVADOR	HIDALGO	FEB70	10360
SANTAANITA	HIDALGO	NOV62	11624
TODOSSANTOS	HIDALGO	DEC64	10686
WESLACONORTH	HIDALGO	MAY59	10242

THE COUNTIES REQUESTED ARE CAMERON

THE MINIMUM, MAXIMUM DEPTH REQUESTED IS ALL

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
HOLLYBEACH	CAMERON	APR62	7185
HOLLYBEACH	CAMERON	APR64	8074
INDIOS	CAMERON	JUN57	9765
LACY	CAMERON	SEP56	7145
PORTISABELW	CAMERON	MAR68	7056
PORTISABELW	CAMERON	FEB64	8152
SANMARTIN	CAMERON	MAR68	8556
SANMARTIN	CAMERON	MAR65	9385
THREEISLANDSEA	CAMERON	JUL59	7275
VISTADELMAR	CAMERON	JUL67	7041

THE COUNTIES REQUESTED ARE WILLACY

THE MINIMUM,MAXIMUM DEPTH REQUESTED IS ALL

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
CHESS	WILLACY	MAR66	7014
CHESS	WILLACY	MAR56	8518
CORBETTMARINE	WILLACY	NOV53	9766
LASALVIEJA	WILLACY	MAY47	7010
LASALVIEJA	WILLACY	AUG49	8290
LASALVIEJA	WILLACY	NOV62	10546
LASALVIEJA	WILLACY	OCT45	9735
LASARAEAST	WILLACY	JAN71	7486
LASARAEAST	WILLACY	SEP69	8229
LASARANORTH	WILLACY	JAN67	7867
LACAL	WILLACY	NOV65	7950
LACAL	WILLACY	NOV65	8226
LYFORD	WILLACY	FEB69	9046
NILE	WILLACY	JUL67	10144
PASOREAL	WILLACY	AUG66	7138
PASOREAL	WILLACY	NOV46	8585
RAYMONDVILLE	WILLACY	JAN45	9650
RAYMONDVILLE	WILLACY	JAN69	7004
RAYMONDVILLE	WILLACY	FEB60	8034
RAYMONDVILLESO	WILLACY	SEP66	7448
RIGGAN	WILLACY	FEB66	8511
RIGGAN	WILLACY	FEB66	9772
TENERIAS	WILLACY	APR53	7847
WILLAMAR	WILLACY	NOV40	7574
WILLAMARSOUTH	WILLACY	SEP54	8006
WILLAMARSOUTH	WILLACY	MAY67	7897
WILLAMARSE	WILLACY	JUL53	7851
WILLAMARWEST	WILLACY	MAR41	7925

THE COUNTIES REQUESTED ARE KENEDY

THE MINIMUM, MAXIMUM DEPTH REQUESTED IS ALL

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
BAFFINBAY	KENEDY	MAR67	13076
BAFFINBAY	KENEDY	AUG66	12301
BAFFINBAYSW	KENEDY	AUG68	12283
BARRETA	KENEDY	DEC54	7180
BARRETA	KENEDY	SEP54	8121
CABAZOS	KENEDY	MAR69	7400
CABAZOS	KENEDY	FEB66	8040
CALANDRIA	KENEDY	FEB52	8674
CALANDRIA	KENEDY	FEB52	8675
CANDELARIA	KENEDY	SEP54	11190
CANDELARIA	KENEDY	MAR56	7028
CANDELARIA	KENEDY	APR64	8094
CANDELARIA	KENEDY	AUG65	9358
CANDELARIA	KENEDY	DEC63	10075
ELPAISTLE	KENEDY	JUL64	14427
ELPAISTLE	KENEDY	SEP69	13835
ELPAISTLE	KENEDY	JUL51	7057
ELPAISTLE	KENEDY	JAN53	9080
ELPAISTLE	KENEDY	JAN52	8280
ELPAISTLE	KENEDY	MAY67	11522
JULIAN	KENEDY	OCT68	8942
JULIANNORTH	KENEDY	NOV53	9976
LAGUNA	KENEDY	AUG54	9404
MAYSOUTH	KENEDY	DEC60	7872
MCGILL	KENEDY	FEB47	7676
MCGILL	KENEDY	JUN63	8131
MCGILL	KENEDY	DEC64	9704
MCGILLSW	KENEDY	JUN71	7707
MESQUITE	KENEDY	APR59	7850
MESQUITE	KENEDY	DEC58	8270
MIFFLIN	KENEDY	OCT69	7685
MIFFLIN	KENEDY	MAY54	9332
MONTEPASTURE	KENEDY	APR61	7359
MONTEPASTURE	KENEDY	APR59	8212
MURDOCKPASS	KENEDY	DEC52	7235
MURDOCKPASSEST	KENEDY	FEB65	7553
MURDOCKPASSEST	KENEDY	JUN65	8083
MURDOCKPASSWST	KENEDY	FEB69	7279
PENASCAL	KENEDY	FEB52	7033
PITAEAST	KENEDY	MAR71	8503
POTRERO	KENEDY	JUL52	9461
POTRERO	KENEDY	JUN65	7456
POTREROSOUTH	KENEDY	DEC66	7430
RITA	KENEDY	JAN49	7076
RITA	KENEDY	JAN49	8058

RITA	KENEDY	AUG64	12898
RITA	KENEDY	JUN69	9017
RITASE	KENEDY	DEC70	11838
RITASE	KENEDY	MAY64	13100
RITAWEST	KENEDY	DEC63	8457
RUDOLPH	KENEDY	APR66	7946
RUDOLPH	KENEDY	APR66	8141
SALTILLO	KENEDY	JUL67	9005
SANTAROSA	KENEDY	JUN58	10660
SARITA	KEN-KLE	MAY48	7174
SARITA	KENEDY	AUG67	7026
SARITA	KENEDY	NOV64	8015
SARITA	KENEDY	APR65	9240
SARITA	KENEDY	JUL64	12193
SARITA	KENEDY	SEP62	10190
SARITAEAST	KENEDY	JUL67	13108
SORILLO	KENEDY	FEB68	11546
STILLMAN	KENEDY	MAY71	8451
STILLMAN	KENEDY	DEC64	7037
STILLMAN	KENEDY	JUL66	8051
STILLMAN	KENEDY	AUG63	9200
STILLMAN	KENEDY	MAY71	10158
STILLMAN	KENEDY	JAN66	11026
STILLMAN	KENEDY	FEB63	12530
TAJOS	KENEDY	OCT64	8204
TORDILLA	KENEDY	OCT63	10464

THE COUNTIES REQUESTED ARE KENEDY

THE MINIMUM, MAXIMUM DEPTH REQUESTED IS 10000, 20000

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
BAFFINBAY	KENEDY	MAR67	13076
BAFFINBAY	KENEDY	AUG66	12301
BAFFINBAYSW	KENEDY	AUG68	12283
CANDELARIA	KENEDY	SEP54	11190
CANDELARIA	KENEDY	DEC63	10075
ELPAISTLE	KENEDY	JUL64	14427
ELPAISTLE	KENEDY	SEP69	13835
ELPAISTLE	KENEDY	MAY67	11522
RITA	KENEDY	AUG64	12898
RITASE	KENEDY	DEC70	11838
RITASE	KENEDY	MAY64	13100
SANTAROSA	KENEDY	JUN58	10660
SARITA	KENEDY	JUL64	12193
SARITA	KENEDY	SEP62	10190
SARITAEAST	KENEDY	JUL67	13108
SORILLO	KENEDY	FEB68	11546
STILLMAN	KENEDY	MAY71	10158
STILLMAN	KENEDY	JAN66	11026
STILLMAN	KENEDY	FEB63	12530
TORDILLA	KENEDY	OCT63	10464

THE COUNTIES REQUESTED ARE BROOKS

THE MINIMUM, MAXIMUM DEPTH REQUESTED IS ALL

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
ALTAMESA	BROOKS	JUL62	7767
ANNMAG	BROOKS	MAY62	9117
ANNMAG	BROOKS	OCT63	7004
ANNMAG	BROOKS	SEP62	8220
ANNMAGSOUTH	BROOKS	SEP66	9152
CAGERANCH	BROOKS	APR69	7813
CAGERANCH	BROOKS	MAY46	8022
CAGERANCH	BROOKS	AUG59	7804
CAGERANCHNORTH	BROOKS	OCT68	8755
CHAMBERLAIN	BROOKS	JUL54	7806
DANSULLIVAN	BROOKS	AUG44	8508
DANSULLIVAN	BROOKS	AUG44	10155
DANSULLIVAN	BROOKS	SEP45	7831
ERFFRIO	BROOKS	SEP69	7566
ENCINITAS	BROOKS	JUL60	8266
ENCINITAS	BROOKS	DEC69	7054
ENCINITAS	BROOKS	APR67	7338
ENCINITASEAST	BROOKS	AUG70	9731
ENCINITASNW	BROOKS	MAY67	7886
ENCINITASSE	BROOKS	APR70	10212
ENCINITASSOUTH	BROOKS	SEP64	10312
ENCINITASWEST	BROOKS	NOV65	10707
FALFURRIAS	BROOKS	AUG63	7254
FLOWELLA	BROOKS	MAY49	7238
GYPHILL	BROOKS	NOV55	7425
GYPHILLSE	BROOKS	NOV67	7430
GYPHILLSE	BROOKS	JUL65	8330
KELSEYDEEP	BROOKS	JAN69	7280
KELSEYDEEP	BROOKS	JUN68	8078
KELSEYDEEP	BROOKS	FEB67	7620
KELSEYDEEP	BROOKS	FEB68	9023
KELSEYSE	BROOKS	MAY71	7789
KELSEYSE	BROOKS	MAY71	9175
KELSEYSE	BROOKS	SEP64	8953
KELSEYSE	BROOKS	SEP64	10312
LAENCANTADA	BROOKS	DEC63	8786
LAENCANTADAEST	BROOKS	NOV65	8603
LAGLORIA	BROOKS	SEP48	7123
LAGLORIA	BROOKS	FEB65	8220
LAGLORIA	BROOKS	MAY64	7870
LAGLORIA	BROOKS	DEC64	7860
LAGLORIASOUTH	BRO-JIMW	MAR55	7270
LAGLORIASOUTH	BROOKS	JUN65	7596
LOMABLANCA	BROOKS	MAY63	7053
LOMABLANCA	BROOKS	DEC62	8979

LOMABLANCA	BROOKS	DEC62	9415
MARIPOSA	BROOKS	APR45	9037
MARIPOSA	BROOKS	JAN49	7781
MARIPOSA	BROOKS	MAR54	8524
MICHELSON	BROOKS	JAN64	7702
MICHELSON	BROOKS	DEC63	8541
PITA	BROOKS	MAR46	7112
PITA	BROOKS	APR47	8004
PITAEAST	BROOKS	AUL61	7753
PITAWEST	BROOKS	OCT64	7816
PITAWEST	BROOKS	JUL69	8025
PITAWEST	BROOKS	SEP61	9050
RACHAL	BROOKS	OCT64	9058
SANTAFE	BROOKS	JAN49	7715
SANTAFEEAST	BROOKS	AUG64	8688
SANTAFESOUTH	BROOKS	AUG61	7621
SCOTT/HOPPER	BROOKS	AUG46	7024
SCOTT/HOPPER	BROOKS	JAN67	8141
SCOTT/HOPPERES	BROOKS	FEB64	10287
SKIPPER	BROOKS	JUN65	8224
SKIPPER	BROOKS	NOV64	9058
TRESENCINOS	BROOKS	MAY62	7252
VIBORAS	BROOKS	AUG49	8110
VIBORAS	BROOKS	AUG49	7925
VIBORAS	BROOKS	NOV66	9221
VIBORAS	BROOKS	FEB67	11545
VIBORASSE	BROOKS	OCT63	12105
VIBORASWEST	BROOKS	FEB53	7089
VIBORASWEST	BROOKS	APR62	8355

THE COUNTIES REQUESTED ARE BROOKS

THE MINIMUM, MAXIMUM DEPTH REQUESTED IS 10000, 20000

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
DANSULLIVAN	BROOKS	AUG44	10155
ENCINITASSE	BROOKS	APR70	10212
ENCINITASSOUTH	BROOKS	SEP64	10312
ENCINITASWEST	BROOKS	NOV65	10707
KELSEYSE	BROOKS	SEP64	10312
SCOTT/HOPPERES	BROOKS	FEB64	10287
VIBORAS	BROOKS	FEB67	11545
VIBORASSE	BROOKS	OCT63	12105

THE COUNTIES REQUESTED ARE LIVEOAK

THE MINIMUM,MAXIMUM DEPTH REQUESTED IS ALL

THE LOWER LIMIT ON YEAR IS 19ALL

FIELD NAME	COUNTY	DATE	DEPTH
BRASLAU8800	LIVEOAK	MAR58	8817
CHAPA	LIVEOAK	JAN44	8166
CHAPASLICKSEG3	LIVEOAK	AUG64	8228
CHAPAWILCOX1ST	LIVEOAK	JAN52	8637
CHAPAWILCOX1SS	LIVEOAK	MAR68	8165
CHAPA8650	LIVEOAK	SEP51	8658
CLAYWESTWLOWER	LIVEOAK	SEP46	10121
CLAYWESTWLNORT	LIVEOAK	OCT52	9446
CLAYWESTWMIDDL	LIVEOAK	JUL52	10064
CLAYWESTWUPPER	LIVEOAK	JAN47	9390
CLAYWESTW9340	LIVEOAK	OCT66	9342
CLAYWEST8900	LIVEOAK	MAR53	8900
DINEROWESTW136	LIVEOAK	AUG62	13606
DUNNLULINGWIL	LIVEOAK	NOV57	8374
DUNNSLICKB	LIVEOAK	JAN63	8202
DUNNSLICKWILC	LIVEOAK	MAY55	8078
GEORGEWEST	LIVEOAK		10170
GEORGEWESTE850	LIVEOAK	NOV59	8521
HARRISWILCOX	LIVEOAK	DEC64	8164
HARRISWILCOX	LIVEOAK		8616
HARRISNEMACK	LIVEOAK	MAY67	8152
HARRISNEMASS	LIVEOAK	APR59	8488
HARRISNESEGA	LIVEOAK	JAN62	8366
HARRISNESEGC	LIVEOAK	FEB59	8612
HARRISSE8060	LIVEOAK	FEB69	8066
HOUDMANWILCOX	LIVEOAK	SEP61	8322
ISAACKSEDWARDS	LIVEOAK	AUG57	12456
KARONSOUTH1ST	LIVEOAK	JAN49	8180
KARONSOUTH2ND	LIVEOAK	MAY60	8182
KATZSLICKWILC	LIVEOAK	MAY59	10531
KITTIEWESTI24	LIVEOAK	FEB68	8237
KITTIEBURNS	LIVEOAK		10170
KITTIEBURNSWUP	LIVEOAK	FEB63	9066
KITTIEBURNSW91	LIVEOAK	SEP63	9122
KITTIEBURNS940	LIVEOAK	MAR66	9404
KITTIEBURNS108	LIVEOAK	FEB70	10817
LEDWIG2NDTOMLY	LIVEOAK	JUL62	9524
LYNEMAXINEMCL	LIVEOAK	DEC61	8865
MAXINE	LIVEOAK	NOV48	8820
MIKESKAWILCOX	LIVEOAK	MAY59	10058
MIKESKANLULING	LIVEOAK	JUN68	9090
OAKVILLESWLCXM	LIVEOAK	APR59	8488
SALTCREEKI24	LIVEOAK	DEC68	8237
SCHULZ	LIVEOAK		9500
SOLWESTMACKHAN	LIVEOAK	MAY61	9100

SPURSSOUTH	LIVEOAK	JUN49	8314
TEXAMWLCXLOWER	LIVEOAK	MAY63	9602
TOMLYNEREAGANC	LIVEOAK	OCT64	10440
TOMLYNE8800	LIVEOAK	NOV55	8758
TOMLYNE9200WLC	LIVEOAK	SEP48	9230
TOMLYNENREAGAN	LIVEOAK	OCT66	9843
TOMLYNENREAGAN	LIVEOAK	FEB66	9980
TOMLYNENWLCX93	LIVEOAK	JAN71	9397

APPENDIX B

Core Record of Shell No. 13 McAllen
McAllen Ranch Field
Hidalgo County, Texas
(Courtesy of Shell Oil Company)

APPENDIX

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-22-65 TYPE CONVENTIONAL

LOCATION CODE 242220006740639800013O090 PERMIAN BASIN NO - -

HIDALGO COUNTY, TEXAS

MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

(3' low to sonic log)

LAB NO.	DEPTH FROM	DEPTH TO	R	CLASS	LITHOLOGY** GS	ST	P	H	SEC	PERM MD	POR PLUG
100602	10775.00	75.50	SD		F	W		H	C	0.8	11.1
100603	10776.00	76.50	SH					H	CSF	0.0	26.1
100604	10777.00	77.50	SH					H	CLS	0.0	19.4
100605	10778.00	78.50	SD		V	W		H	CR	0.2	19.2
100606	10779.00	79.50	SD		F	W		H	CR	1.4	15.7
100607	10780.00	80.50	SD		F	M		H	CR	1.4	21.8
100608	10781.00	81.50	SD		F	M		H	CR	0.1	9.9
100609	10782.00	82.50	SD		F	M		H	CR	2.6	25.2
100610	10783.00	83.50	SD		F	M		H	CR	39.4	21.1
100611	10784.00	84.50	SD		V	M		H	CR	0.5	20.5
100612	10785.50	86.00	SD		V	W		H	CR	0.09	19.7
100613	10786.00	86.50	SD		V	W		H	CR	0.2	16.6
100614	10787.00	87.50	SD		V	M		H	CR	0.5	17.5
100615	10788.00	88.50	SD		V	W		H	CR	2.9	20.2
100616	10789.00	89.50	SD		F	M		H	CR	2.3	21.0
100617	10790.00	90.50	SD		V	M		H	CR	1.4	21.7
100618	10791.00	91.50	SD		F	P		H	CR	1.0	22.1
100619	10792.75	93.25	SD		V	M		H	CRL	0.2	22.2
100620	10793.00	93.50	SD		F	P		H	CR	3.3	19.9
100621	10794.00	94.50	SD		F	M		D	CR	25.66	21.3
100622	10795.00	95.50	SD		F	M		H	CR	0.2	11.5
100623	10795.75	96.25	SD		F	M		H	CR	6.7	23.7
100624	10797.00	97.50	SD		F	M		H	CR	6.69	26.0
100625	10798.00	98.50	SD		F	M		H	CR	0.1	8.0
100626	10799.00	99.50	SD		F	W		D	CR	12.8	21.3
100627	10800.00	.50	SD		F	W		H	CR	2.8	18.5
100628	10800.75	1.25	SD		F	M		H	CR	0.2	14.0
100629	10802.00	2.50	SD		V	W		H	CR	0.4	21.5
100630	10803.25	3.75	SD		F	M		H	CR	1.0	24.1

**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE		V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVEN
PAGE 1	SL SILTSTONE	V V. FINE		C FROM CAP. PRES. DATA

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-22-65 TYPE CONVENTIONAL

LOCATION CODE 2422200067406398000130090 PERMIAN BASIN NO

HILDALGO COUNTY, TEXAS

MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

LAB NO.	DEPTH FROM	TO	R	CLASS	LITHOLOGY** GS	ST	P	H	SEC	PERM MD	S S	POR PLUG
100631	10804.00	4.50	SD		F	M		H	CR	1.5		21.8
100632	10805.00	5.50	SD		F	P		H	CR	-0.1		8.4
100633	10806.00	6.50	SD		V	W		H	CR	0.2		10.6
100634	10807.00	7.50	SD		V	M		H	CR	8.9		17.7
100635	10808.00	8.50	SD		M	M		H	CR	0.3		20.6
100636	10809.00	9.50	SD		V	W		H	CR	18.3		19.7
100637	10810.00	10.50	SD		F	M		H	CR	2.9		27.0
100638	10811.00	11.50	SD		F	M		H	CRL	1.4		21.9
100639	10812.00	12.50	SD		F	P		H	CRX	-0.1		10.2
100640	10813.00	13.50	SD		F	M		H	CR	1.1		20.5
100641	10814.00	14.50	SD		F	P		H	CR	0.8		17.2
100642	10815.50	15.75	SD		V	W		H	CRL	0.2		20.2
100643	10816.00	16.50	SD		V	W		H	CRL	0.2		10.1
100644	10817.00	17.50	SD		V	W		H	CR	0.2		20.3
100645	10818.00	18.50	SD		V	W		H	CRL	0.2		18.2
100646	10819.00	19.50	SD		V	M		H	CR	0.7		23.4
100647	10820.00	20.50	SL					H	SRC	0.2		16.8
100648	10821.50	22.00	SD		V	W		H	CR	1.3		19.1
100649	10822.00	22.50	SD		F	W		H	CR	0.7		24.1
100650	10823.00	23.50	SD		V	W		H	CR	-0.1		7.8
100651	10824.50	25.00	SD		F	M		H	CR	0.8		26.4
100652	11006.00	5.50	SD		V	M		H	CLI	8.1		22.7
100653	11007.00	7.50	SD		V	W		H	CL	1.4		17.9
100654	11008.50	9.00	SD		V	W		H	CR	1.2		19.6
100655	11009.00	9.50	SD		V	W		H	CR	1.4		19.8
100656	11010.00	10.50	SD		V	W		H	CLR	0.4		16.0
100657	11011.00	11.50	SD		F	M		H	CR	1.4		17.2
100658	11012.00	12.50	SD		F	M		H	CR	6.7		22.1
100659	11013.00	13.50	SD		F	W		D	CR	8.0		20.6

**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE	I	V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVEN
PAGE 2	SL SILTSTONE	V V. FINE		C FROM CAP. PRES. DATA

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-22-65 TYPE CONVENTIONAL

LOCATION CODE 2422200067406398000130090 PERMIAN BASIN NO - -

HILDALGO COUNTY, TEXAS

MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

LAB NO.	DEPTH FROM	TO	R	CLASS	GS	ST	P	H	SEC	PERM MD	S S	(POR PLUG
100660	11014.00	14.50	SD		F	W		D	CR	8.4		20.4
100661	11015.25	15.75	SD		F	M		H	CR	17.7		23.4
100662	11016.00	16.50	SD		F	M		H	CR	10.3		22.1
100663	11017.00	17.50	SD		F	M		H	CR	19.3		20.6
100664	11018.50	19.00	SD		F	M		H	CR	0.7		12.7
100665	11019.00	19.50	SD		F	W		H	CR	17.8		22.8
100666	11020.00	20.50	SD		F	M		H	CR	0.8		13.5
100667	11021.00	21.50	SD		F	W		H	CR	2.2		19.5
100668	11022.00	22.50	SD		F	M		H	CR	6.3		15.2
100669	11023.00	23.50	SD		F	M		H	CR	4.1		17.7
100670	11024.00	24.50	SD		V	W		H	CR	0.4		12.1
100671	11025.50	26.00	SD		F	M		H	CRL	0.7		17.6
100672	11026.00	26.50	SD		V	W		H	C	0.6		14.1
100673	11027.00	27.50	SD		V	W		H	CR	0.4		13.9
100674	11028.00	28.50	SD		V	W		H	CR	0.4		19.8
100675	11029.25	29.75	SD		V	W		H	CR	0.4		21.6
100676	11030.00	30.50	SD		F	M		H	CR	29.0		20.2
100677	11031.00	31.50	SD		F	M		H	CR	2.8		23.8
100678	11032.00	32.50	SD		F	M		D	CR	0.4		21.3
100679	11033.00	33.50	SD		V	W		H	CR	0.2		12.0
100680	11034.00	34.50	SD		V	W		H	CR	1.7		18.7
100681	11035.00	35.50	SD		V	W		H	CR	2.0		16.3
100682	11036.00	36.50	SD		V	W		D	CR	0.4		18.8
100683	11037.25	37.75	SD		V	W		H	CRL	0.4		18.7
100684	11038.00	38.50	SD		V	W		H	CR	0.2		19.4
100685	11039.00	39.50	SD		V	W		H	CR	0.8		16.1
100686	11040.50	41.00	SD		V	W		H	CR	0.4		14.4
100687	11041.00	41.50	SD		V	W		H	CR	0.5		14.6
100688	11042.00	42.50	SD		V	W		H	CR	0.2		15.6

**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE	I	V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVE
PAGE 3	SL SILTSTONE	V V. FINE		C FROM CAP. PRES. DAT.

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-22-65 TYPE CONVENTIONAL

LOCATION CODE 24222000674063980001300090 PERMIAN BASIN NO

HILDALGO COUNTY, TEXAS

MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

LAB NO.	DEPTH FROM	TO	R	LITHOLOGY** CLASS	GS	ST	P	H	SEC	PERM MD	S S.	(POR PLUG
100689	11043.00	43.50	SD		V	W		H	CR	1.0		20.0
100690	11044.00	44.50	SD		V	W		H	CR	0.3		16.4
100691	11045.00	45.50	SD		V	W		H	CR	0.2		17.3
100692	11046.00	46.50	SD		V	W		H	CR	2.0		17.0
100693	11047.00	47.50	SD		V	W		H	CR	0.2		13.5
100694	11048.00	48.50	SD		F	M		H	CR	1.2		22.2
100695	11049.00	49.50	SD		F	M		H	CR	4.5		20.8
100696	11050.00	50.50	SD		V	W		H	CR	0.3		18.3
100697	11051.00	51.50	SD		V	W		H	CR	6.1		21.4
100698	11052.00	52.50	SD		V	W		H	C	0.6		15.1
100699	11053.00	53.50	SD		V	W		H	CR	0.2		13.1
100700	11054.00	54.50	SD		V	W		H	CR	0.2		16.6
100701	11055.25	55.75	SD		V	W		H	CR	0.3		17.7
100702	11055.00	56.00	SD		V	W		H	CR	0.2		12.7

**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE	I	V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVEN
PAGE 4	SL SILTSTONE	V V. FINE		C FROM CAP. PRES. DATA

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-24-65 TYPE CONVENTIONAL

LOCATION CODE 242220006740639800013O125 PERMIAN BASIN NO -

HILDALGO COUNTY, TEXAS

MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

LAB NO.	DEPTH FROM	TO	R	CLASS	LITHOLOGY** GS	ST	P	H	SEC	PERM MD	S S	(POR PLUG
100733	11458.00	58.50	SD		F	P		D	C	32.7		22.5
100734	11459.00	59.50	SD		F	M		H	RC	13.8		20.2
100735	11460.00	60.50	SD		F	M		D	C	8.7		22.1
100736	11461.00	61.50	SD		F	M		H	C	6.1		20.7
100737	11462.00	62.50	SD		F	W		H	CR	0.5		17.6
100738	11463.00	63.50	SD		F	M		H	LC	3.9		18.5
100739	11464.00	64.50	SD		F	M		H	RC	10.0		19.4
100740	11465.00	65.50	SD		V	W		H	CR	0.6		12.6
100741	11466.00	66.50	SD		V	M		H	CR	12.9		21.1
100742	11467.50	68.00	SD		F	W		H	C	0.5		13.3
100743	11468.00	68.50	SD		V	W		H	C	1.1		14.3
100744	11469.00	69.50	SD		V	W		H	CR	0.4		19.1
100745	11470.00	70.50	SD		F	W		H	CR	0.2		8.5
100746	11471.00	71.50	SD		F	W		H	CR	0.5		15.4
100747	11472.00	72.50	SD		V	W		H	CR	0.2		9.3
100748	11473.00	73.50	SD		V	W		H	CR	0.3		15.5
100749	11474.00	74.50	SD		V	W		H	CR	0.2		10.6
100750	11475.00	75.50	SD		V	W		H	CR	0.1		13.8
100751	11476.00	76.50	SD		V	V		H	CR	0.1		10.2
100752	11477.50	78.00	SL					H	CR	0.5		14.5
100753	11478.00	78.50	SD		V	W		H	CR	0.2		13.2
100754	11479.00	79.50	SD		V	V		H	CR	0.2		14.6
100755	11480.00	80.50	SD		V	W		H	CR	0.2		12.6
100756	11481.00	81.50	SL					H	CRF	0.2		14.6
100757	11482.00	82.50	SD		V	W		H	CRF	0.4		15.5
100758	11483.50	84.00	SL					H	CR	0.0		17.9
100759	11484.00	84.50	SH					H	CL	0.0		7.1
100760	11484.50	85.00	SD		F	M		H	CR	0.1		5.9

**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE	I	V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVE
PAGE 1	SL SILTSTONE	V V. FINE		C FROM CAP. PRES. DAT

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-30-65 TYPE CONVENTIONAL

LOCATION CODE 2422200067406398000130150 PERMIAN BASIN NO - -

HIDALGO COUNTY COUNTY, TEXAS

MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

T.Sd. (5' low to sonic log)

LAB NO.	DEPTH FROM	TO	R	LITHOLOGY** CLASS	GS	ST	P	H	SEC	PERM MD	S S	POR. PLUG
100772	12170.00	70.50	SD		F	W		H	RC	1.2		18.7
100773	12171.00	71.50	SD		F	M		H	RC	0.2		26.7
100774	12172.00	72.50	SD		F	W		H	RC	0.2		8.0
100775	12173.00	73.50	SD		F	M		H	C	-0.0		4.8
100776	12174.00	74.50	SH					H	C	-0.1		9.9
100777	12175.00	75.50	SL					H	CR	-0.1		8.1
100778	12176.00	76.50	SL					H	CR	-0.1		8.4
100779	12177.00	77.50	SD		V	V		H	CR	0.2		8.6
100780	12178.00	78.50	SL					H	CR	-0.1		6.6
100781	12179.00	79.50	SL					H	CR	0.2		9.2
100782	12180.00	80.50	SL					H	CR	-0.1		6.6
100783	12181.00	81.50	SL					H	CR	-0.1		10.2
100784	12182.00	82.50	SL					H	CR	-0.1		9.3
100785	12183.00	83.50	SD		V	V		H	CRX	-0.1		8.1
100786	12184.00	84.50	SL					H	CR	-0.0		9.2
100787	12185.00	85.50	SD		V	V		H	CRX	0.2		9.4
100788	12186.00	86.50	SD		V	V		H	CRL	0.2		12.6
100789	12187.00	87.50	SL					H	CR	0.2		12.4
100790	12188.00	88.50	SD		V	V		H	CR	0.2		12.3
100791	12189.00	89.50	SD		V	V		H	CR	-0.1		7.3
100792	12190.00	90.50	SD		V	V		H	CR	0.2		12.2
100793	12192.00	92.50	SD		V	V		H	CR	0.2		14.0
100794	12193.50	94.00	SD		F	W		H	RC	-0.1		9.4
100795	12194.00	94.50	SD		F	W		H	RC	0.2		13.9
100796	12195.00	95.50	SD		F	W		H	RCI	0.3		17.4
100797	12196.00	96.50	SD		F	W		H	RCI	0.2		16.6
100798	12197.25	97.75	SD		F	W		H	RC	-0.1		10.3
100799	12198.00	98.50	SD		F	W		H	RC	0.2		17.2
100800	12199.00	99.50	SD		V	W		H	RC	-0.1		6.6

**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE	I	V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVEN
PAGE 1	SL SILTSTON	V V. FINE		C FROM CAP. PRES. DATA

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT

WELL CORED ON - - ANALYSIS RUN ON 3-30-65 TYPE CONVENTIONAL

LOCATION CODE 2422200067406398000130150 PERMIAN BASIN NO -

HIDALGO COUNTY COUNTY, TEXAS

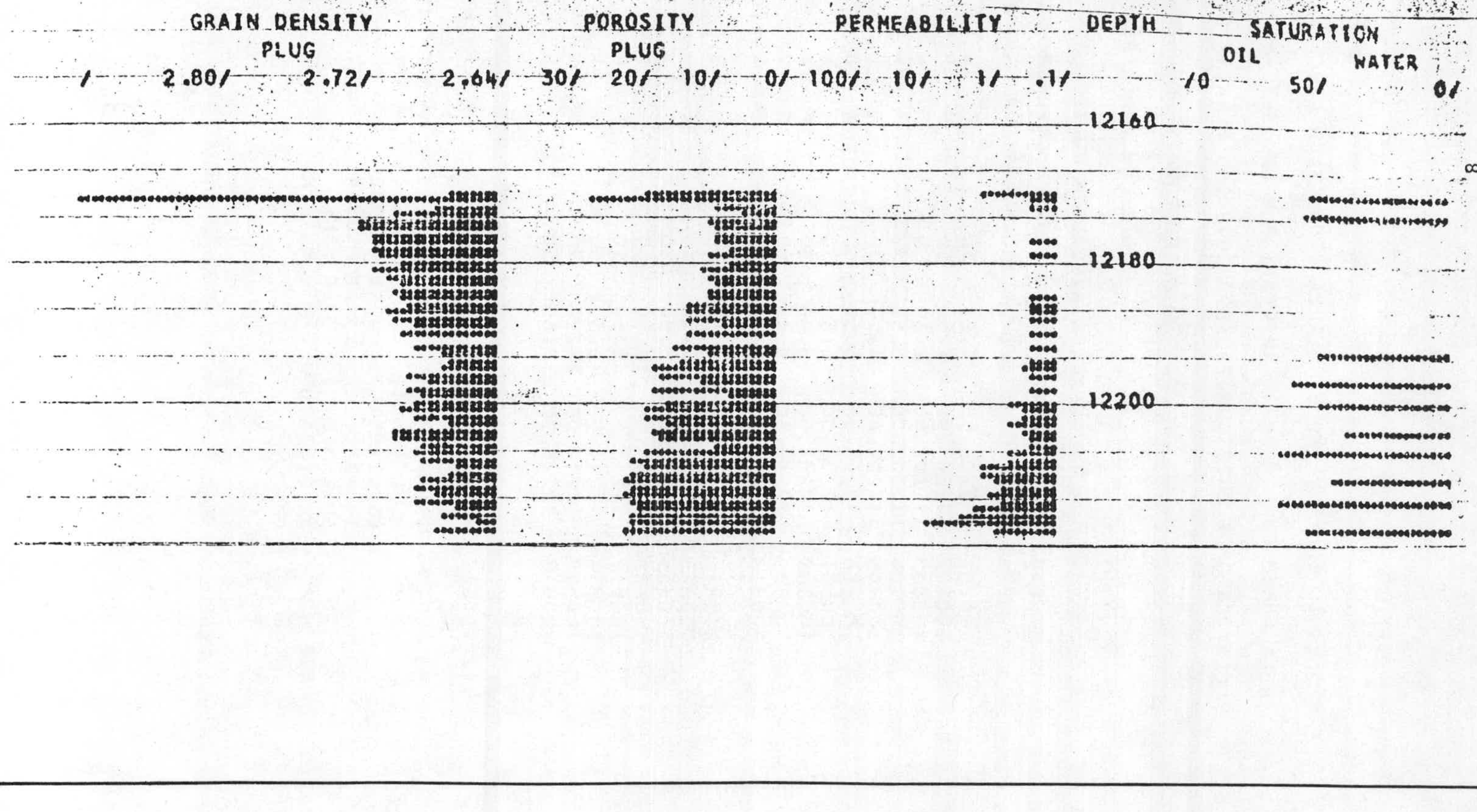
MCALLEN RANCH FIELD

SHELL A.A.MCALLEN NO.13

LAB NO.	DEPTH FROM	DEPTH TO	R	LITHOLOGY** CLASS	GS	ST	P	H	SEC	PERM MD	SS	POR PLUG
100801	12200.50	1.00	SD		F	W		H	RC	0.4		15.7
100802	12201.00	1.50	SD		F	M		H	RC	0.3		18.0
100803	12202.00	2.50	SD		F	W		H	RC	0.3		18.0
100804	12203.00	3.50	SD		F	W		H	RC	0.5		15.7
100805	12204.00	4.50	SD		V	W		H	RC	0.3		17.2
100806	12205.00	5.50	SD		V	M		H	RC	0.2		16.2
100807	12206.00	6.50	SD		F	W		H	RC	0.2		8.7
100808	12207.50	8.00	SD		F	W		H	RC	0.4		18.8
100809	12208.50	9.00	SD		F	W		D	RC	0.4		20.0
100810	12209.00	9.50	SD		F	W		H	RC	1.0		18.8
100811	12210.00	10.50	SD		F	W		H	RC	1.1		20.2
100812	12211.00	11.50	SD		F	M		H	RC	0.7		21.5
100813	12212.00	12.50	SD		F	W		D	RC	0.6		20.4
100814	12213.00	13.50	SD		F	W		D	RC	0.9		21.6
100815	12214.00	14.50	SD		F	M		H	RC	0.6		20.4
100816	12215.00	15.50	SD		F	W		D	RC	1.3		19.5
100817	12216.00	16.50	SD		F	W		D	RC	2.5		20.2
100818	12217.00	17.50	SD		F	W		D	RC	7.6		20.1
100819	12218.00	18.50	SD		F	W		H	RC	0.7		21.7

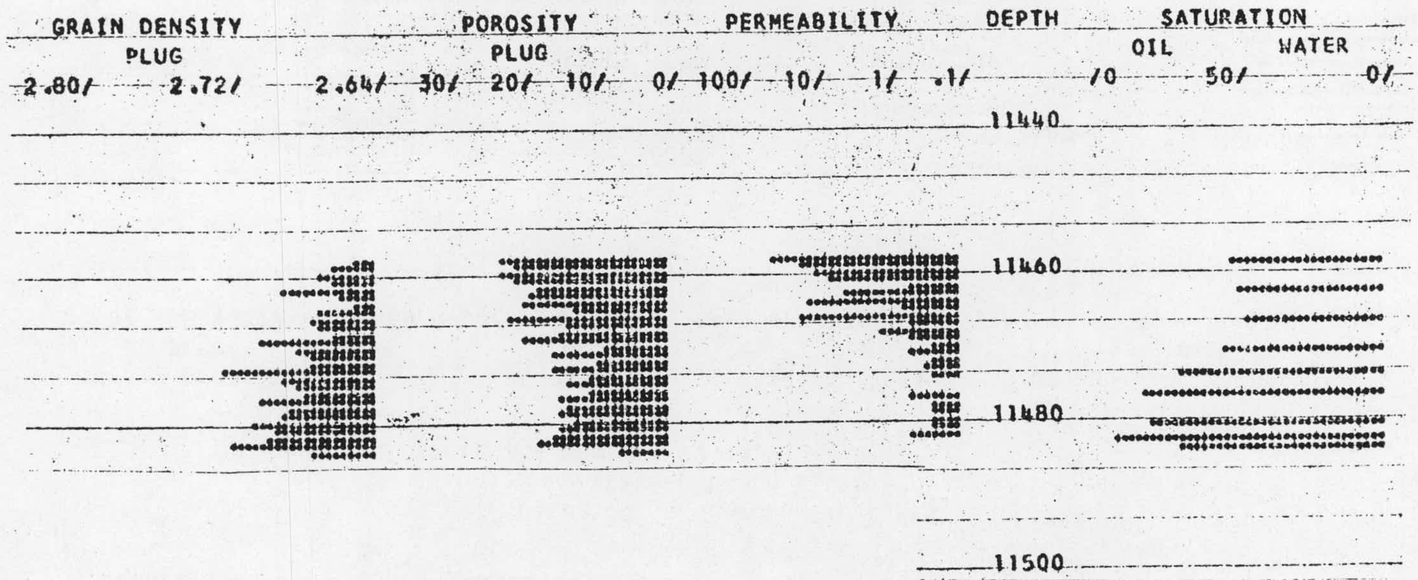
**	ROCK TYPE	CLASS	SORTING	POROSITY
LITHOLOGIC	AN ANHYDRITE	I	V VERY WELL	A NOT VISIBLE
CODE	CG CONGLOMERATE	II ARCHIE	W WELL	B -0.1 MM
	CH CHERT	III CLASS	M MODERATELY	C 0.1-2.0 MM
	DO DOLOMITE	GR. SIZE	P POORLY	D +2.0 MM
	LS LIMESTONE	L COARSE		SS--SPECIAL SYMBOLS
	SD SAND	M MEDIUM		E EST. GRAIN DENSITY
	SH SHALE	F FINE		* PERM. AND POR. GIVEN
PAGE 2	SL SILTSTONE	V V. FINE		C FROM CAP. PRES. DATA

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT HIDALGO COUNTY COUNTY, TEXAS
WELL CORED ON 3-30-65 ANALYSIS RUN ON - - TYPE CONVENTIONAL MCALLEN RANCH FIELD
LOCATION CODE 2422200067406398000130150 SHELL A.A.MCALLEN NO.13



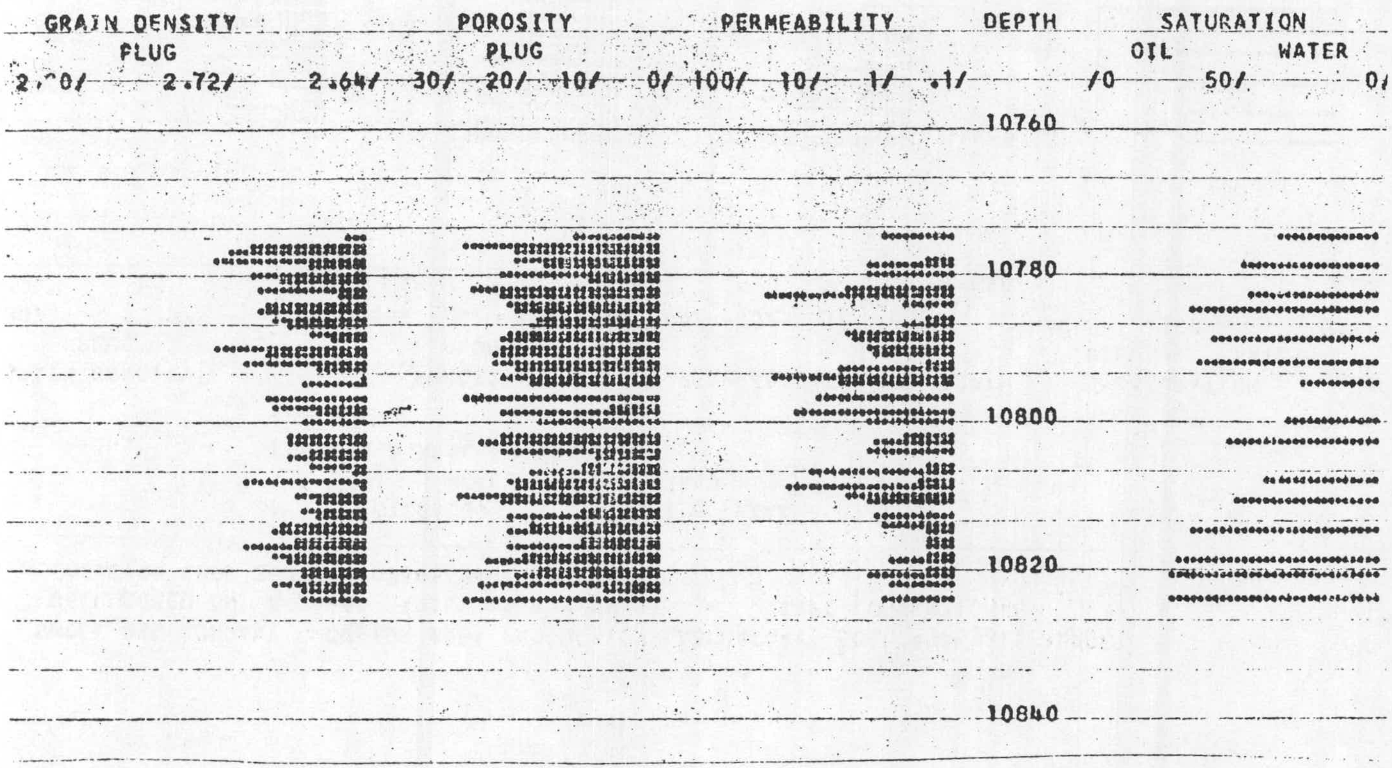
SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT
WELL CORED ON 3-24-65 ANALYSIS RUN ON - - TYPE CONVENTIONAL
LOCATION CODE 242220006740639800013012S

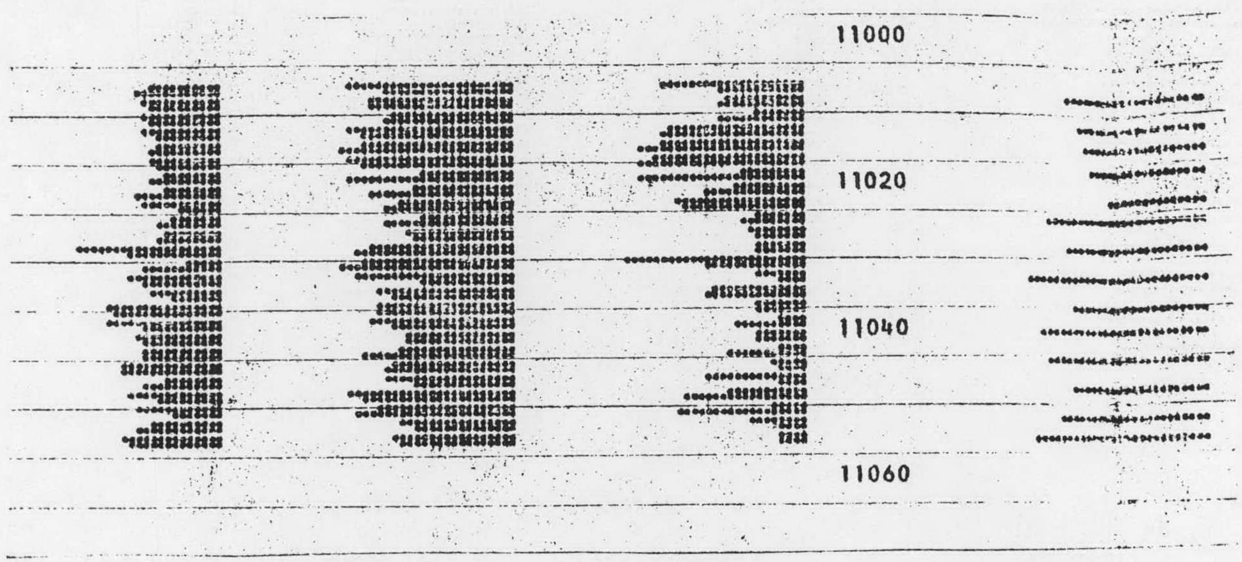
HILDALGO COUNTY, TEXAS
MCALLEN RANCH FIELD
SHELL A.A.MCALLEN NO.13



SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT
WELL CORED ON 3-22-65 ANALYSIS RUN ON - - TYPE CONVENTIONAL
LOCATION CODE 242220006740639800013009O

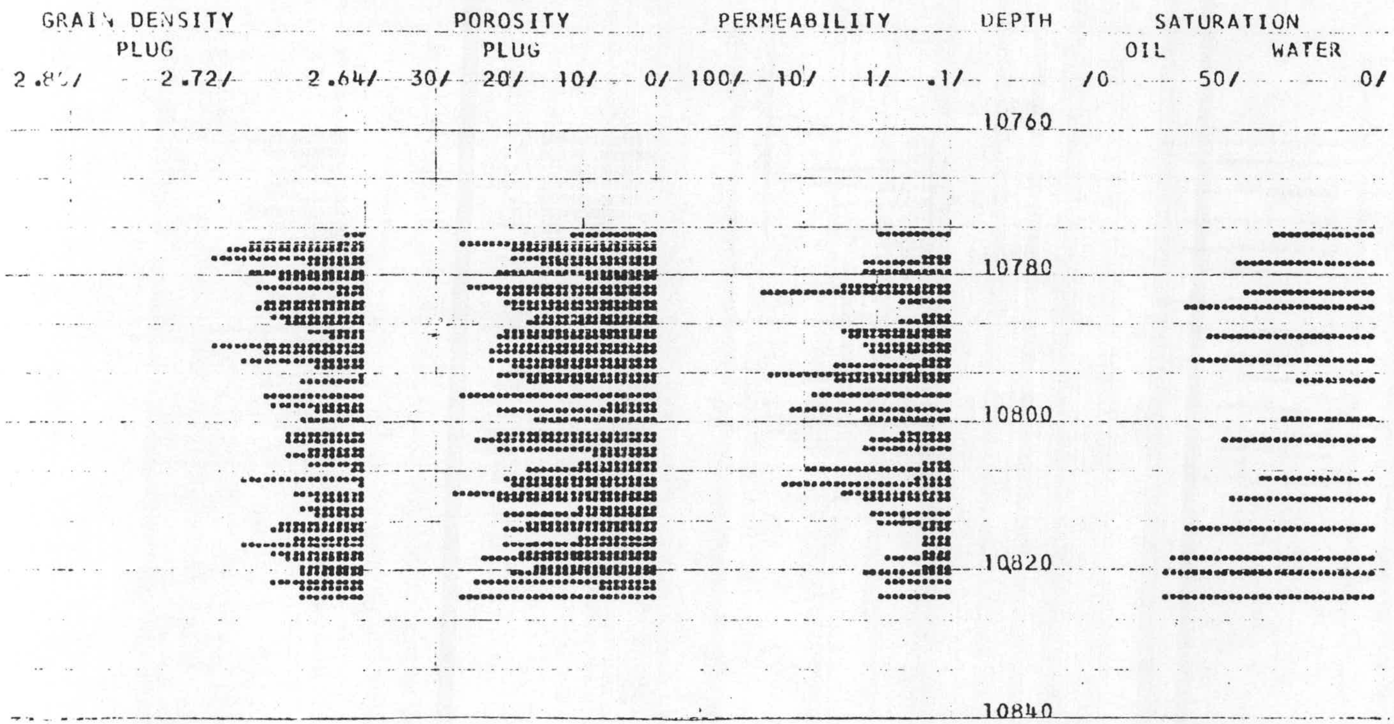
HILDALGO COUNTY, TEXAS
MCALLEN RANCH FIELD
SHELL A.A.MCALLEN NO.13

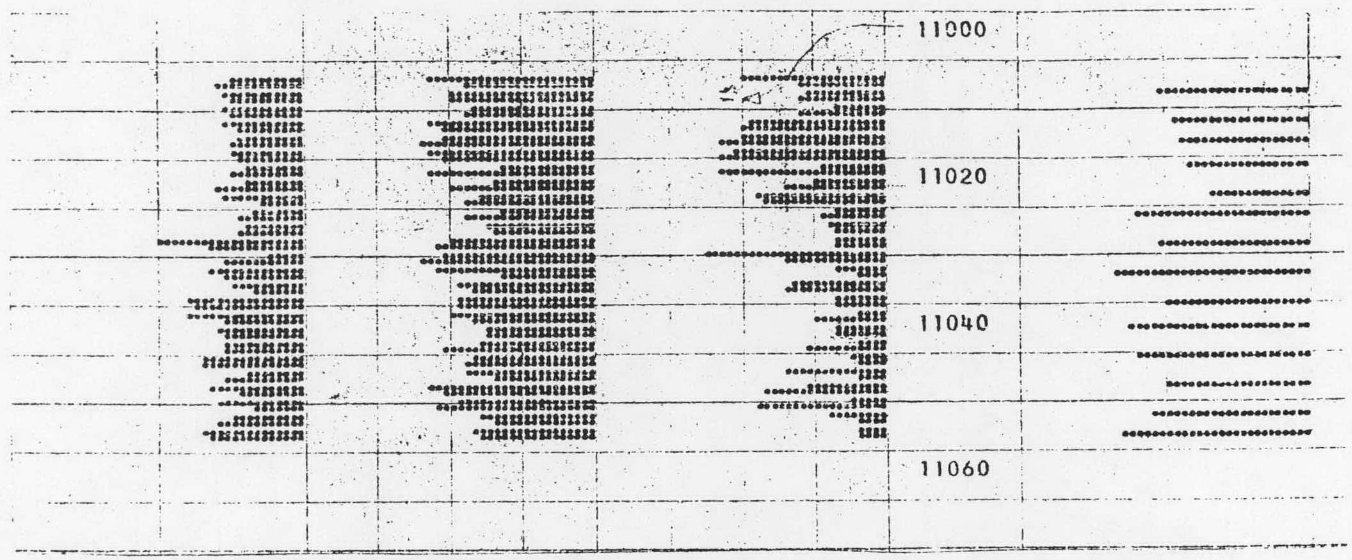



11000
11020
11040
11060

SHELL OIL COMPANY HOUSTON AREA PRODUCTION LABORATORY CORE ANALYSIS REPORT
WELL CORED ON 3-22-65 ANALYSIS RUN ON - - TYPE CONVENTIONAL
LOCATION CODE 24222000674063980001300090

HILDALGO COUNTY, TEXAS
MCALLEN RANCH FIELD
SHELL A.A.MCALLEN NO.13




11000
11020
11040
11060

APPENDIX C

Calculation of Pressure and Flow From a Single Well in the Center of a Circular Reservoir

APPENDIX C–CALCULATION OF PRESSURE AND FLOW FROM A SINGLE WELL IN THE CENTER OF A CIRCULAR RESERVOIR

1. Flow During Transient Conditions. For time less than the readjustment time, which is the time for the pressure disturbance to reach the edge of the reservoir,

$$T_r = \frac{0.04\mu\, C_e\, r_e^{\,2}}{k}$$

where

- T_r –The readjustment time
- μ –Viscosity of the fluid in centipoise (0.2 in example in text)
- C_e –Compressibility of the reservoir (6.23×10^{-5} in example)
- r_e –Radius of the reservoir (9,326 ft in example)
- k –Permeability (100 md in example)

The calculation of T_r for example in the text,

$$T_r = \frac{04(0.2)(6.23 \times 10^{-5})(9326)^2}{0.1}$$

$$= 433.5 \text{ days, or } 1.2 \text{ yr.}$$

2. An Equation for the Flow of Fluids from a Reservoir During the Transient Period.

$$Q = \frac{14.16\, kh}{\mu \ln \dfrac{14.22\, kt}{\phi\mu C_e r_w^{\,2}}}\,[P_r - P_s - P_h - P_f]$$

where

- Q –Flow in bbl/day
- k –Permeability in md
- h –Thickness in feet
- t –Time in days
- ϕ –Porosity, fraction
- μ –Viscosity centipoise
- C_e –Compressibility
- r_w –Radius of the well in ft
- P_r –Initial pressure in reservoir
- P_s –Pressure at the surface
- P_h –Pressure due to the hydrostatic head
- P_f –Friction loss due to flow up the pipe (for 9-5/8-in.-diameter pipe 12,000-ft long flowing at rate of 100,000 bbl/day, pressure drop is 280 psi)

Sample calculation after one day of open flow (parameters from example in text)

$$Q = \frac{14.16(0.1)(500)}{0.2\ ln \dfrac{(14.22)(0.1)(1)}{(0.2)(6.23 \times 10^{-5})(0.401)^2}} = [(10{,}000) - (0) - (5200) - (280)]$$

$Q = 1{,}026{,}000$ bbl/day

3. For Times Greater Than $2Tr_2$ the Semisteady-State Flow Equation is

$$P_s = (P_r - P_h - P_f) - \left(\frac{5.615Qt}{\pi r_e{}^2 h \phi C_e}\right) - \left(\frac{Q \cdot \mu}{7.08kh}\right)\left\{\left[ln\left(\frac{r_e}{r_w}\right)\right] - \frac{3}{4}\right\}$$

A sample calculation at 867 days (beginning of semisteady-state flow) for the example in the text

$$P_s = (10000 - 5200 - 280) - \frac{5.615 \times 10^5 (867)}{\pi(9326)^2(500)(0.12)(6.23 \times 10^{-5})}$$

$$- \frac{(10^5)(0.2)}{\pi(9326)^2(500)(0.12)(6.23 \times 10^{-5})}\left\{\left(ln\frac{9326}{0.401}\right) - \frac{3}{4}\right\}$$

$P_s = 3517$ psi

4. Pressure at the Surface During Transient Period

$$P_s = (P_r - P_h - P_f) - \left[\frac{Q/\mu}{14.16kh\ ln\left(\dfrac{14.22\ kt}{\mu C_e \phi r_w{}^2}\right)}\right]$$

The initial pressure at the surface at $t = 0$ in the example,

$$P_s = 10{,}000 - 5{,}200 - 280 = 4{,}520 \text{ lb}$$

Pressure at the surface after one day with $Q = 100{,}000$ bbl water/day in the example,

$$P_s = \frac{4{,}520 - (10^5)(0.2)}{14.16(0.1)(500)}\left[ln\left(\frac{(14.22)(0.1)(1)}{(0.2)(6.23 \times 10^{-5})(0.12)(0.401)^2}\right)\right] = 4{,}080 \text{ lb}$$