PRELIMINARY EVALUATION OF GEOTHERMAL RESOURCES
OF SOUTH TEXAS

for

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Lawrence Livermore Laboratory

by

Bureau of Economic Geology
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Cover Map - total thickness of
Frio Formation, South Texas

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BASIC OBJECTIVE--DETERMINE REGIONAL DISTRIBUTION OF FRIO SANDS--SOUTH TEXAS

A preliminary study was proposed to initiate sand-facies analysis of the Frio Formation, South Texas, and integrate this with existing temperature and pressure information in order to define prospective areas in which more detailed reservoir analysis is necessary prior to site selection.

The presence of a geopressured zone containing fluids with high temperatures has been well known from wells penetrating Tertiary sediments in search for oil and gas reservoirs along the Texas Gulf Coast. However, few oil or gas wells produce from these high temperatures and, as a result, the regional sand distribution within these zones has not received much attention. Consequently, the regional fabric and trends of the sands within the geopressured zone is not well known. Limited data, however, indicate that the pore spaces within the sands in the geopressured zone are filled with water with high temperatures, relatively low dissolved solids, and saturated with methane. These waters are believed to be an important potential source of thermal energy and methane gas.

The first step in appraising the Gulf Coast geothermal resources entails a detailed geologic study of the main sand trends, the most prospective of which appear to be the Frio and Wilcox (fig. 1). The Wilcox Formation has been studied in detail by Fisher and McGowen (1967). This report will deal largely with the Frio. Other parts of the Tertiary which have been studied in detail are the Queen City Formation (Claiborne) by Guevara and Garcia (1972) and the Jackson by Fisher and others (1970).

A proposal was submitted to the United States Atomic Energy Commission through the Lawrence Livermore Laboratory for \$26,000 in order

to conduct a five-month preliminary study of the geothermal resource of the Frio sands in South Texas (fig. 2). The South Texas area (from just north of Corpus Christi south to the Rio Grande) was selected because the geopressured zone is known to occur at shallowest depths and because of the abundance of oil-well records in the area. This study was to include a sand-facies analysis and then integration of the facies data with existing information relative to temperatures and pressures. This mutual project was to begin on 1 June 1974 and terminate on 31 October 1974 with a written report. The Center for Energy Studies, The University of Texas at Austin, provided an additional \$12,000 to the study.

The objectives of this proposal were to:

- (1) assemble well logs and other subsurface data on the Frio sediments needed to evaluate the geothermal potential,
- (2) assemble existing data as available from companies and other organizations relative to Gulf Basin geothermal resources,
- (3) prepare regional work maps depicting sand trend and facies analysis and defining areas within the geopressured zones most likely to have adequate sand reservoir conditions, and
- (4) prepare regional cross sections depicting the relationship of principal Frio sand facies to the geopressured zones.

CENOZOIC – TEXAS GULF COAST

AGE	SERIES	GROUP/FORMATION
Quaternary	Recent	Undifferentiated
	Pleistocene	Houston
	Pliocene	Goliad
Tertiary	Miocene	Fleming
		Anahuac
	?	?
	Oligocene	Frio
		Vicksburg
	Eocene	Jackson
		Claiborne
		Wilcox
		Midway

Fig. 1. Tertiary formations - Gulf Coast of Texas. Of prime interest in this report is the Frio and upper part of the Vicksburg (shown in the darker pattern); other formations already studied and summarized in Bureau reports are shown with the lighter pattern.

Fig. 2. Area of study.

DEPOSITIONAL PATTERNS--GULF COAST TERTIARY

The Tertiary of the Gulf Coast comprises a large number of basinward thickening sand-shale wedges which, because of their similarities, are very difficult to separate stratigraphically one from another.

The Tertiary of the Gulf Coast is made up of a number of sand-shale packages which dip steeply into the Gulf of Mexico; each of these packages also thickens considerably in the same direction forming a wedge-shaped body (fig. 3). The wedges are made up dominantly of shale with scattered, discontinuous sand bodies at the thin landward end; thick sand with thin shales in the central portion; and thick shale with thin, relatively continuous sands at the downdip edge of the wedge. In general, each younger wedge is displaced gulfward from the preceding wedge.

This Tertiary section is too thick and areally extensive to study as a single unit; consequently, it has been necessary to subdivide it into genetic units. This subdivision is difficult on the basis of lithology alone because of

the repetitiveness of sand-shale occurrence and the lack of recognizable physical breaks. Thus, organizations exploring for oil and gas in this section found it necessary to use evolutionary change within foraminiferal groups, present in the marginal marine portions of the wedges, to subdivide grossly the Tertiary section. Major foraminiferal zones significant to this study are shown on Figure 4. The marine portion of each wedge containing foraminiferal markers is displaced progressively gulfward from the preceding wedge; this phenomenon is well shown on the foraminiferal zone "up dip" limit map (fig. 5) on which each older zone lies farther inland than the next younger, thus substantiating the pattern shown on Figure 3.

Fig. 3. Regional cross section on a sea-level datum showing the pattern of sand-shale packages offlapping toward the coast.

FORAMINIFERAL ZONATION TEXAS GULF COAST

SERIES	GROUP/FORMATION	
Miocene	Anahuac	Discorbis nomada Heterostegina texana* Marginulina vaginata*
Oligocene	Frio	Cibicides hazzardi Nonion struma Nodosaria blanpiedi* Textularia mississippiensis Anomalina bilateralis
	Vicksburg	Textularia warreni*

Fig. 4. Foraminifera zonation, Texas Gulf Coast Miocene and Oligocene.

Fig. 5. Updip limits of foraminifer markers (after Holcomb, 1964) and updip limits of "T" markers (this report).

GROWTH FAULTS--MECHANISM FOR DOWNDIP THICKENING

Abundant down-to-the-basin growth faults are well known as a method of thickening sand-shale sections in the Tertiary of the Gulf Basin.

Much of the thickening, which is manifest regionally as thick sand-shale wedges, is believed to have been caused by contemporaneous growth faults (fig. 6). Because the faults are active as sedimentation is taking place, older strata are displaced more than younger strata and considerable thickening of the sedimentary units involved occurs on the gulfward or down side of the fault. A regional or structural cross section (fig. 7) shows the cumulative effect of crossing several growth faults; the uniform thickening shown on the regional facies sections actually represents an averaging of the effects of these faults.

Because of the complexity of the faulting in South Texas, which is well illustrated by their distribution as mapped by Geomap (fig. 8) and by Bruce (1973) (figs. 6 and 9), it is impossible to portray these faults on the regional sections. The displacement is quite variable along most of the faults and for many is only a few hundred feet. Because of this complexity and small displacement, it was

considered preferable to study the sand distribution regionally, at first without regard to the faults, though realizing that growth faulting is common and is the normal mechanism for providing space to thicken the section rapidly downdip. The faults are not believed to have affected the depositional patterns appreciably except for significantly more thickening.

The location of growth faults, confirmed by seismic sections of regional and local nature, will be of critical importance later when attention is focused on the selection of local prospective areas. As a result of growth faulting, porous sand reservoirs once in contact with time equivalent extensive sand units updip may be displaced downward on the coast side of the fault to then be in contact, across the fault, with impermeable shale (fig. 9). Thus, extensive oil and gas reservoirs and potential geothermal reservoirs developed not only as a result of sedimentary processes but also were controlled by contemporaneous structure (fig. 10).

Fig. 6. Depositional thickening as a result of contemporaneous growth faulting (from Bruce, 1973).

Fig. 7. Diagrammatic regional cross section adapted from a seismic section and from electrical log and paleontological control. This section parallels the B-B' section near the Rio Grande; the "T" markers from the B-B' section have been projected into this section to show the relationship of the depositional patterns (interpreted from electrical logs) to the growth faults (interpreted from the seismic sections).

Fig. 8. Known growth faults in South Texas as mapped by Geomap Company. Most of these faults are believed to affect at least part of the Frio section.

Fig. 9. Seismic section showing the location of a growth fault and the displacement of sand bodies and development of a shale ridge resulting from the faulting. The diagrams A-D illustrate the sequential development of the structure (from Bruce, 1973).

Fig. 10. Relationship of known oil and gas fields to growth faults (from Geomap Company).

APPROACH TO OBTAINING SAND DISTRIBUTION

In order to determine regional sand distribution, it is necessary to obtain optimum well-log control, construct cross sections, and develop a correlation framework.

Reliable resource assessment is based on a thorough understanding of the sand distribution and geometry. In sand-shale sections this type of regional information is commonly obtained through the construction of a grid of dip and strike electric log cross sections. On these cross sections detailed correlations lead to the subdivision of the section into smaller more meaningful and easily handled units.

For the Frio study electric logs were obtained from wells spaced approximately 10-15 miles apart throughout the South Texas area, a total of 232 logs (fig. 11). Only those wells which penetrated the entire Frio were selected except in the downdip

areas along the coast where no wells penetrated the entire Frio section. The top and base of the section were picked with the aid of micropaleontology--Heterostegina and Marginulina are near the top of the Frio and Textularia warreni is near the base. Where these markers are lacking structure and major shale breaks were used.

A total of 7 dip sections and 2 strike sections were constructed of the Frio section using the top of the formation as a datum. These sections illustrate the Frio as a wedge of sediment less than 1,000 feet thick on the updip end of the section and more than 10,000 feet thick on the downdip end.

Fig. 11. Well log control and cross sections constructed for this Frio study.

RELIABLE CORRELATIONS FROM REGIONAL CROSS SECTIONS

Regional cross sections, composed of electrical logs from closely spaced wells, along with adequate micropaleontological control, allow for reliable correlations within the Frio and the subdivision of this formation into several units.

In order to subdivide the Frio wedge into more manageable units, correlation points within the Frio must be established. This was accomplished on the basis of several assumptions: (1) the entire Frio thickens significantly downdip and, therefore, each genetic unit within the Frio also thickens; (2) major shale breaks represent longer periods of deposition than the intervening sand and will carry for greater distances with some reliability; (3) each genetic unit is transposed slightly seaward of the previous or older unit; and (4) each unit consists of a dominantly shale section with thin, discontinuous sands

on the updip portion, thick extensive sands in the central portion, and dominantly shale on the downdip portion.

The pattern then obtained consists of a series of sand-shale packages (figs. 12 and 13) which thicken toward the Gulf; sand percentages increase to approximately the present coast and then shale deposition becomes dominant. The updip limit of each package occurs nearer the Gulf than the preceding package (fig. 5), a pattern which parallels very closely the updip limit of foraminiferal markers.

Fig. 12. Sand facies distribution along section A-A', datum on the top of the Frio. "T" markers indicate correlation points interpreted using major shale beds and foraminifer zones. The top of the geopressured zone is indicated by the broken line.

Fig. 13. Sand facies distribution along section B-B', datum on the top of the Frio. "T" markers indicate correlation points interpreted using major shale beds and foraminifer zones. The top of the geopressured zone is indicated by the broken line.

DEPOSITIONAL SYSTEMS FROM SAND-PERCENTAGE MAPS

Depositional systems, interpreted from sand percentage maps, regional cross sections, and log patterns within each correlation unit, include fluvial plain, high-destructive wave-dominated delta, and strand plain.

Sand-percentage maps have been made of each unit (T0-T1, T1-T2, T2-T3, T3-T4, T4-T5, and T5-T6); data for these maps were obtained from the interpretation of the spontaneous potential curve of electric logs on the cross section and from infill wells between sections. The total sand thickness for each unit was calculated for each well and then converted to percentage of the total thickness of the unit. These values, plotted on maps, have been contoured to depict sand distribution for each unit (figs. 14, 15, 17, 18, 19, and 20).

Depositional systems recorded by these sands and shales must be interpreted using sand percentage maps in addition to the cross sections and characteristic log patterns, thickness relationships of the associated sands and shales, and core data. Core control is sparse and contributed only to a very minor extent.

The depositional systems identified here include fluvial, high-destructive delta, and strand plain. The variations in the sand-shale ratio and distribution and geometry of the sand bodies which lead to the identification of the depositional systems is well shown on a cross section of the T4-T5 zone (fig. 16).

Fluvial system--Sand is distributed in narrow, somewhat sinuous bands perpendicular to the coastline along the updip portion of the area. The sand bodies are commonly thin and are discontinuous laterally along strike. Individual sand bodies range in thickness from approximately 10 to 50 feet. The log patterns between and enclosing these fluvial channels indicate extensive areas very poor in sand. These areas, which are dominantly clay with very thin lignites,

represent overbank and swamp or marsh environments.

High-destructive wave-dominated delta system--Along the Rio Grande in Hidalgo and Cameron Counties, thick sand bodies are oriented in a dip direction. The sand bodies are 100 to 600 feet thick and commonly are represented by a log pattern which indicates a gradational base and coarsening upward of the grain size. The tendency for parts of the sand body to be strike oriented and the lack of significant lignites on an extensive delta plain suggests that the delta was highly destructive and wave dominated. Similar deltas of lesser lateral extent may also occur at the seaward end of the fluvial channels elsewhere along strike but are very minor in importance.

Few wells penetrate the Frio section seaward of the area of thick sand accumulation. Those that do show a dominantly shale section are interpreted as prodelta clay. The few sands in the prodelta environment are relatively thin (from 10 to 75 feet thick), become thinner gulfward, and are probably sheetlike in distribution.

Strand-plain systems--Strand plain sands are by far the most dominant type of sand body in the South Texas Frio. These sand bodies are mapped as narrow bands parallel to strike and deposited by wave action and long-shore currents into beach ridges and offshore bars. Complexes of these ridges and bars accumulate to form a broad belt 5 to 10 miles wide and 30 to hundreds of miles long. Individual sand bodies are from 10 to several hundred feet thick and are separated by shale units of a few feet to more than 100 feet thick.

Fig. 14. Sand percentage in zone T5-T6.

Fig. 15. Sand percentage in zone T4-T5.

Fig. 16. Sand distribution between T4 and T5 along section F-F'.

Fig. 17. Sand percentage in zone T3-T4.

Fig. 18. Sand percentage in zone T2-T3.

Fig. 19. Sand percentage in zone T1-T2.

Fig. 20. Sand percentage in zone T0-T1.

GEOPRESSURED FRIO RELATED TO SAND DISTRIBUTION

By mapping the top of the geopressured zone in the Frio, it can be shown that well-defined pressure patterns can be correlated with sand body geometry and distribution.

Geopressure is commonly defined as any zone in which the subsurface fluid pressure significantly exceeds that of normal hydrostatic pressure or approximately 0.464 psi for each foot of water column (Jones, 1969). An increase in the temperature and reduction of the salinity of the water in the sand reservoirs in the geopressure zone accompany this increase in pressure. The occurrence of geopressure (considered in this report as 0.7 psi per foot) is identified primarily on the basis of well-log data. The criteria used to identify this zone are (1) gradual reduction in the negative self-potential deflection, (2) increase in bottom-hole temperatures in excess of 225°F, (3) increase in weight of drilling mud used to control geopressure, (4) location of the point of setting of intermediate casing which is usually at the top of the transition zone, and (5) reduction of density and resistivity of shale.

The presence of a broad band of geopressured sediments parallel to the Texas coast has been well known

for years (Jones, 1970). Where the geopressured zone crosses the Frio it defines an irregular surface which varies in depth from -8,000 to -12,000 feet below sea level (fig. 21). The depth to the geopressured zone relates not only to the depth of the sediments below sea level but also to the amount of fluid leakage around growth faults which displaces the zone downward (fig. 7) and to the nature of the sand-shale section. High sand areas which are made up of relatively thin sand bodies separated by thin shales, typical of strand-plain sediments, characteristically have depressed or deeper geopressured zones (fig. 12); on the other hand, high sand areas which contain thick deltaic sand bodies separated by thick shales do not appear to affect the depth of geopressure (fig. 13). This relationship reflects the effectiveness of the thick shales separating the deltaic sands to seal the reservoir and the probability of considerable leakage through the thin shales of the strand-plain sediments.

Fig. 21. Top of the geopressed zone, South Texas.

ISOTHERMAL MAPS - T3, T4, and T5

Isothermal maps, constructed from well log bottom-hole temperatures, show a steepening of the thermal gradients below 225°F and a relationship of high-sand areas with lower temperatures.

Isothermal maps have been constructed for correlation points T3, T4, and T5 (figs. 22, 23, and 24) based on uncorrected well log bottom-hole temperatures. Ramey (1962) has shown that stabilized temperature readings require extensive effort and commonly result in corrected temperatures only approximately 5°F higher than the routine readings. Because each of the wells used here has only one temperature reading in the Frio interval, the density of the data used for these maps is approximately one-third that used in the preparation of the other maps.

Two observations should be made on the basis of these very general isothermal maps, however. First, steepening of dip occurs in each interval approximately at the 225°F isothermal line; this is consistent with Jones (1970) observation that the top of geopressure occurs at temperatures between 210°-240°F and that thermal gradients may double below this zone. Secondly, lower temperatures seem to occur in areas of maximum sand deposition because the geopressure zone is displaced deeper in these areas.

Fig. 22. Isothermal map on T3 datum.

Fig. 23. Isothermal map on T4 datum.

Fig. 24. Isothermal map on T5 datum.

CONCLUSIONS AND POTENTIAL GEOTHERMAL FAIRWAYS

As a result of this preliminary study of sand distribution in the Frio, two potential geothermal fairways have been identified--one in the south part of the area in Hidalgo, Willacy, and Cameron Counties, and the other in the north part in north-central Nueces County.

Three major Frio sand depocenters have been delineated.

1. Southeastern Hidalgo, western Willacy, and western Cameron Counties. The highest sand ratios were deposited in the lower Frio as thick sand bodies (100 to 600 feet thick) which are primarily dip oriented. These sand bodies were deposited as high-destructive deltas.

2. Eastern Kenedy and Kleberg Counties. A high-sand area occurs in the upper Frio where sand bodies 10 to 100 feet thick are separated by thin shale intervals. These sand bodies are oriented in strike direction and accumulated mainly as strand-plain deposits.

3. North-central Nueces County. In the middle Frio (T3-T4) a high ratio of sand occurs just at the northern part of the study area. Preliminary work farther north indicates that these thicken considerably in that direction.

Comparison of the sand-percent maps with that of the top of the geopressure (fig. 21) further helps to delineate prospective geothermal fairways. The sand reservoirs in the southern area (Hidalgo, Willacy, and Cameron Counties) and in the northern area (Nueces County) are geopressed at a shallow depth (7,000 to 9,000 feet) and are thus of considerable interest as a source of geothermal energy. In the central area (Kenedy and Kleberg Counties), on the other hand, the Frio sand percentage is as high as that of the area to the south but the sands are not geopressed. Thus, the central area is not as prospective for geothermal energy in the Frio section. The contrast in prospectiveness be-

tween the southern and central areas relates directly to the depositional origin of the sand bodies. In the southern area, the thick deltaic sands are separated by thick prodelta muds which effectively formed a seal for formation of geopressure (figs. 13 and 21). In the central area, thin strand-plain sands are separated by very thin muds which apparently were not effective seals; thus, geopressure is not maintained and the top of geopressure has been depressed to 10,000 to 12,000 feet (figs. 12 and 21).

The northern high-sand area is on the southern edge of a much thicker, more extensive sand complex developed north of the study area. A better understanding of the depositional system which deposited these sands will be obtained during the study of the regional sand distribution along the central Texas Gulf coast.

Although the results of this study are preliminary, two potential geothermal fairways in the Frio of South Texas have been delineated--a southern area (Hidalgo, Willacy, and Cameron Counties) and a northern area (Nueces County). The next step necessary prior to selection of potential geothermal well sites is the initiation of local, detailed studies. Dense well control, core data, detailed well-history records, and short seismic sections will serve as the data base for the local studies. These studies should result in better correlation of individual sand bodies, more precise definition of depositional systems, and, ultimately, better understanding of the nature of the reservoirs (fig. 25).

Fig. 25. Potential geothermal fairways.

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