PROCEEDINGS

SECOND GEOPRESSURED GEOTHERMAL ENERGY CONFERENCE

VOLUME II

RESOURCE ASSESSMENT

BY

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VOLUME II OF FINAL REPORT

UNITED STATES GULF COAST GEOPRESSURED GEOTHERMAL
RESOURCES MANAGEMENT AND SCOPE-OF-WORK STUDY
FOR GENERATION OF ELECTRIC POWER

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SUBSURFACE TECHNIQUES FOR LOCATING AND EVALUATING GEOPRESSURED GEOTHERMAL RESERVOIRS ALONG THE TEXAS GULF COAST[1]

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PHASE 0

SCOPE-OF-WORK AND MANAGEMENT STUDY

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INTRODUCTION

A potential geothermal reservoir along the Texas Gulf Coast should have a volume of at least three cubic miles (which translates into a cumulative sand thickness of greater than 300 feet and areal extent of 50 square miles), greater than 250°F uncorrected subsurface fluid temperature, and permeability greater than 20 millidarcies. Based on analyses from actual water samples and interpretation from log analysis, deep-subsurface fluids are expected to have salinities lower than 20,000 ppm and perhaps as low as 5,000 ppm (Jones, 1975). Most well reports indicate that the water will be saturated with methane gas.

This report describes techniques being used in the assessment of geopressured geothermal resources along the Texas Gulf Coast and defines geologic procedures for test- or industrial-site selection. These approaches have been proven in petroleum exploration and are applicable in geothermal exploration here in the Gulf basin and in other sedimentary basins.

GULF COAST GEOLOGIC FRAMEWORK

The Tertiary section along the Texas Gulf Coast (fig. 1) comprises a number of off-lapping and basinward-thickening wedges of sand and shale (fig. 2). The thin, updip part of each wedge consists dominantly of shale with thin, discontinuous sand bodies deposited in a fluvial system. Gulfward of the fluvial system is the main sand depocenter characterized by thick sands separated by thick shale sections and deposited in a deltaic system (Holcomb, 1964) or by thin sands separated by thin shales and deposited in a strandplain or barrier-bar system (Boyd and Dyer, 1964). Finally, the downdip part of the wedge is characterized by a thick shale section containing thin, laterally restricted sand bodies deposited in a prodelta or shelf system. An understanding of the general processes which controlled the deposition of these wedges along the Gulf Coast was developed more than 20 years ago by petroleum geologists from outcrop data, micropaleontological studies, and subsurface well logs and was well described in an excellent paper by Deussen and Owen (1939).

Growth faults, which develop from loading along the main sand depocenter (Bruce, 1973), allow abnormally thick sections of sediment to accumulate (fig. 3). The displacement of sand bodies against shales along growth faults contributes to the trapping of fluids within the sediments.

At least eight sand/shale wedges are easily recognized on regional electrical-log cross sections (figs. 4-10). Hardin (1961) illustrated the major wedges as the Midway/Wilcox, Reklaw/Queen City, Weches/Sparta, Cook Mountain/Yegua, Jackson, Vicksburg, Frio, and Anahuac/Fleming. The Pliocene and Pleistocene comprise additional cycles but are undifferentiated in this study because of lack of control. These cycles reflect changes in the ancient shoreline resulting from variations in sediment supply, rate of subsidence, and position of sea level. In general, in the updip end of the wedge the main sand depocenter is in the lower part of the section and downdip it is progressively higher in the section, thus describing a progradational cycle.

When basinward progradation was far enough that sand facies of a later wedge migrated Gulfward over the soft, earlier-deposited offshore-mud facies of the previous wedge, large growth faults developed (Bruce, 1973). However, in each of these wedges the main sand depocenter is rarely

CENOZOIC – TEXAS GULF COAST

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

Figure 1. Tertiary formations--Gulf Coast of Texas. The Frio Formation is shown in the dot pattern.

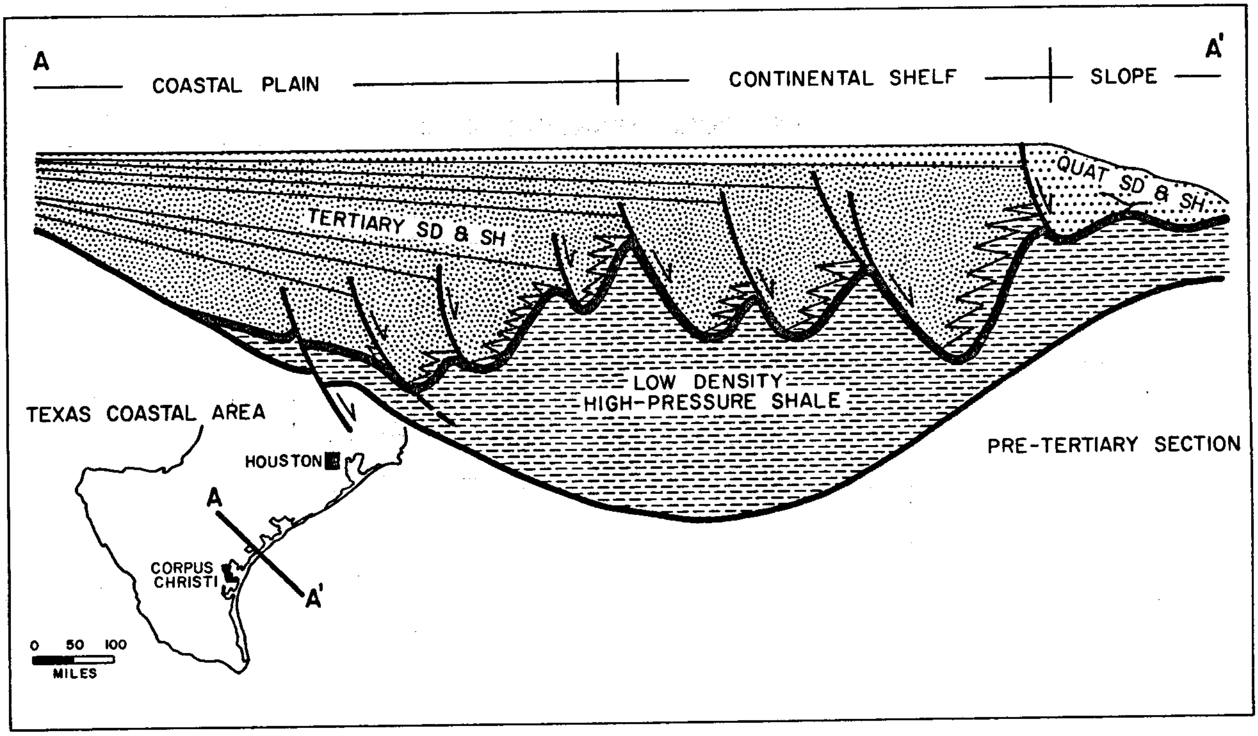

Figure 2. Depositional style of the Tertiary along the Texas Gulf Coast (Bruce, 1973).

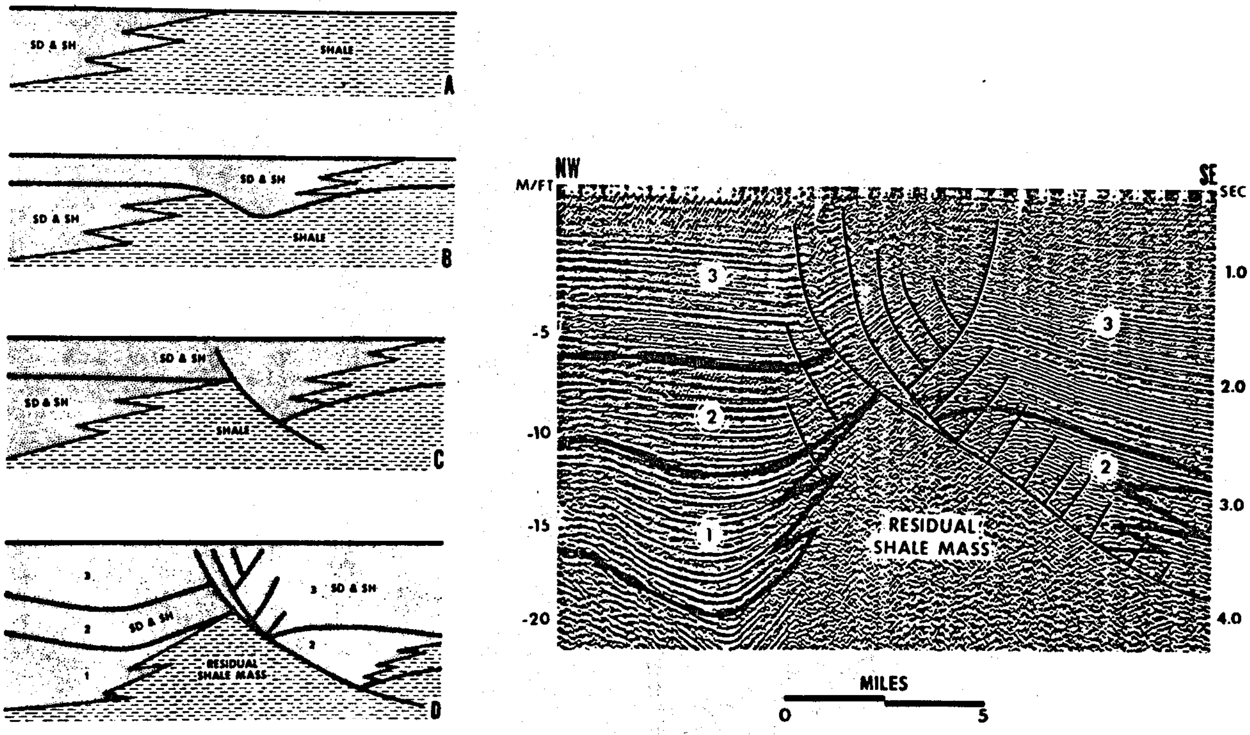

Figure 3. Growth fault development interpreted from a seismic section and shown sequentially by diagrams (from Bruce, 1973).

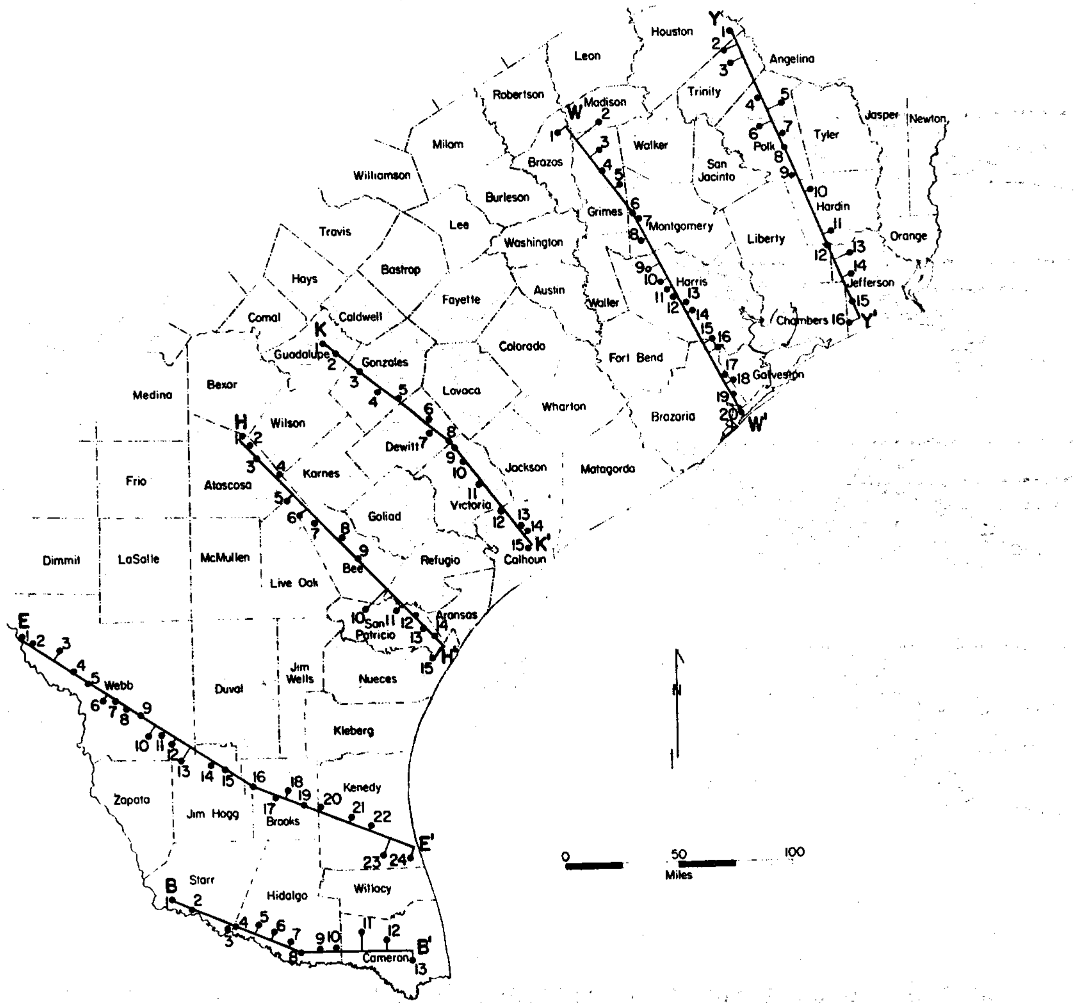

Figure 4. Index to regional cross sections.

Figures 5 - 10 are on the following fold-out pages.

Figure 5. Regional cross section HH'. The top of geopressure is indicated by the arrow on the left side of each well log. Areas within the geopressured zone which contain or are believed to contain significant thickness of sand are shown by the dot pattern. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns. The wells used in this cross section are identified in Table 1.

Figure 6. Regional cross section EE'. The top of geopressure is indicated by the arrow on the left side of each well log. Areas within the geopressured zone shich contain or are believed to contain significant thickness of sand are shown by the dot pattern. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns. The wells used in this cross section are identified in Table 1.

Figure 7. Regional cross section HH'. The top of geopressure is indicated by the arrow on the left side of each well log. Areas within the geopressured zone which contain or are believed to contain significant thickness of sand are shown by the dot pattern. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns. The wells used in this cross section are identified in Table 1.

Figure 8. Regional cross section KK'. The top of geopressure is indicated by the arrow on the left side of each well log. Areas within the geopressured zone which contain or are believed to contain significant thickness of sand are shown by the dot pattern. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns. The wells used in this cross section are identified in Table 1.

Figure 9. Regional cross section WW'. The top of geopressure is indicated by the arrow on the left side of each well log. Areas within the geopressured zone which contain or are believed to contain significant thickness of sand are shown by the dot pattern. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns. The wells used in this cross section are identified in Table 1.

Figure 10. Regional cross section YY'. The top of geopressure is indicated by the arrow on the left side of each well log. Areas within the geopressured zone which contain or are believed to contain significant thickness of sand are shown by the dot pattern. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns. The wells used in this cross section are identified in Table 1.

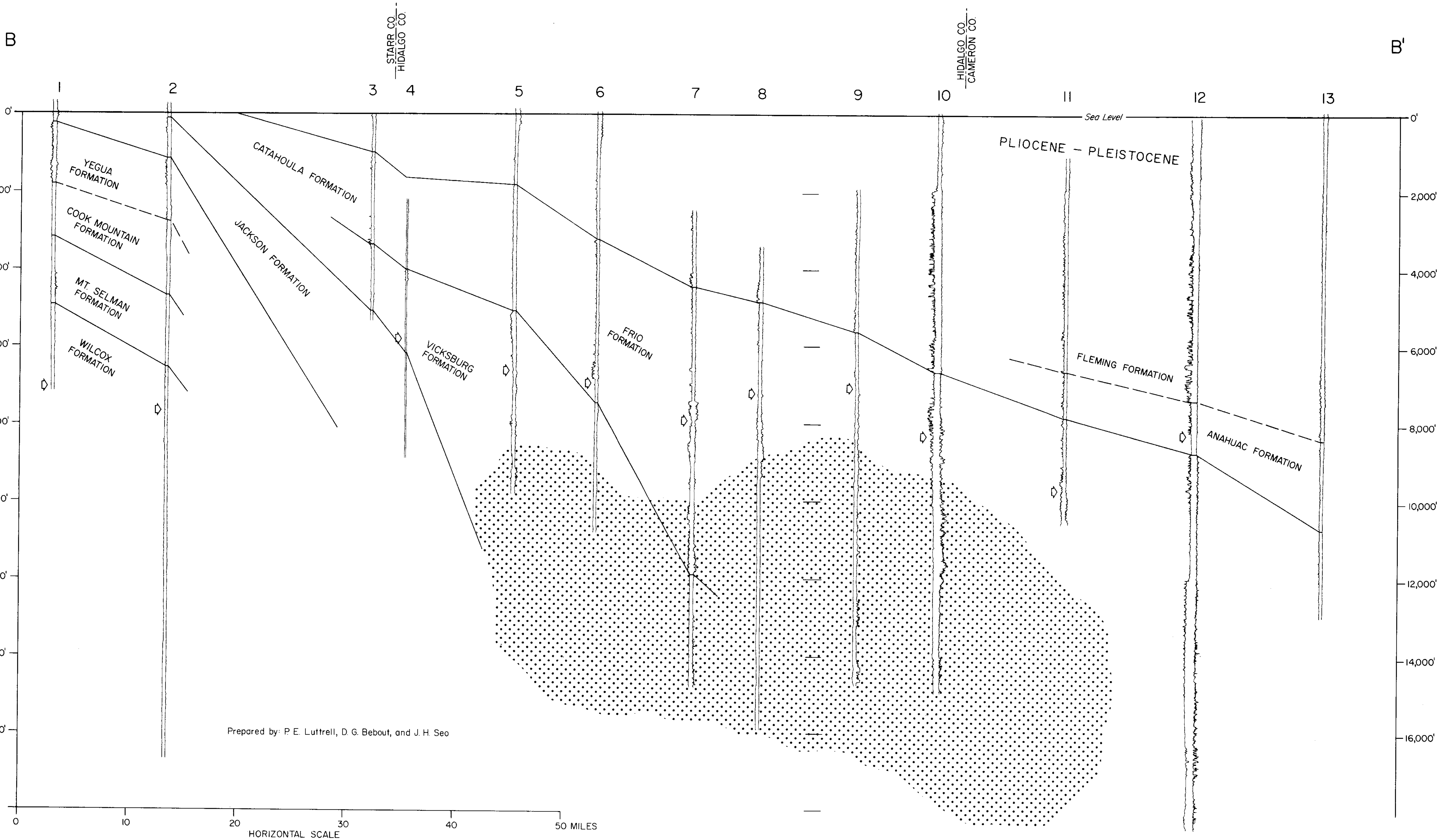

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Figure 5.

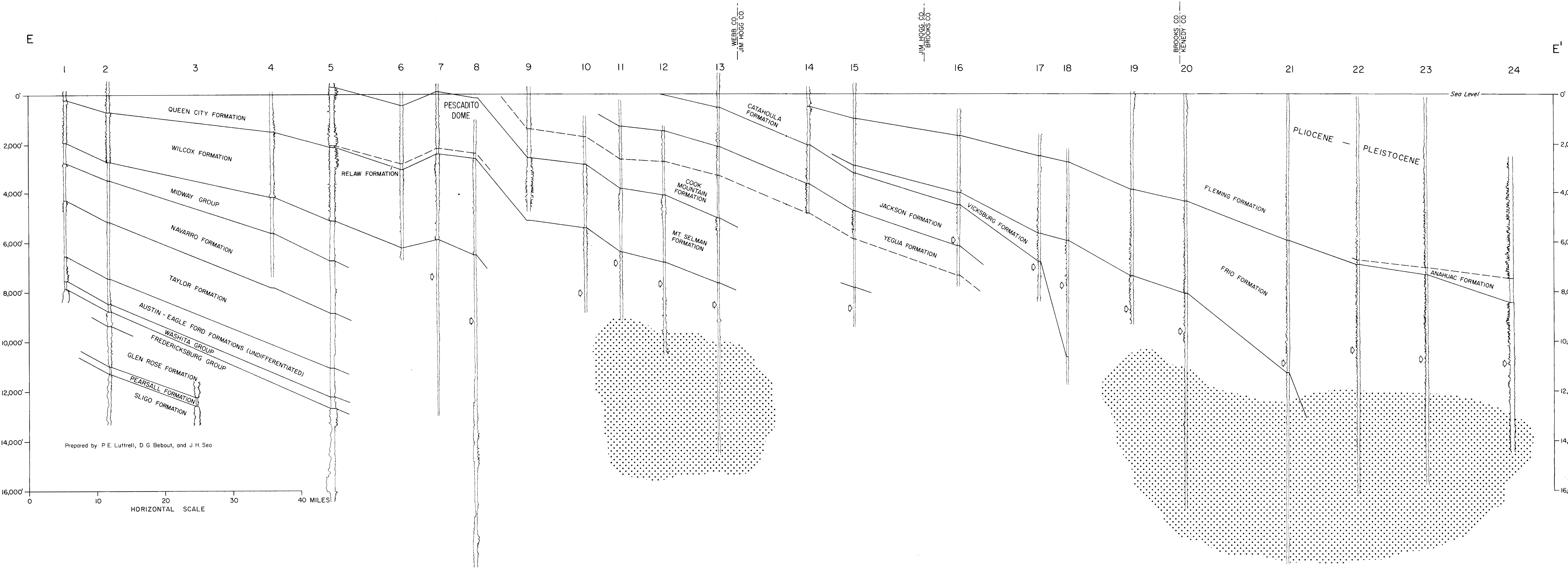

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Figure 6.

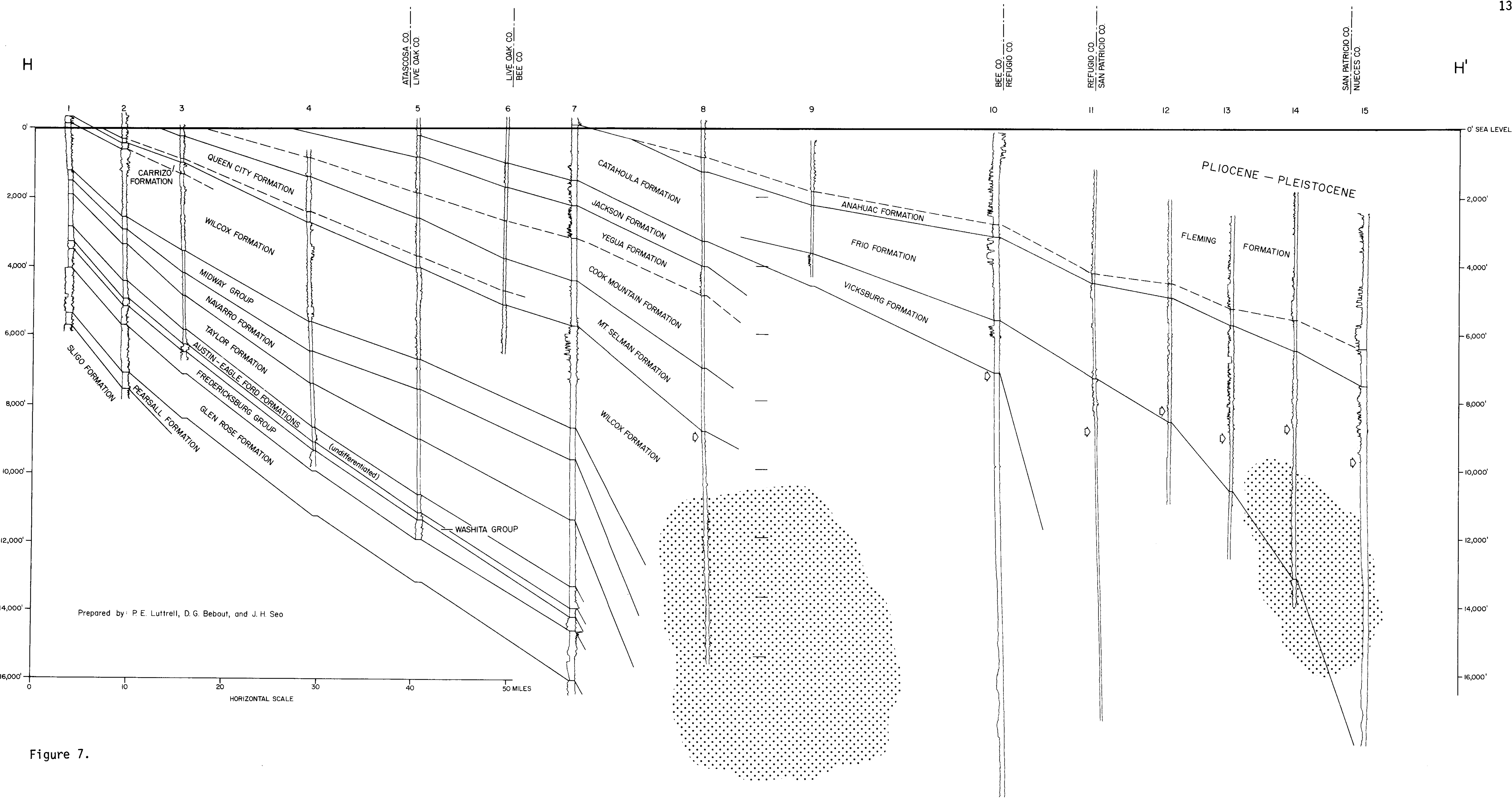

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Figure 7.

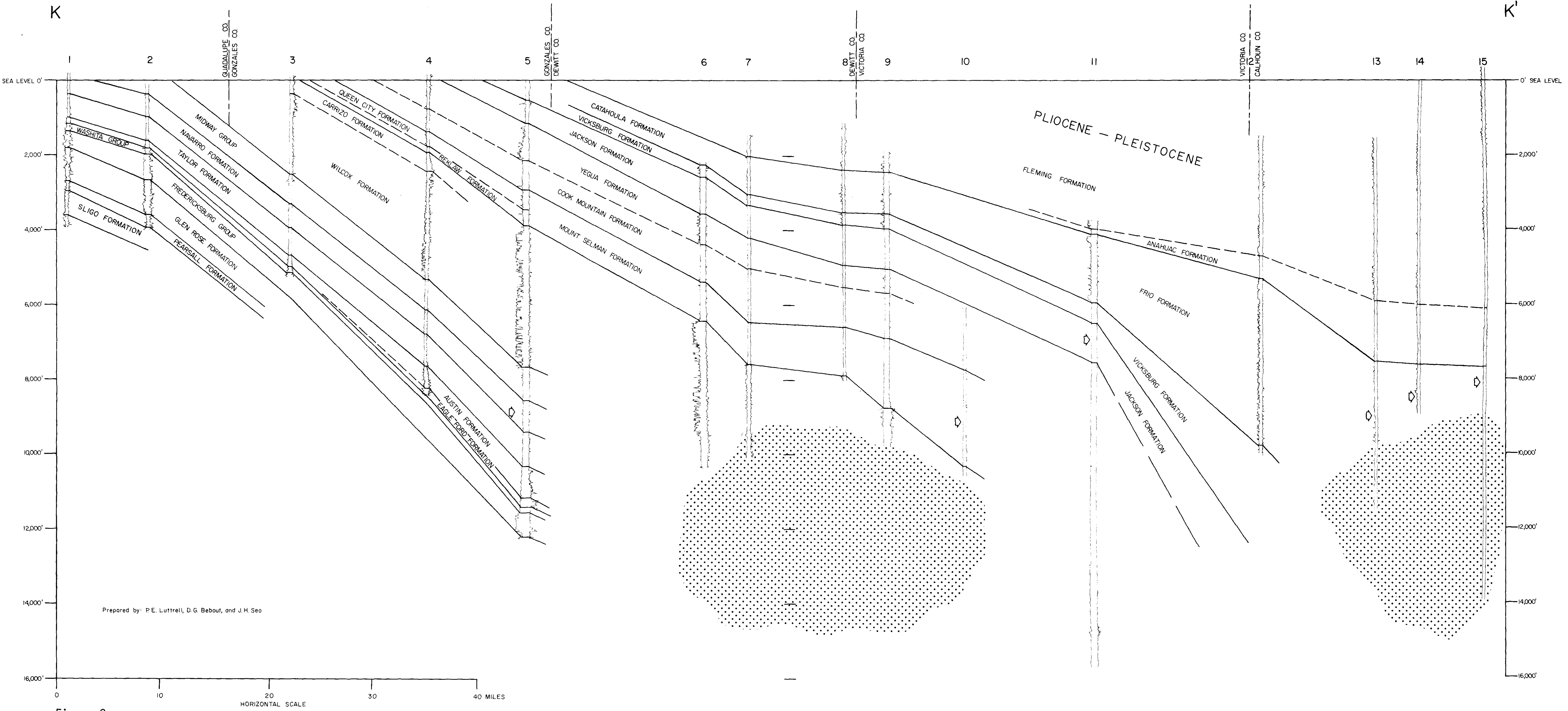

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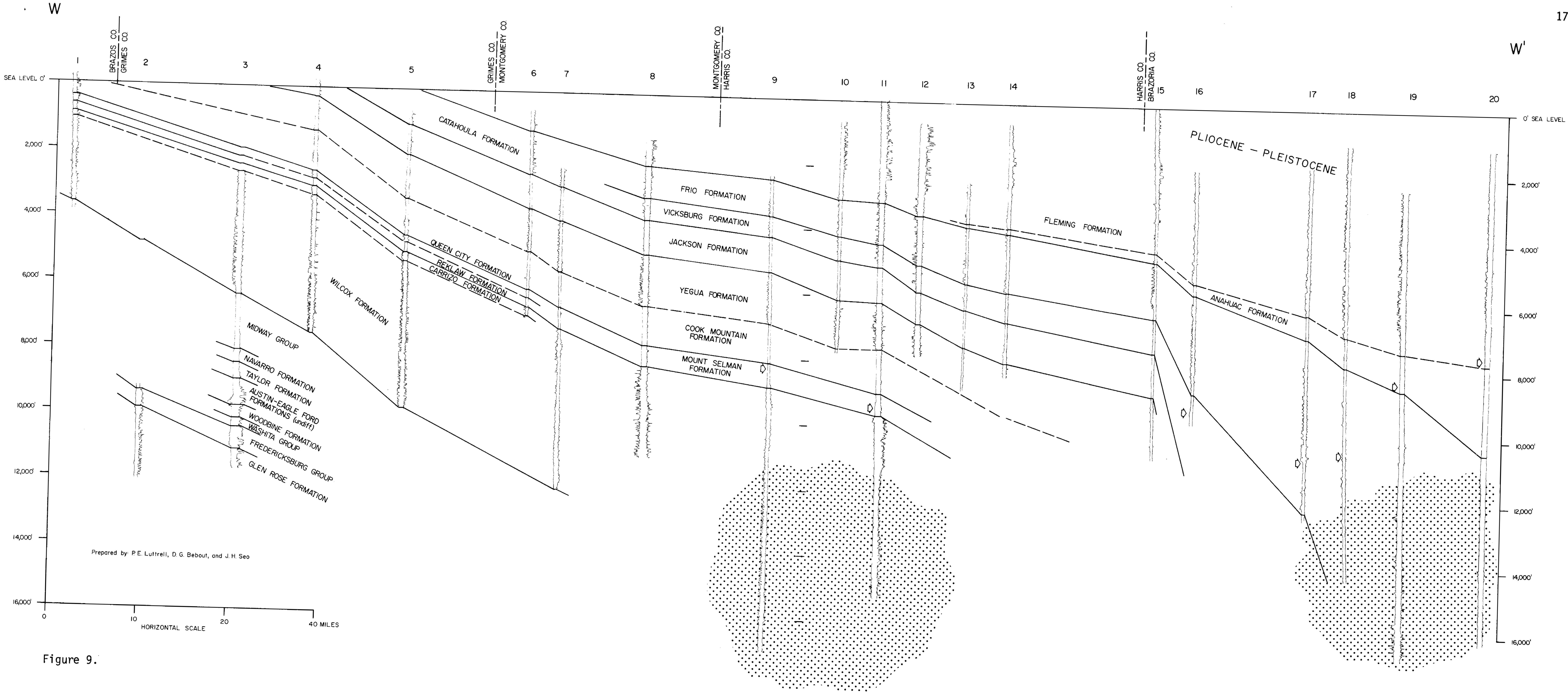
Figure 8.


W
W'
BRAZOS CO
GRIMES CO
GRIMES CO
MONTGOMERY CO
MONTGOMERY CO
HARRIS CO
HARRIS CO
BRAZORIA CO
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
SEA LEVEL 0'
2,000'
4,000'
6,000'
8,000'
10,000'
12,000'
14,000'
16,000'
0' SEA LEVEL
2,000'
4,000'
6,000'
8,000'
10,000'
12,000'
14,000'
16,000'
PLIOCENE – PLEISTOCENE
CATAHOULA FORMATION
FRIO FORMATION
VICKSBURG FORMATION
JACKSON FORMATION
YEGUA FORMATION
COOK MOUNTAIN FORMATION
MOUNT SELMAN FORMATION
FLEMING FORMATION
ANAHUAC FORMATION
QUEEN CITY FORMATION
REKLAW FORMATION
CARRIZO FORMATION
WILCOX FORMATION
MIDWAY GROUP
NAVARRO FORMATION
TAYLOR FORMATION
AUSTIN-EAGLE FORD FORMATIONS (undiff)
WOODBINE FORMATION
WASHITA GROUP
FREDERICKSBURG GROUP
GLEN ROSE FORMATION
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0
10
20
40 MILES
HORIZONTAL SCALE

Figure 9.

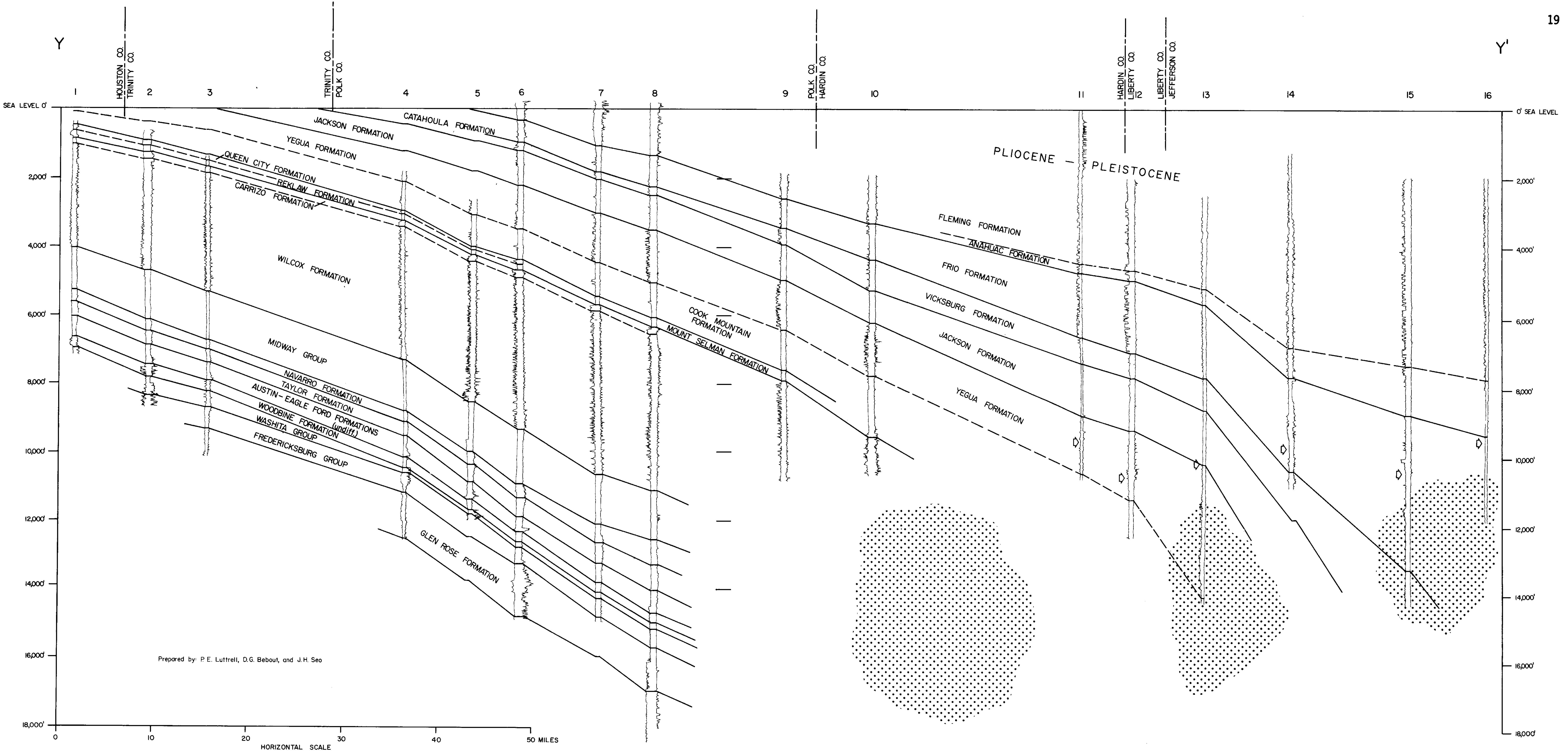

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Figure 10.

Table 1. List of Wells.

BB'

1.	Atlantic Refg. Co.	Tomas Saenz #1
2.	Shell Oil Co.	H. W. Lehman #1
3.	Sun Oil Co.	Reilly #1-A
4.	Phillips Petr. Co.	N. Flores #1
5.	Humble Oil Co.	Texan Devel. Co. #1
6.	Continental Oil Co.	M. L. Talbot #1
7.	Tenneco Oil Co.	McAllen Field Wide Unit #36
8.	Sinclair Oil & Gas Co.	Houston Unit #2
9.	La Gloria Corp.	South Weslaco Gas Unit #10
10.	Shell Oil Co.	W. H. Drawe #1
11.	Harkins & Mosbacher	Leona Rohman #1
12.	Chevron Oil Co.	Jose A. Rodriguez #1
13.	Dow Chemical Co.	Continental Oil Co. Mineral Fee #1

EE'

1.	Copano Oil Co. et al.	Apache Ranch #A-1
2.	Copano Oil Co. et al.	Palafox Exploration Co. #A-1
3.	Pan American Petr. Corp.	Sophie Martin #1
4.	Tejas Gas Corp. & Vanderbilt Resources Corp.	Ben F. Vaughan, Jr. #1
5.	Lamar Hunt	Reuthinger #1
6.	Exsun Oil Corp.	Killam & Hurd, Ltd. #1
7.	Ginther, Warren & Ginther, Gulf & Halbouty	O. W. Killam #1-A
8.	Humble Oil Co.	Carlos Y. Benavides #1
9.	O. W. Killam	Killam #1
10.	Skelly Oil Co.	J. C. Martin #6
11.	Texaco, Inc.	O. G. De Da Camara #28
12.	Atlantic Refg. Co.	E. Garcia #1
13.	Atlantic Richfield	Marrs McLean #3-C
14.	Northern Pump Co.	Silver Lake Ranch #1
15.	Humble Oil Co.	Mestena #1-D
16.	McGuire	Saunders #1
17.	Humble	C. F. Hopper #2
18.	Forest Oil Co.	Ed Rachal Foundation #1
19.	Humble Oil Co.	R. J. Kleberg, Jr. #7
20.	Humble Oil Co.	Mrs. S. K. East #22
21.	Humble Oil Co.	Charles M. Armstrong #20
22.	Humble Oil Co.	Mrs. S. K. East #1-G
23.	Humble Oil Co.	King Ranch-Tio Moya #2
24.	Gulf Oil Corp.	State Tract #427 #1

HH'

1.	Alvin C. Hope	Francis Korus #1
2.	Petro Tex, Inc.	Pedro Garcia, Jr. #1
3.	Sorelle & Sorelle	D. D. Heinen #1
4.	Carrl Oil & Dan Auld	Tom Campbell #1
5.	Stewart Petr. Co.	McIlvaine et al. #1
6.	Hewit & Dougherty	Cleo Dubose #1
7.	Shell Oil Co.	Juan Alvarado et al. #1
8.	Atlantic Richfield Co.	J. R. Dougherty Est. #1
9.	Hancock & Young	Klipstein #1
10.	Amerada Petr. Corp.	Bernice Stalcup #1
11.	The Superior Co.	Minnie S. Welder #27
12.	McCulloch	Boehm #1
13.	Hamon	Harvey #3
14.	Tenneco Oil Co.	McCampbell #1
15.	Pel-Tex Petr. Co.	Ima Hogg #1

KK'

1.	Cecil Hagen	Calvert #1
2.	Sutton Prod. Co.	Ida Weinaug #1
3.	Lecuno Oil Corp.	M. K. Towns #1
4.	Humble Oil & Rfg.	Allie Barnett #1
5.	H. L. Hunt	E. M. Stoeltje #1
6.	Avalanche Jour. Publ. Co.	P. S. Rittner #1
7.	W. L. Sinclair, Coastal States Gas Prod. Co., & Greenbriar, Ltd.	Stiles Cattle Co., Inc. #1
8.	Shell	Gohlke Heirs #4-A
9.	The Texas Co.	Gonzales #1
10.	Skelly Oil Co.	Welder-Cliburn #1
11.	Amerada Petr. Co.	Allan Kovar #1
12.	Lone Star Prod. Co.	L. J. Foester #1-A
13.	Coastal States Gas Prod. Co. & Royal Resources	Duncan #1
14.	Alcoa Mining Co. & Southern Prod. Co.	Melbourn #1-C
15.	Walter Van Norman	Powderhorn #1

WW'

1.	Mudge Oil Co.	Koppe #1
2.	Pure Oil Co.	Hendrix #1
3.	Gulf Oil Corp.	Fannie Upchurch #1
4.	The Texas Co.	J. W. Harris #1
5.	Placid Oil Co.	Thomas #1
6.	Petroleum Management Co.	Jones & Shands #1
7.	Sinclair Oil & Gas Co.	Martin Estate #1
8.	Steve Gose	Katherine K. Kramer #1
9.	Texaco, Inc.	H. H. Mergele #1
10.	Oil Properties Inc.	Anna M. Gaylor #1
11.	Pan American Petr. Corp.	Dorothy D. Brown #1
12.	Carl Casey	R. H. Autrey #1
13.	Jack Frazier	Lackner #1
14.	Curry B. Davis & Co.	Susholts-Ziebe Co. #1
15.	Gulf Coast Leaseholds, Inc.	G. Y. Hastings Unit #1
16.	Gulf Coast Leaseholds, Inc.	Yost #1
17.	Superior Oil Co.	Conklin Oil Unit #1
18.	The Texas Co.	J. W. Harris #1B
19.	Phillips Petr. Co.	Houston "JJ" #1
20.	Phillips Petr. Co.	State Lease 51000, Block 32 #1

YY'

1.	Pulaski & Bock	Alpha Musick #1
2.	Associated Oil & Gas Exploration, Inc.	J. T. Kee #1
3.	Continental Oil Co.	R. E. Holcombe #1
4.	American Liberty Oil Co. & Webb & Knapp	Cameron Heirs #1
5.	Wainoco	Carter Bros. #1
6.	Shell Oil Co.	E. E. Alexander #1
7.	Shell Oil Co.	Southland Paper Mills #2
8.	Hassie Hunt Trust	Wirt Davis #1
9.	Oil Reserves Corp.	W. T. Carter #1
10.	International Nuclear Corp.	Harris #1
11.	Sun Oil Co.	Dishman-Lucas #1
12.	Sun Oil Co.	Stone #2
13.	Texaco, Inc.	P. B. Leger #1
14.	Deep South Oil Co. of Texas	Aldridge #1
15.	Belco Petroleum Corp.	Crawford 161 #2
16.	Sun Oil Co.	J. T. White "B" #1

geopressured and only the more seaward-reaching sand bodies are prospective as geothermal reservoirs. These sand bodies thus occur at greater depths and are enveloped by thick shale sections. Three Tertiary wedges prograded in this manner and were found to contain significant thickness of sand within the geopressured zone--the Wilcox, Vicksburg, and Frio Formations (figs. 4-10).

From the cross sections shown here (figs. 4-10) and published cross sections (Corpus Christi Geological Society, 1954-1955, 1964; Deussen and Owen, 1939; Houston Geological Society, 1954, 1972; and South Texas Geological Society, 1951), parts of select wedges can be readily outlined which do or are expected to contain thick sand bodies deeper than 10,000 feet below sea level in the geopressured zone. On the cross sections which show little or no control in the geopressured zone the prospective areas were outlined using other nearby sections. By plotting these prospective areas on a map, broad corridors expected to contain geothermal fairways are delineated (fig. 11). The inland-most corridor is that of the Wilcox Formation which extends from eastern Zapata and western Starr Counties on the south to southern Jasper and Newton Counties on the northeast. The band along the present-day Gulf Coast is the Frio corridor which extends from Hidalgo and western Cameron Counties on the south to southern Jefferson County on the northeast. The Vicksburg corridor is in two parts: the southern part overlaps with the Frio corridor in Hidalgo, western Cameron and Willacy Counties, and southwestern Kenedy County, and the northeastern part occurs between the Wilcox and Frio corridors from southern Harris County on the south to northern Orange and southern Newton Counties on the north.

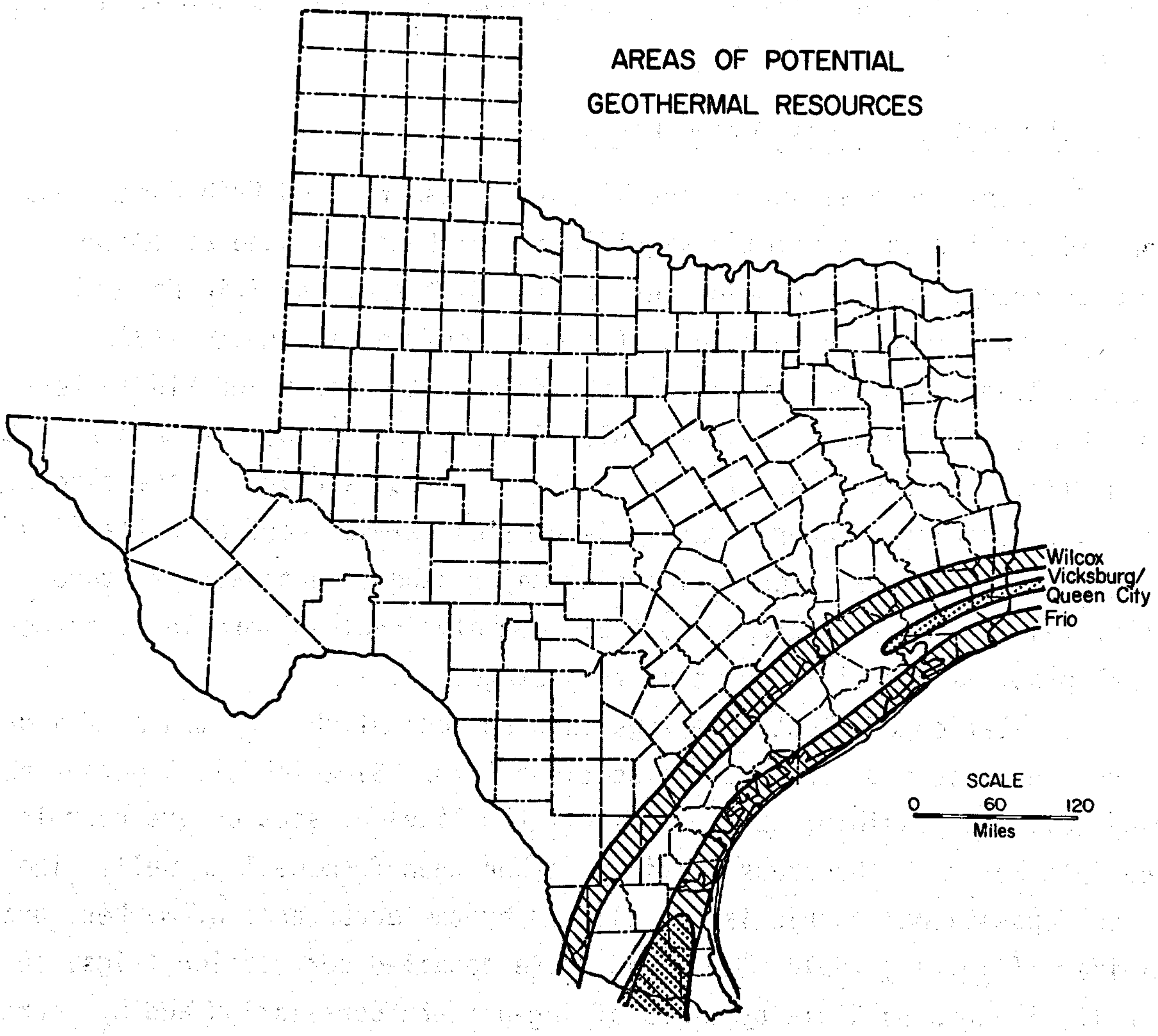

Figure 11. Geothermal corridors of potential fairways.

SUBSURFACE TECHNIQUES FOR LOCATING GEOPRESSURED GEOTHERMAL RESERVOIRS (Table 2)

Regional Statewide Survey.

Broad corridors which can be expected to contain geothermal fairways are outlined by regional electrical-log cross sections constructed on a sea-level datum (figs. 4-10). The significance of these sections was discussed in an earlier section.

Regional Studies of Prospective Formations.

From the regional survey the Wilcox, Vicksburg, and Frio Formations were identified as containing significant thickness of sand at depths greater than 10,000 feet below sea level. Of these, the Frio Formation (fig. 1) has already been studied (Bebout, Dorfman, and Agagu, 1975; Bebout, Agagu, and Dorfman, 1975); the Frio of the Lower and Middle Texas Gulf Coast will be used as an example of a regional study for this report (fig. 12). The basic tool for regional subsurface studies is the electrical log. Spacing of approximately 5-10 miles between control wells (fig. 13) was found adequate for delineating major sand trends and structure (fig. 14). The use of closer control commonly involves more local structural problems not significant at this stage.

Correlation of electrical logs is best accomplished by means of a grid of regional dip and strike cross sections (fig. 13) which tie together as many wells as possible; then, wells off the lines of section are correlated into wells on the cross sections rather than from well to well. The gross depositional fabric is established by the occurrence of marker foraminifers (fig. 15) (Holcomb, 1964). More detailed correlation (figs. 16 and 17) is then possible by means of log-pattern correlation and by correlating major shale units (figs. 16 and 17). A knowledge of depositional patterns expected from various environments is useful at this stage. These correlation units which are bounded by "T" markers are the basic mapping units for all sand maps constructed later. In addition, top of geopressure (discussed later) and bottom-hole temperatures (from all logging runs) are recorded on these work sections.

Sand-percent and net-sand maps of each unit (fig. 18) show the areal

Table 2. Subsurface Techniques for Locating Geopressured Geothermal Reservoirs.

Activity	Application of Data
Regional Statewide Survey	
Locate regional geothermal corridors	Regional electrical-log cross sections of the entire Tertiary section constructed using deepest penetrating wells aid in locating broad areas in which sands are expected to occur in the geopressured zone.
Regional Study of Specific Formation	
Well-log acquisition	Electrical logs are primary data source. Well spacing of 5-10 miles between wells is adequate for regional study.
Gross Correlation	
Correlation on formation cross section	The correlation fabric is established largely on micropaleontology and knowledge concerning location of major growth faults. Then well-log pattern correlation is used locally, aided by knowledge of sediment distribution of various depositional environments. Regional seismic lines aid at this stage.
Map construction	Sand-percent and net-sand maps constructed from correlation units on formation cross sections. Isothermal maps from bottom-hole temperatures recorded on well-log headings. Top of geopressure calculated from well-log data.
Geothermal fairway	Based on the combination of sand, isothermal, and top-of-geopressure maps.
Fairway Study	
Detailed fairway studies	Detailed mapping of the reservoir interval using electrical logs from closely spaced wells. Incorporation or porosity-permeability data into the geologic model.
Site Selection	
Selection of geothermal well site	With a grid of dip and strike seismic sections correlate major events across prospective areas in order to understand structural configuration. With detailed velocity studies tie lithology from electrical-log sections into seismic sections. Using porosity-permeability, reservoir configuration, subsurface pressure and temperature, apply site-specific reservoir data to the reservoir-simulation model in order to estimate potential production capability.

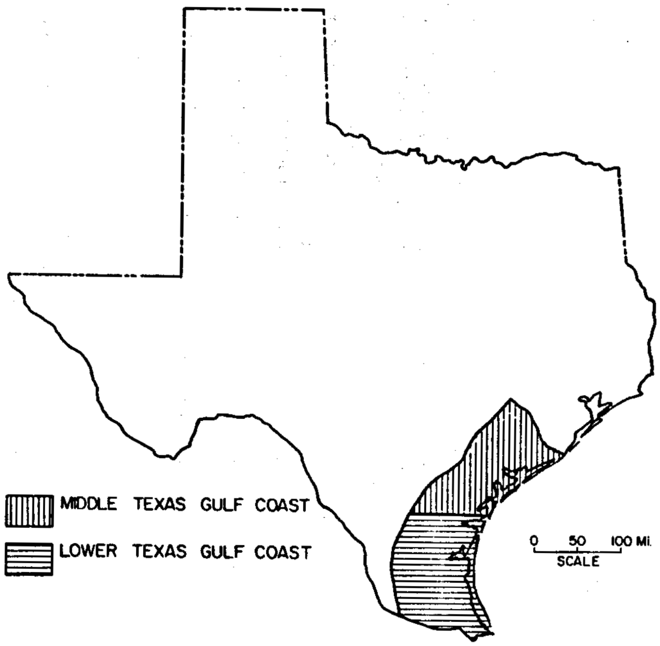

Figure 12. Lower and Middle Texas Gulf Coast study areas.

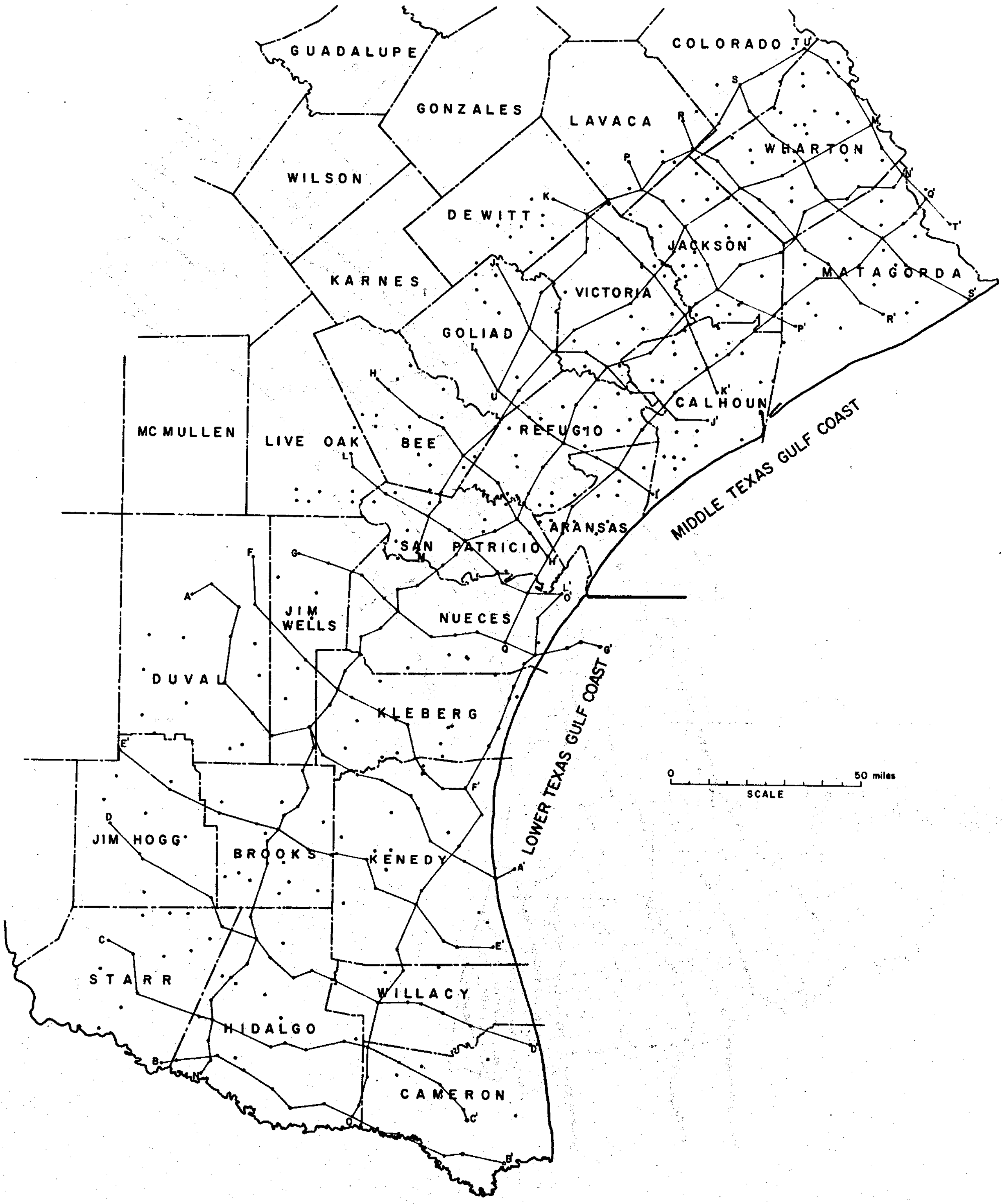

Figure 13. Well-log control and cross sections constructed for Lower and Middle Texas Gulf Coast studies.

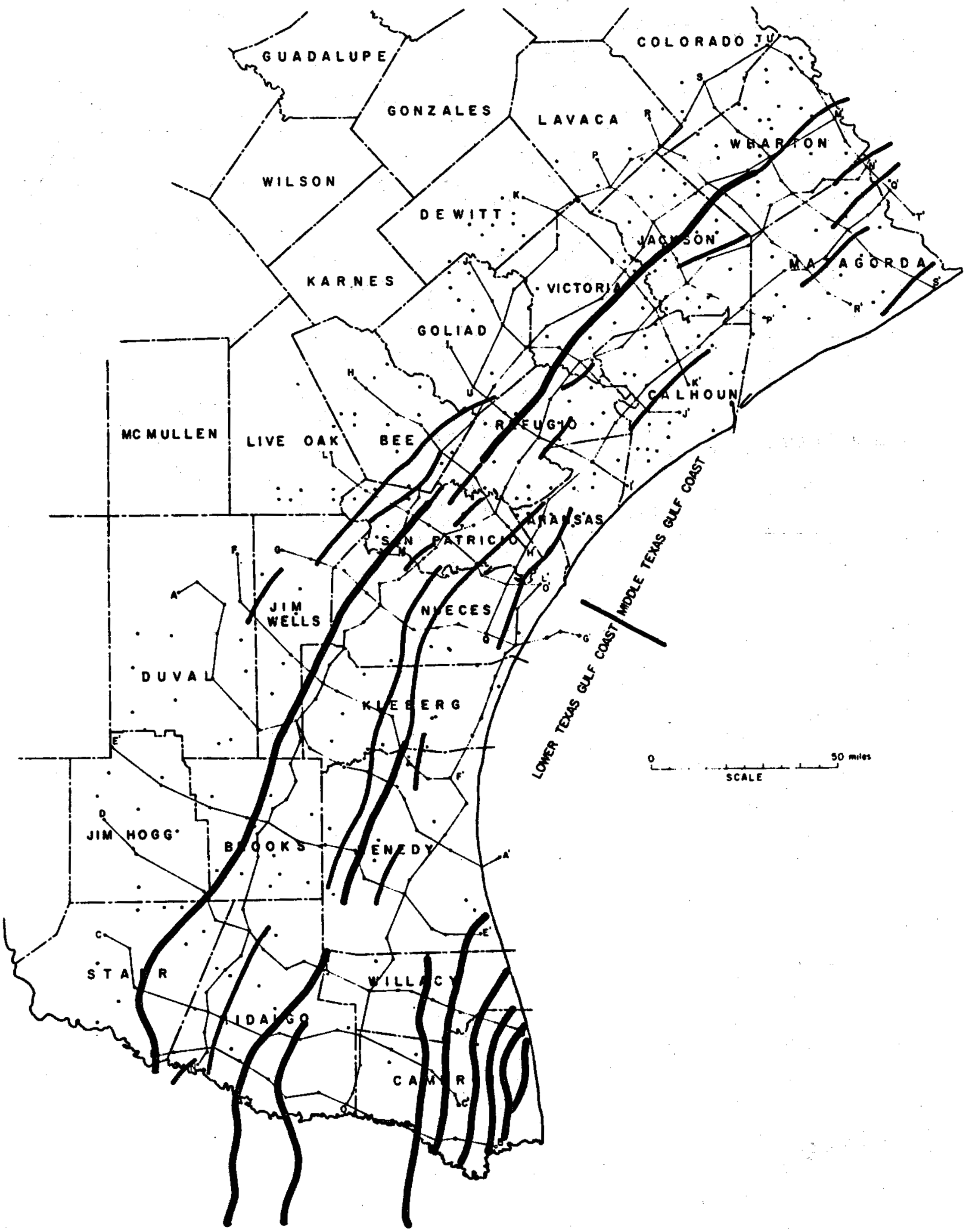

Figure 14. Major growth faults along the Lower and Middle Texas Gulf Coast.

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

Figure 15. Foraminifer zonation, Oligocene and Miocene of the Texas Gulf Coast.

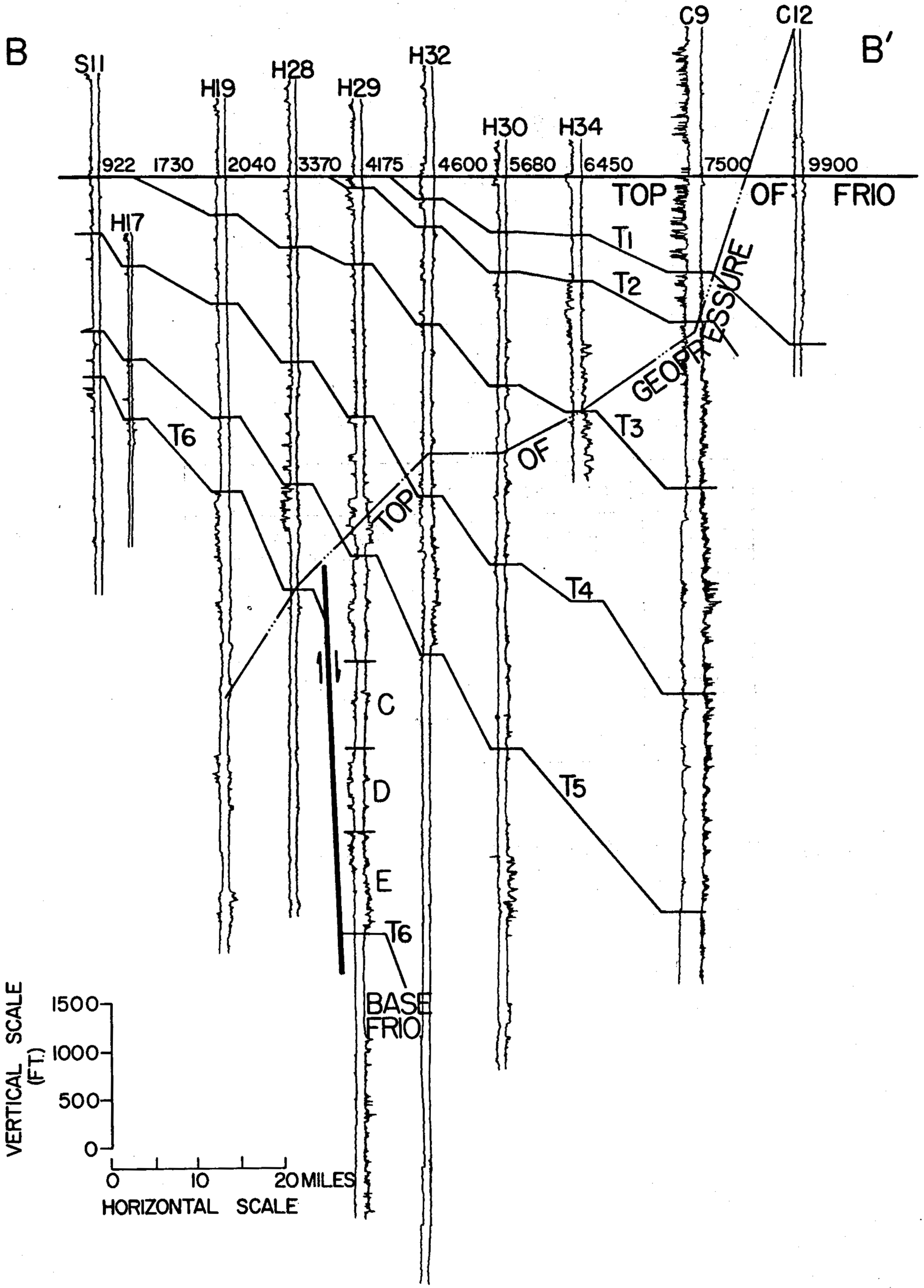

Figure 16. Correlation cross section BB'. "T" correlation lines subdivide the Frio into six mapping units.

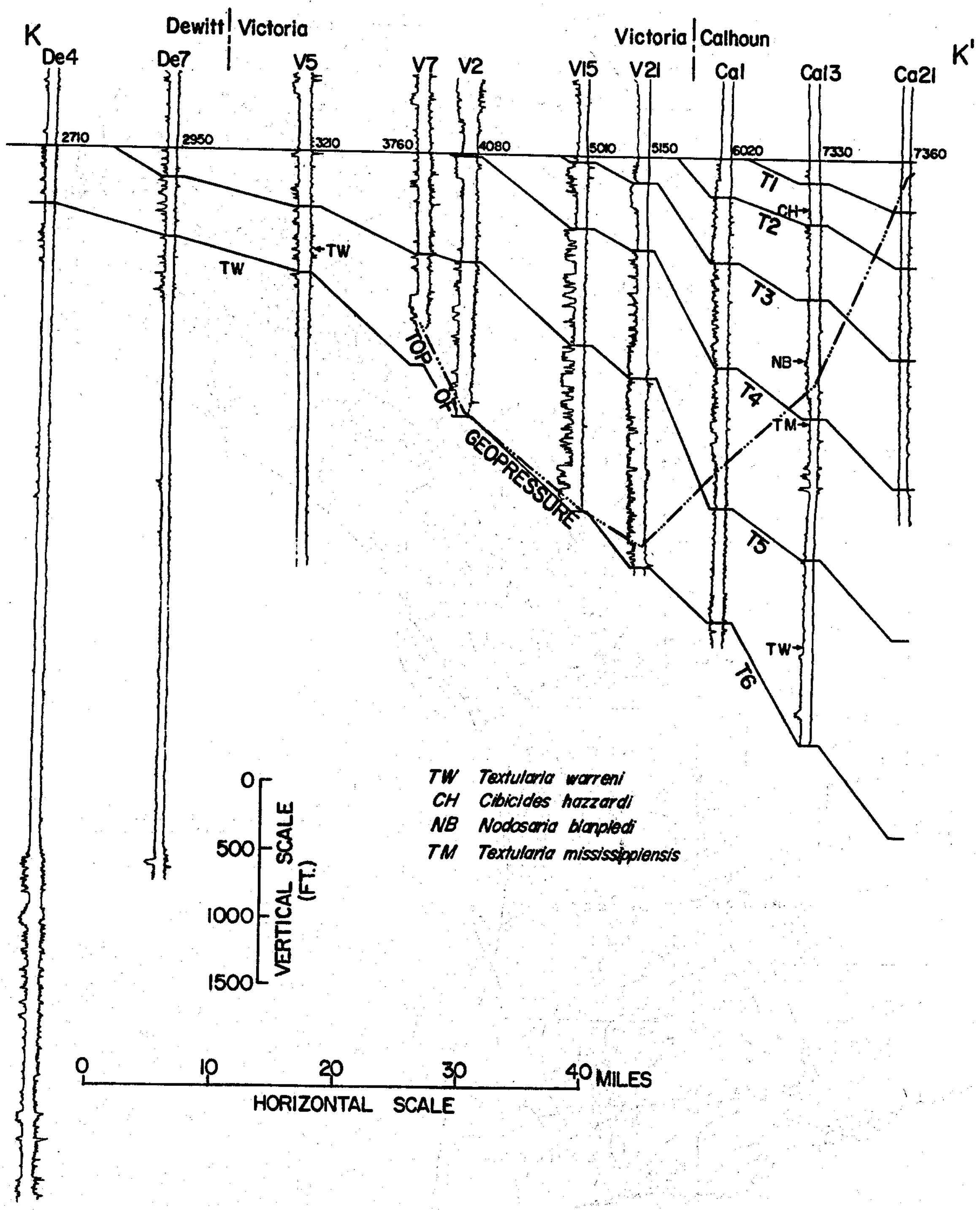

Figure 17. Correlation cross section KK'. "T" correlation lines subdivide the Frio into six mapping units. Occurrence of marker foraminifers is also shown.

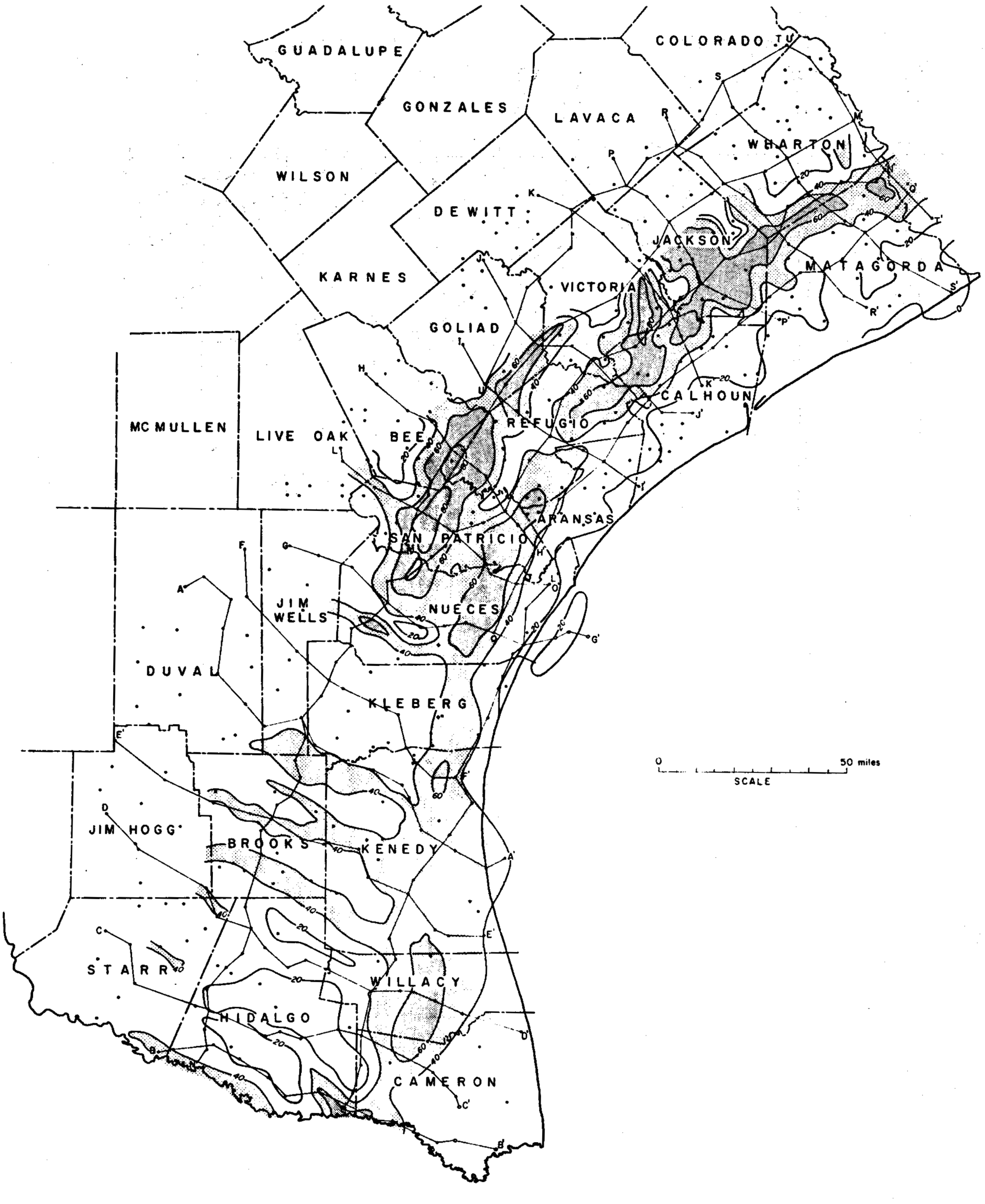

Figure 18. Sand-percent map of unit T3-T4.

distribution of sand in relatively thin depositional wedges and are considerably more meaningful than maps of the distribution of sand from the entire formation.

The top of geopressure is calculated from well-log data. The criteria used are increase in drilling-mud weight above 13.5 lbs/gal, gradual reduction in the negative self-potential deflection, reduction in the density and resistivity of the shale, and location of intermediate casing point (Bebout, Dorfman, and Agagu, 1975; Bebout, Agagu, and Dorfman, 1975). The top-of-geopressure map shows an irregular surface which in Lower Texas lies between 5,000 to 13,000 feet and in Middle Texas, between 7,000 to 9,000 feet below sea level (fig. 19). Fluid temperatures at this level are commonly between 180-200°F, considerably lower than that sought as a source of geothermal energy. Consequently, the top of geopressure as an exploration tool defines a surface which lies about 2,000 feet above reservoirs with acceptable fluid temperatures of greater than 250°F. Regional irregularities in depth to top of geopressure seem most related to distribution of the sand depocenters; the top of geopressure is deeper in areas of high sand and shallower in dominantly shale areas. In the Frio Formation, the main sand depocenter is shallower than the top of geopressure along the Texas Gulf Coast.

Bottom-hole temperature is recorded on each logging run of wells drilled along the Gulf Coast. Because deep wells commonly have several runs, temperatures are often available at various depths and are recorded on the well-log heading. The temperatures recorded in this manner are uncorrected and because they are not measured under stable-hole conditions, they are expected to be slightly lower than the actual subsurface temperature. Isothermal maps of correlation units (fig. 20) show an increase in temperature downdip within each unit, an increase in the gradient at approximately the 200°F isotherm equivalent to the top of geopressure, and fluid temperature within the main sand depocenter lower than 200°F. Fluid temperatures greater than 250°F occur in sands within the prodelta and shelf environments except in Hidalgo and Cameron Counties where distal parts of the deltaic lobes have fluid temperatures higher than 250°F.

Geothermal fairways within each correlation unit are outlined by combining the sand distribution, from the sand-percent and net-sand maps, and

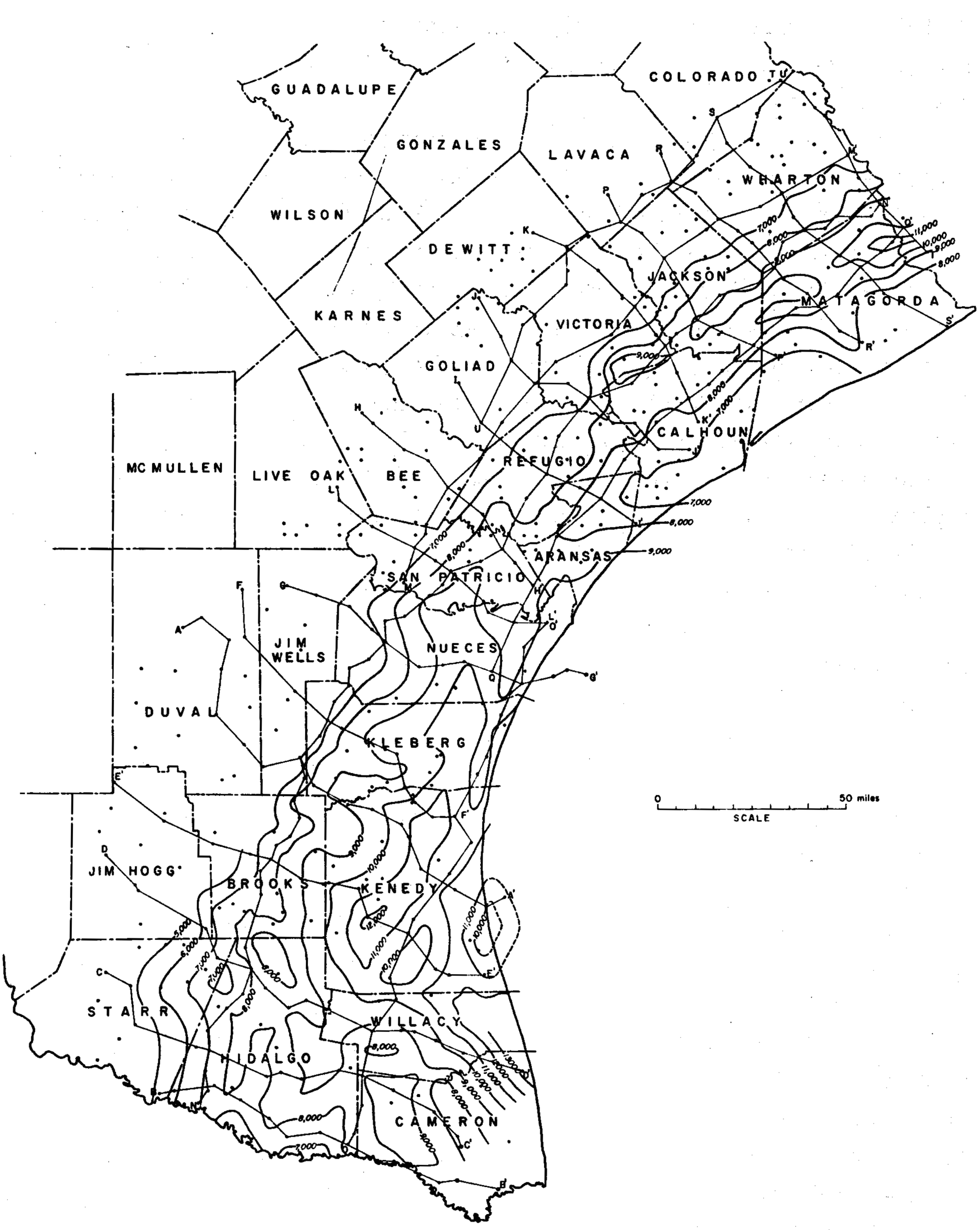

Figure 19. Top of geopressure along the Lower and Middle Texas Gulf Coast.

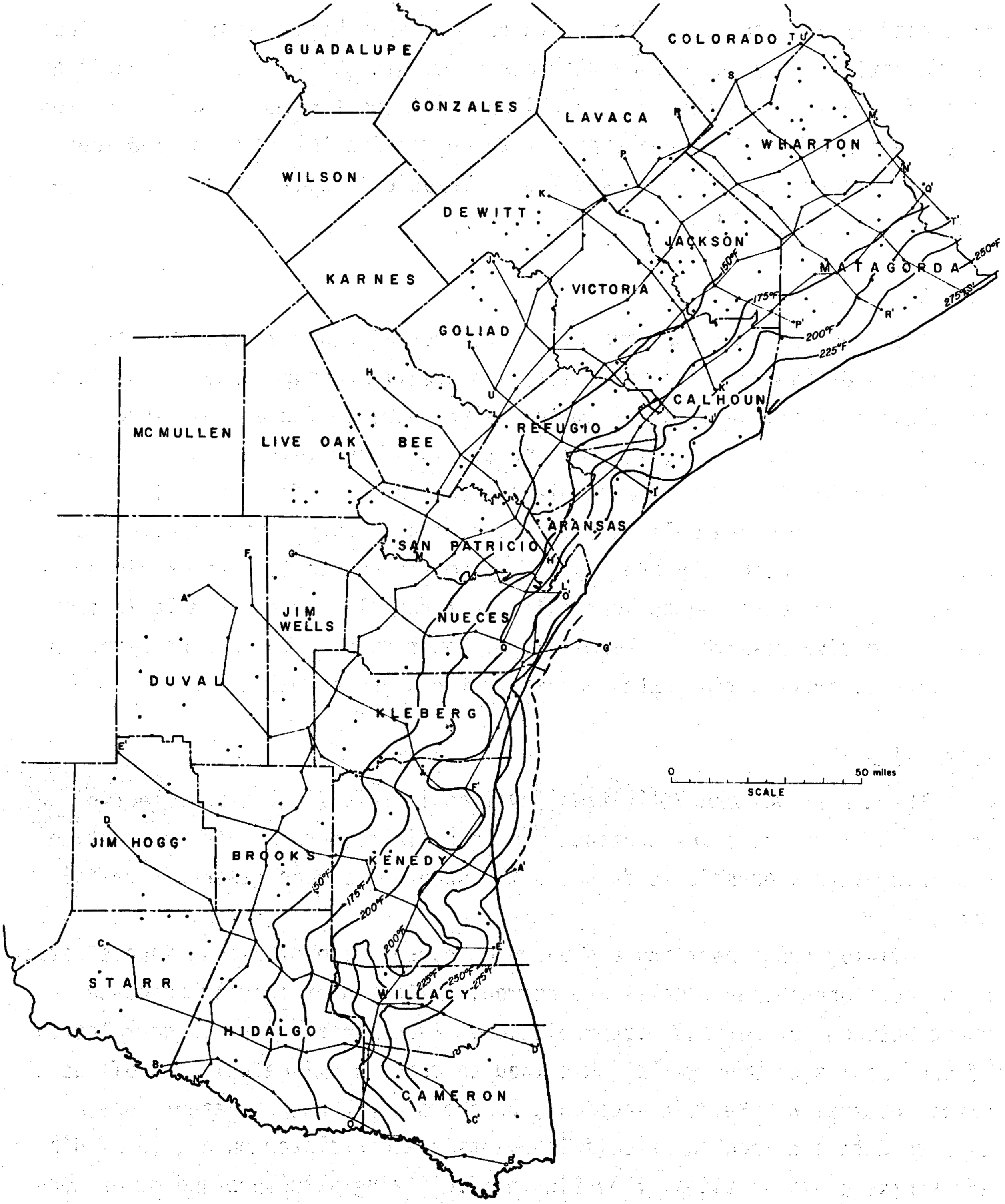

Figure 20. Isothermal map of unit T3-T4.

temperature distribution, from the isothermal maps. Thus, the fairways are high-sand areas with subsurface fluid temperatures higher than 250°F. Then, reexamination of the sand-body thicknesses within these fairways identifies those fairways with adequate sand thickness of greater than 300 feet or two or three closely spaced sand bodies with cumulative thickness of 300 feet. Several fairways in the Lower and Middle Texas Gulf Coast areas meet these requirements (fig. 21).

Fairway Study.

The boundaries of the prospective geothermal reservoir can be more accurately delineated both vertically and areally through detailed pattern correlation of all well logs from the fairway area. The example shown here of a detailed study (figs. 22 and 23) is of the fairway in south-central Kenedy County and is the result of study of data from 18 wells as compared to data from one well used in the regional study. Core analyses of porosity and permeability are examined from the prospective reservoir or projected from nearby sands vertically or laterally, if not available from the prospective reservoir. Permeability lower than 20 md is considered inadequate to provide flow rates necessary for a geothermal well.

Site Selection.

There are two main activities involved in this final site-selection phase--the first concerns continued, more definitive reservoir delineation centering mainly on seismic data and the second includes reservoir definition.

Well-log cross sections are based on correlation of discontinuous data; even the closest-spaced wells are commonly miles apart leaving adequate space between for serious miscorrelation. Even minor errors in correlation of sand bodies between wells could lead to enormous miscalculation of reservoir dimension. Seismic sections, on the other hand, represent continuous data and when major seismic events are correlated on a grid of dip and strike cross sections, they aid in identifying structure and major correlative rock units. Preparation of synthetic seismograms from sonic logs of selected wells allows calibration of seismic data to actual depth. Then, lithologic information from detailed electrical-log cross sections can be

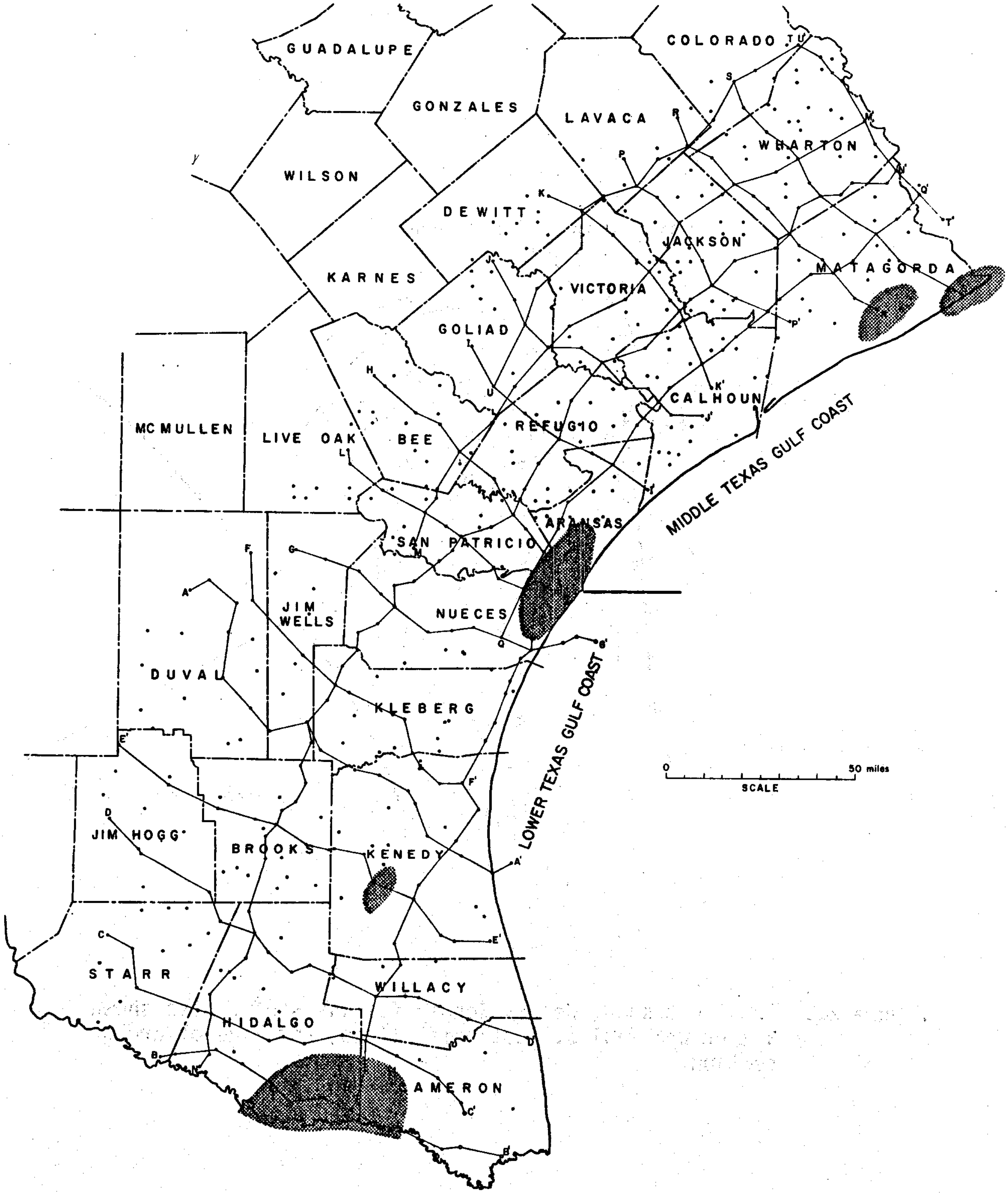

Figure 21. Geothermal fairways of the Lower and Middle Texas Gulf Coast.

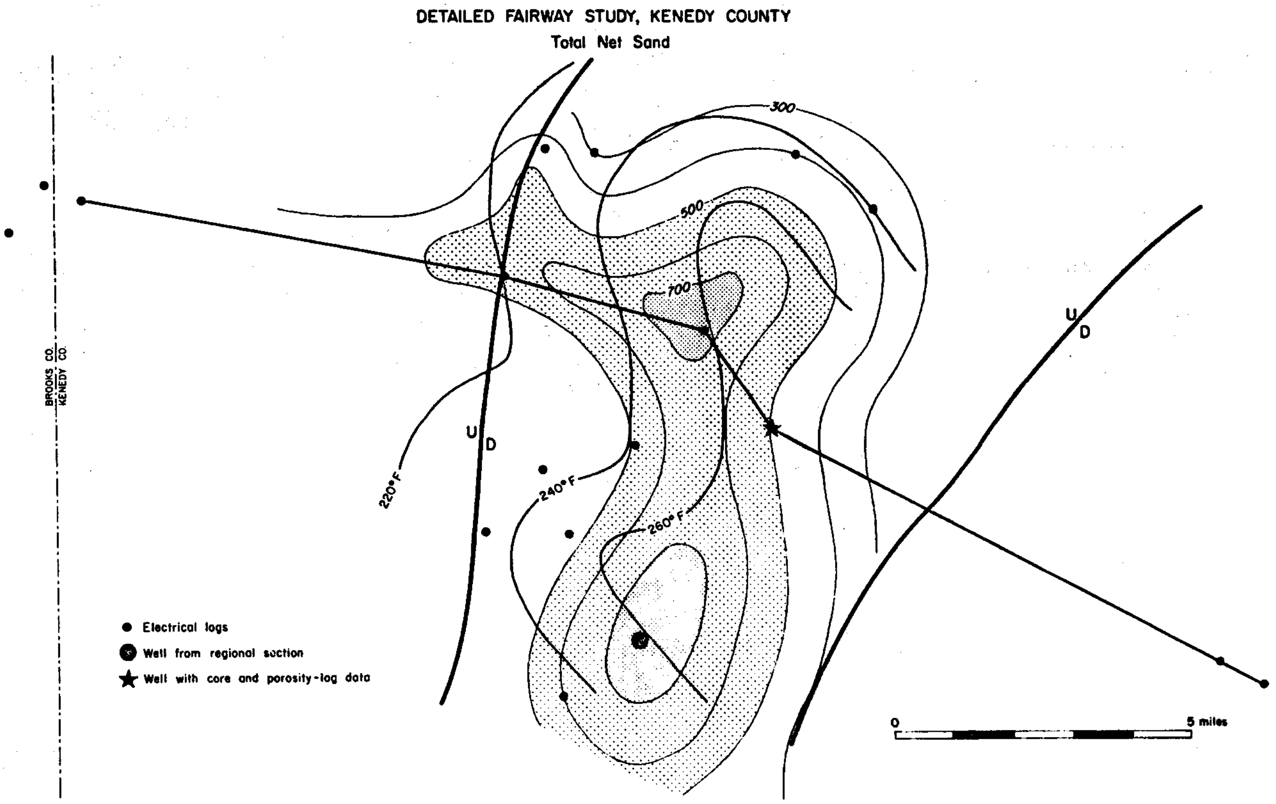

Figure 22. Total net sand, Kenedy County fairway study. Also shown are growth faults, isothermal lines, and line of cross section.

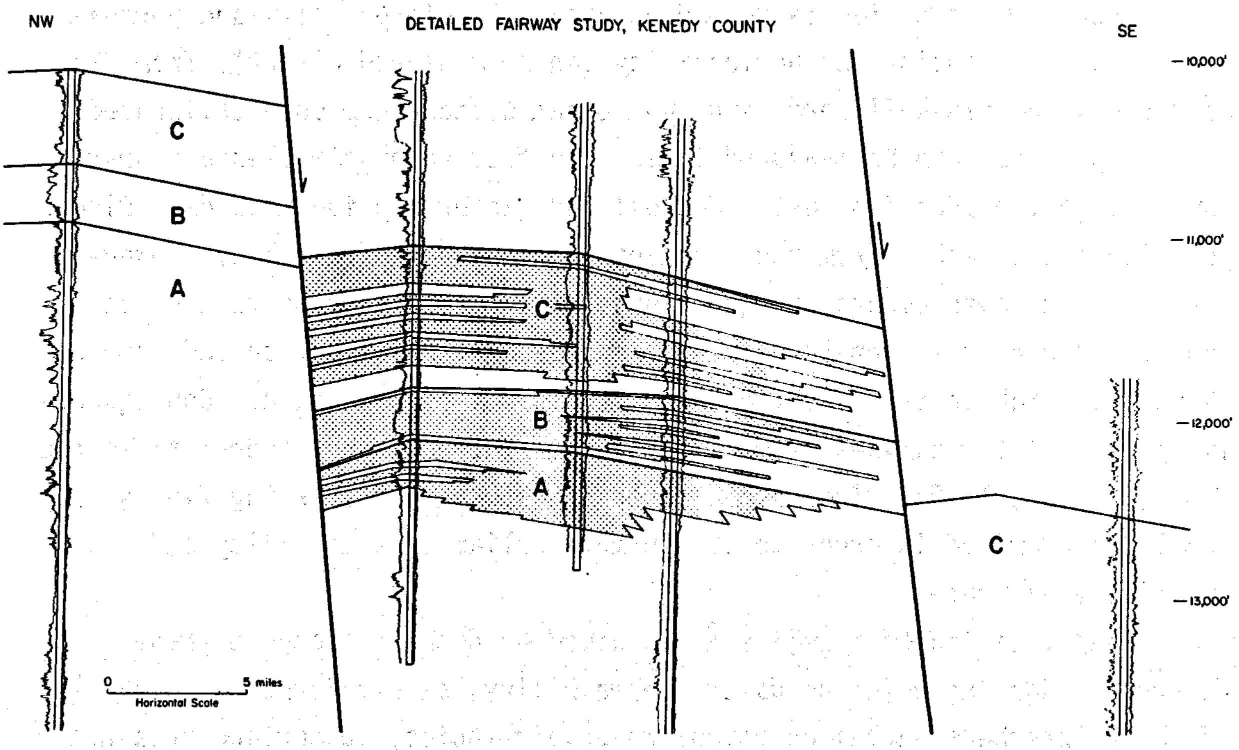

Figure 23. Cross section across the Kenedy County fairway.

incorporated into the seismic sections, thus resulting in more definitive reservoir delineation.

Detailed velocity studies comprising feasibility seismic-stratigraphic modeling from sonic logs determine the seismic response to changing geologic configuration (such as change in sand-body thickness). The results of modeling are applied to actual seismic data to interpret lithology, top of geopressure, porosity, and other physical parameters directly from the seismic sections.

Reservoir definition is dependent upon reliable porosity and permeability data. Porosity and permeability can be measured directly from diamond cores and sidewall cores and can be calculated from core-calibrated sonic logs; they can be measured indirectly from reservoir pressure drawdown studies, production tests, and oil and gas production records. Direct porosity measurements from rock samples are considered reliable. However, permeability measurements are questionable because measurements are not made under higher temperatures and pressures of the subsurface and commonly the rock fabric is disrupted during the sampling procedure. Consequently, permeability analyses from cores are considered to be several times too high (Hartman, 1975). Therefore, reservoir studies of existing fields should be examined in order to obtain more reliable permeability and producibility estimates.

Final location of a well site is aided by detailed computer-based reservoir modeling using porosity, permeability, sand thickness, thickness of shale interbeds, areal extent of reservoir facies, subsurface pressure and temperature, and salinity of the water.

SITE SELECTION: RECOMMENDATIONS, TIMING, AND BUDGET

Several geothermal fairways have been identified by regional studies of the Frio Formation of the Lower, Middle, and Upper Texas Gulf Coast. Those of the Lower and Middle Texas Gulf Coast are outlined in Figure 21. As mentioned earlier, these fairways are merely areas containing thick sand bodies with fluid temperatures higher than 250°F.

Preliminary site work within two of these fairways, consisting of more detailed mapping of individual sand bodies, has resulted in the identification of several reservoirs of adequate lateral extent and thickness to meet the specifications set for a geothermal well; it has also identified problems or difficulties in correlation even between closely spaced wells. Also, examination of a limited number of core analyses (sidewall and diamond) indicates that permeabilities of 20 md or greater are not widespread at depths greater than 12,000 feet. In general, permeability is lowest to the south along the Lower Texas Gulf Coast and increases to the north into the Middle Texas area.

Upon completion of the preliminary site study which will take approximately three months, the two or three most favorable sites will be identified. The final site-selection stage of the Frio study will take six months and will consist of two main activities--reservoir delineation and reservoir definition. Further delineation of the reservoir will center on one long regional section and several short local dip and strike seismic sections across each preliminary site area. The objectives of the seismic studies were discussed previously in this paper. Reservoir definition will consist of detailed studies of regional and local porosity and permeability variations in order to verify as accurately as possible the conditions to be expected in the prospective reservoirs. The reliability of directly measured porosity and permeability can be compared to reservoir production records and pressure drawdown studies, also discussed earlier in this paper. And finally, computer-based reservoir modeling of all reservoir parameters will aid in evaluating reservoir performance.

The total cost of this final site-selection process is approximately $275,000. The larger part of this, $180,000, is for purchase of three regional and several local seismic lines.

DATA PROCESSING

Lithologic Calculations from Electrical Logs.

Electrical logs of 4,000-5,000 wells have been assembled for the regional studies of the Frio and older Tertiary formations along the Texas Gulf Coast. In the course of study of each of these formations it is necessary to calculate net sand and sand percent for various depth units. In order to facilitate this highly mechanical operation, the location of sands within each well is digitized and stored by computer. The top and base of each sand recognizable on electrical logs is recorded and stored on cassette tape through an interface between the Strato-Timer (a precision-measuring device) and the Wang 2200 minicomputer. Sand calculations of any unit can now be obtained by inputting into the Wang the depth to top and bottom of the desired unit.

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