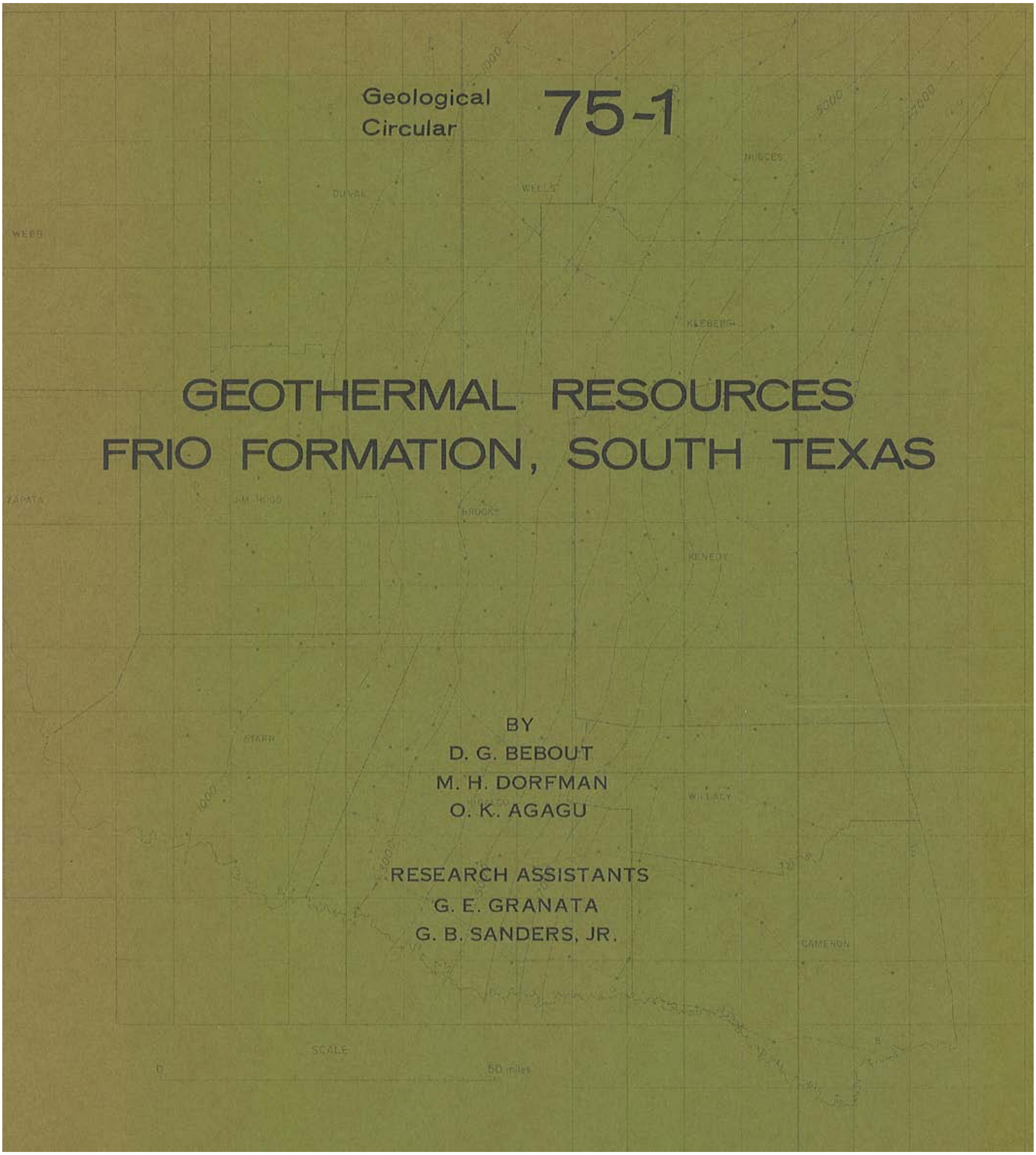

Geological Circular 75-1

GEOTHERMAL RESOURCES FRIO FORMATION, SOUTH TEXAS

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

A preliminary study of the Frio sand distribution and formation temperatures and pressures was undertaken in order to define prospective areas in which a more detailed reservoir analysis is necessary prior to the selection of a site for a geothermal well.

As the result of prospective oil wells that penetrated the Tertiary sediments, a geopressured zone containing fluids with high temperatures is known to occur along the Texas Gulf Coast. Few oil or gas wells produce from this area, and the regional sand distribution within these zones is not well known. Limited data, however, indicate that the pore spaces within the sands in the geopressured zone are filled with water which has high temperatures and relatively low dissolved-solids content, and which is saturated with methane. These waters are believed to be an important source of thermal energy and methane gas. For more information concerning the origin of the geopressured zone, see Dorfman and Kehle (1974) and Jones (1970).

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

The United States Atomic Energy Commission, through the Lawrence Livermore Laboratory, and the Center for Energy Studies, The University of Texas at Austin, supported this preliminary study of the geothermal resource of the Frio sands in South Texas. The South Texas area (from just north of Corpus Christi and south to the Rio Grande, fig. 2) was selected because the geopressured zone is known to occur here at shallow depths (Jones, 1970), and because of the abundance of oil well records for the area. The study includes a sand-facies analysis and an integration of the facies data with existing information relative to temperatures and pressures.

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

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.

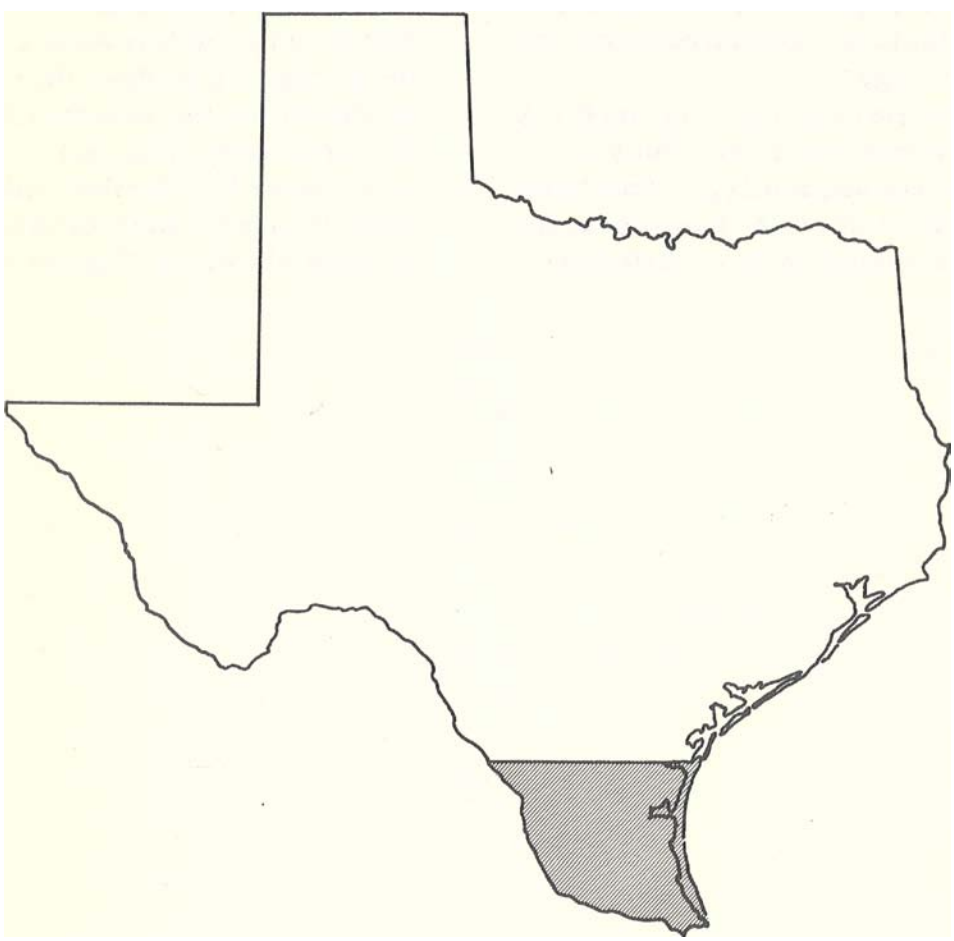


Fig. 2. Area of study.

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 from one 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 (fig. 3); each of these packages also thickens considerably in the same direction forming a wedge-shaped body (fig. 4). The wedges are dominantly 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 portion 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 5. The marine portion of each wedge containing foraminiferal markers is displaced progressively gulfward from the preceding wedge; this phenomenon is shown on the foraminifer zone updip limit map (fig. 6a) on which each older zone lies farther inland than the next younger, thus substantiating the pattern shown on Figure 4.

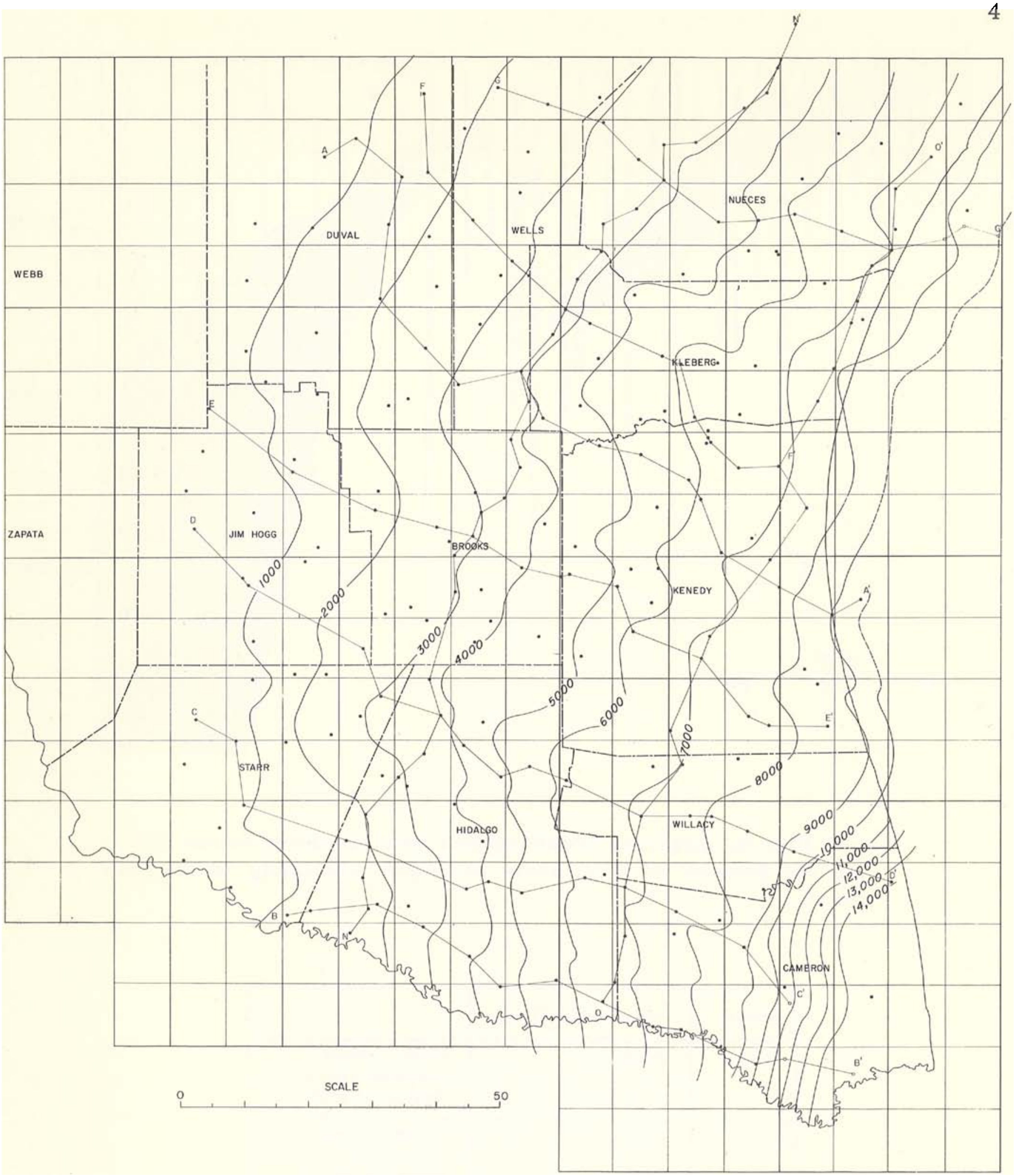


Fig. 3. Structure on top of the Frio Formation.

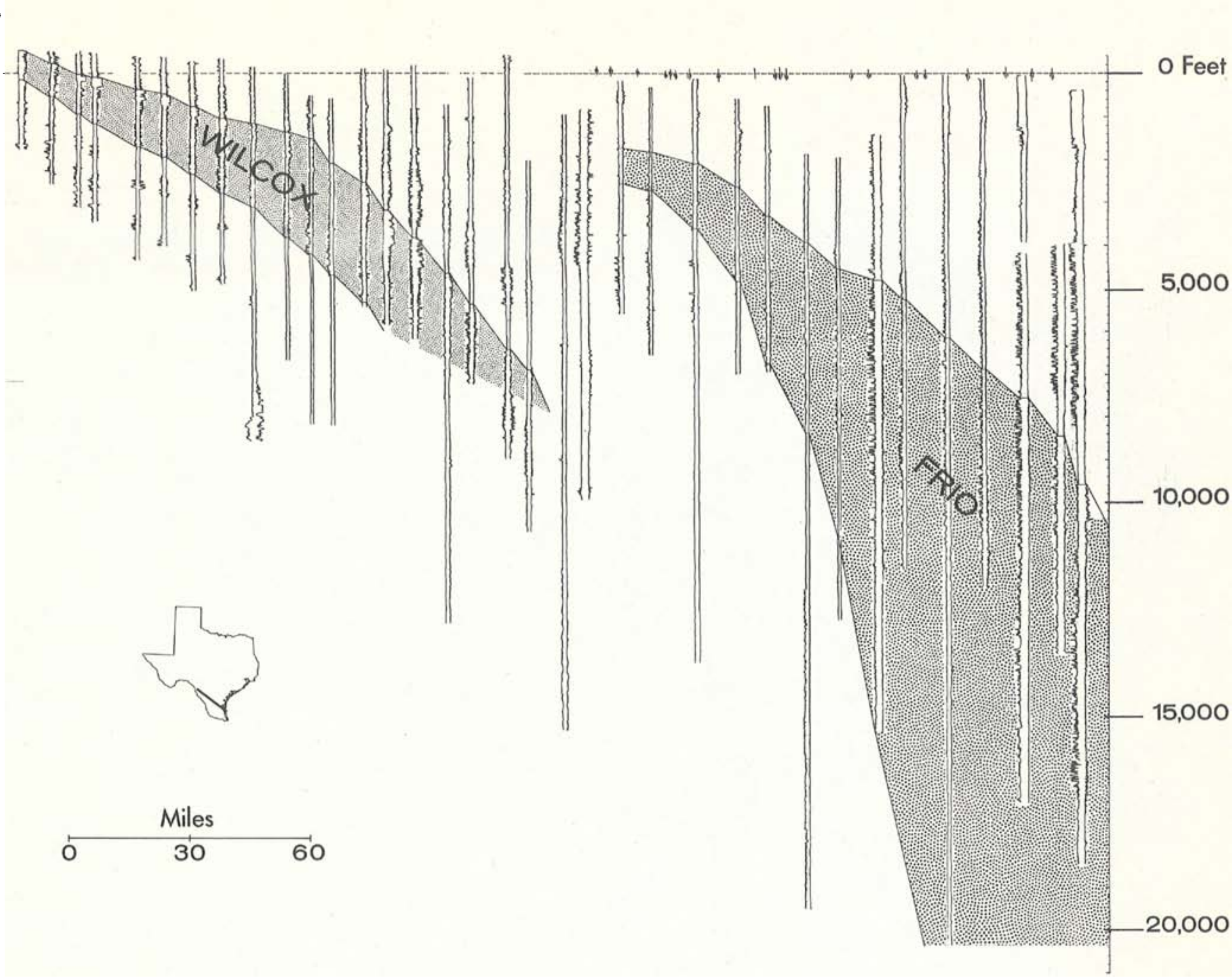
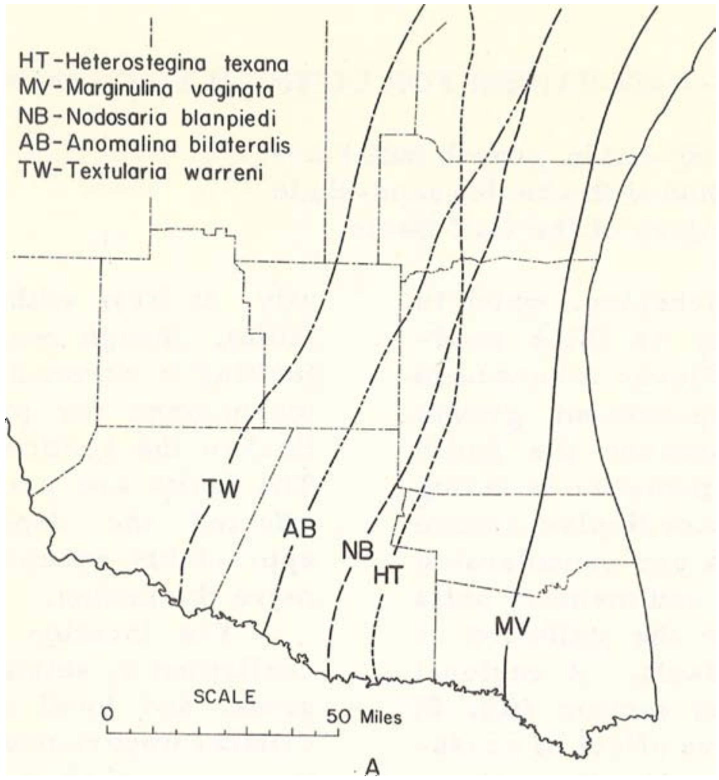


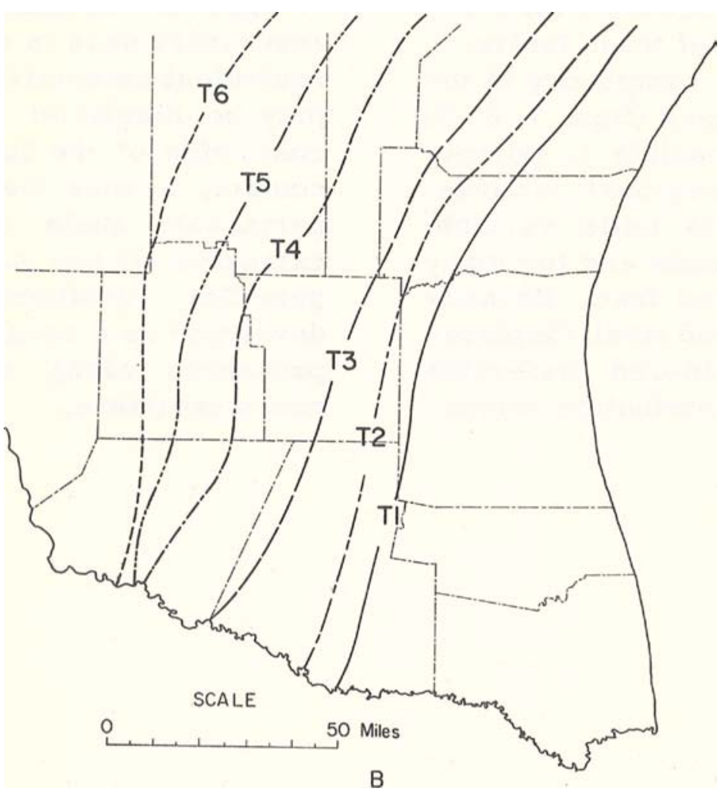
Fig. 4. Regional cross section on a sea-level datum showing the pattern of sand-shale packages offlapping toward the coast.

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

Fig. 5. Foraminifer zonation, Texas Gulf Coast Miocene and Oligocene.



A



B

Fig. 6. (A) Updip limits of foraminifer markers (after Holcomb, 1964) and (B) Updip limits of "T" markers.

GROWTH FAULTS--MECHANISM FOR DOWNDIP THICKENING

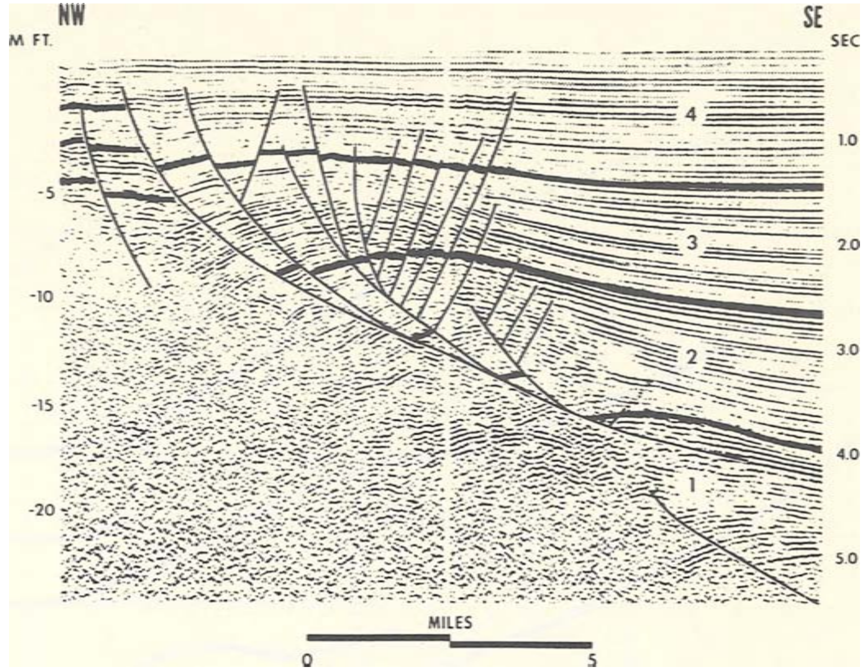
Abundant down-to-the-basin growth faults are well known as a method of thickening sand-shale sections in the Tertiary of the Gulf Basin.

Much of the thickening, which is manifest regionally as thick sand-shale wedges, is believed to have been caused by contemporaneous growth faults (fig. 7). 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. 8) 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 (figs. 7, 8, 9, and 10), 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. 10). Thus, extensive oil and gas reservoirs and potential geothermal reservoirs developed as a result of sedimentary processes along with contemporaneous structure.

Fig. 7. Depositional thickening as a result of contemporaneous growth faulting (from Bruce, 1973).



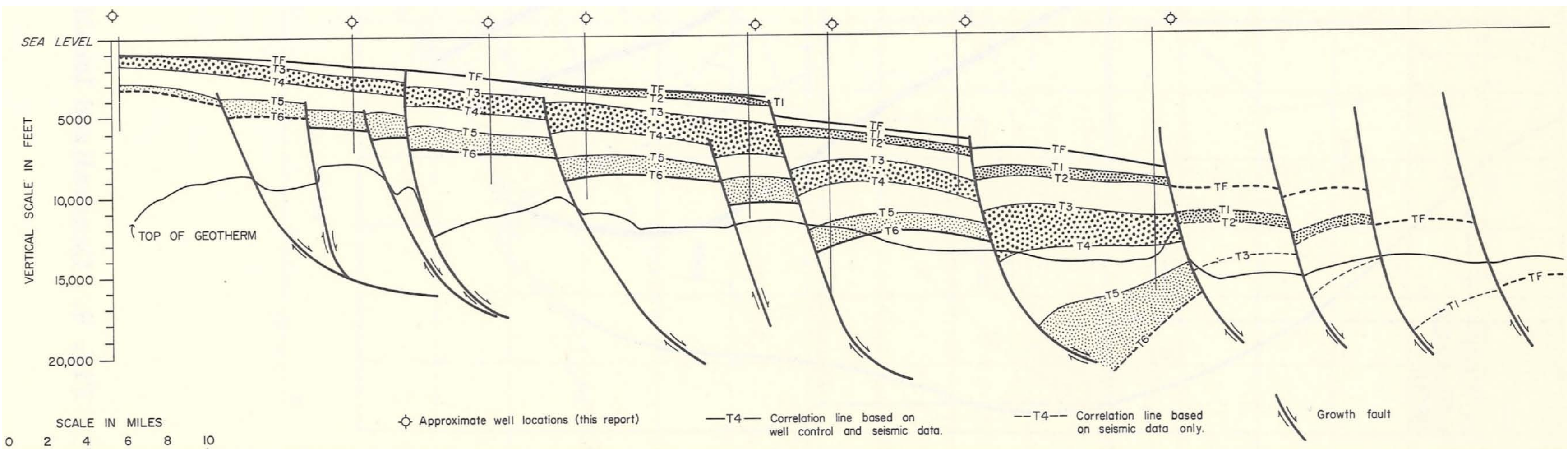


Fig. 8. Diagrammatic regional cross section adapted from a seismic section and from electrical log and paleontological control. This section parallels the B-B' section near the Rio Grande; the "T" markers from the B-B' section have been projected into this section to show the relationship of the depositional patterns (interpreted from electrical logs) to the growth faults (interpreted from the seismic sections).

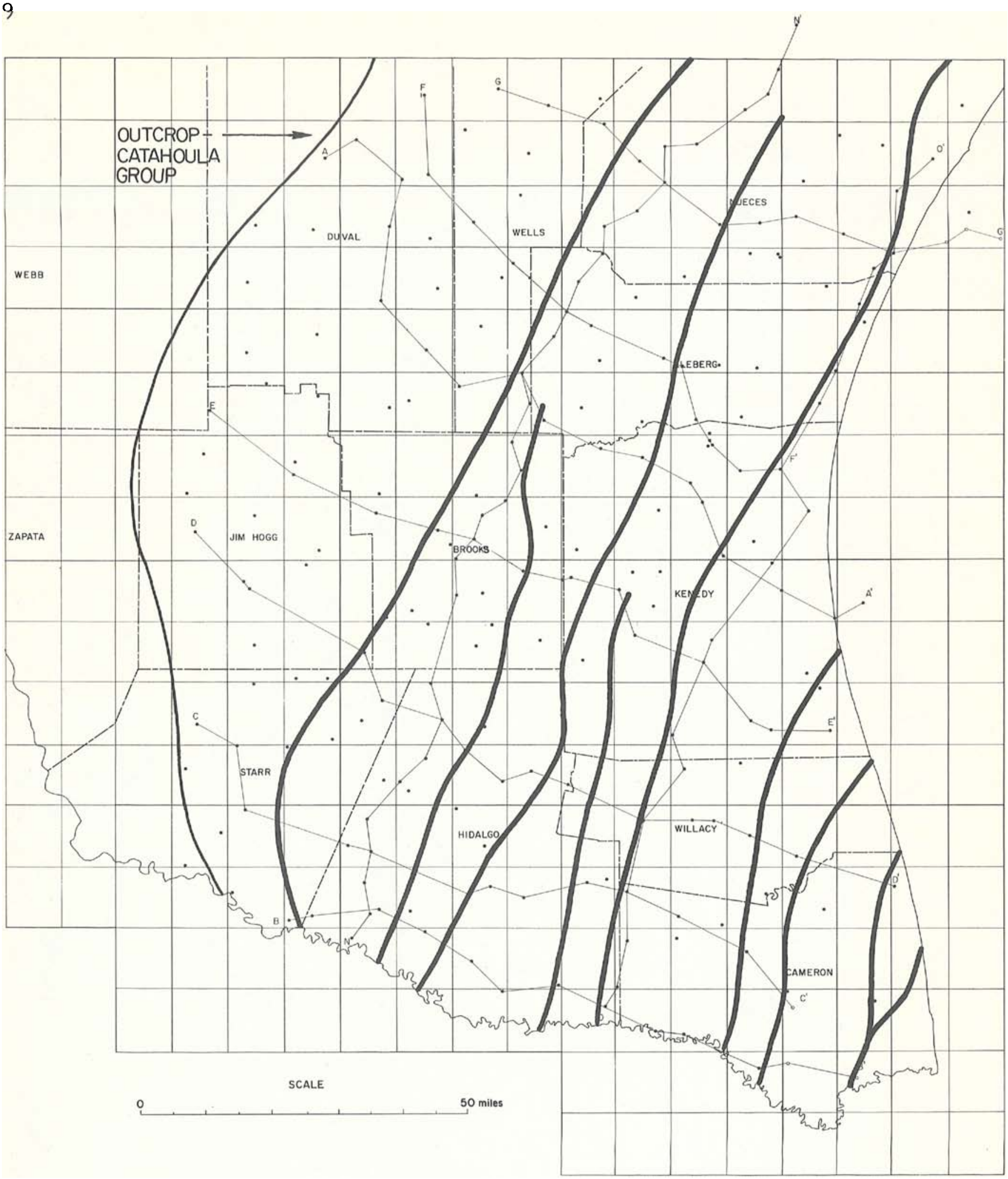


Fig. 9. Generalized location of growth faults in South Texas.

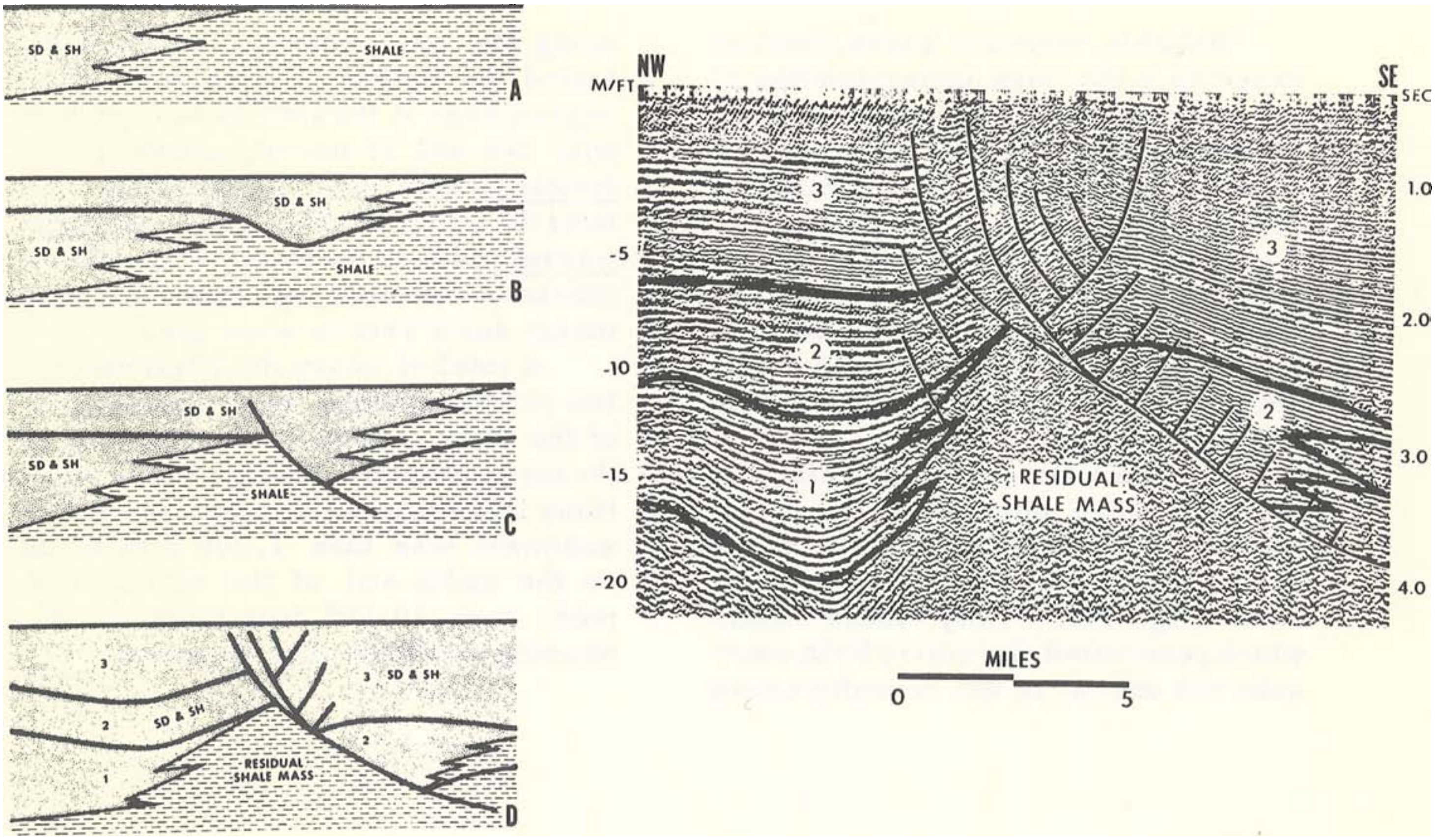


Fig. 10. Seismic section showing the location of a growth fault and the displacement of sand bodies and development of a shale ridge resulting from the faulting. The diagrams A-D illustrate the sequential development of the structure (from Bruce, 1973).

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 electrical 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, 232 electrical logs were obtained from wells spaced approximately 5-10 miles apart throughout the South Texas area (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 seven dip sections and two 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 (see map on cover).

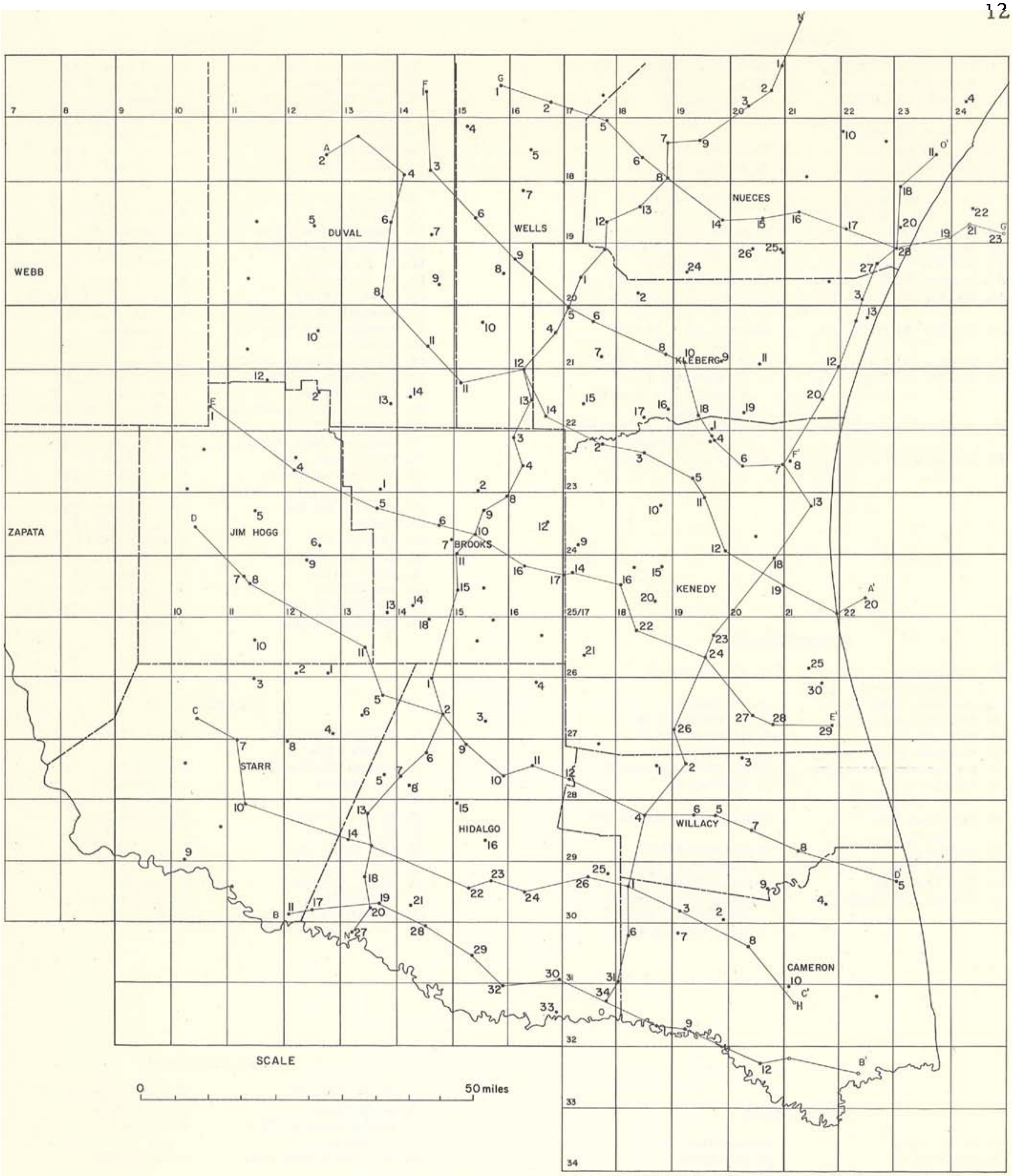


Fig. 11. Well-log control and cross sections constructed for this Frio study.

Brooks County

1.	City Products Corp.	G. S. Saunders et al. #1
2.	Shell Oil Co.	J. L. Cage #C-1
3.	General Crude Oil Co.	R. G. Garza #1
4.	Gunther, Warren & Gulf Oil Corp.	Miller et al. #1
5.	Russell McGuire	Saunders #1
6.	NOR-MAC-Burns	J. L. Cage #1
7.	Humble Oil & Rfg. Co.	C. F. Hooper #7
8.	Carrl Oil, General Crude, Pan Am.	R. G. Cage et al. #1
9.	Forest Oil Co.	Cage Ranch #1
10.	Forest Oil Co.	Ed Rachal Foundation #1
11.	Humble Oil & Rfg. Co.	C. F. Hopper #5
12.	Humble Oil & Rfg. Co.	D. J. Sullivan "B" #28
13.	Humble Oil & Rfg. Co.	Mestena Oil & Gas Co. #G-5
14.	Humble Oil & Rfg. Co.	Mestena Oil & Gas Co. #G-3
15.	Humble Oil & Rfg. Co.	B. A. Skipper, Jr. #11
16.	Humble Oil & Rfg. Co.	R. J. Kleberg, Jr., Trustee, Los Muertos Pasture #7
17.	Humble Oil & Rfg. Co.	J. Kleberg, Jr., Trustee, Sacahuista Pasture #2
18.	Standard Oil of Texas	Braulia de Garcia #1-14

Cameron County

1.	Texaco, Inc. (proprietary)	C. A. Johnson #1
2.	Amerada Petr. Corp.	W. O. Huff #1
3.	Gulf Oil Corp.	J. H. McDaniel #1
4.	Shell Oil Co.	Continental Fee #1
5.	Magnolia Petr. Co.	G. Kerlin #1
6.	Hydrocarbon Prod. Co.	J. R. Bevers et al. #1
7.	Harkins & Co. & R. Mosbacher	L. Rohman #1
8.	Aluminum Co. of America	Old Colony Trust Est. #1
9.	Brazos Oil	State Tract 215 #1
10.	Holmes Drlg. Co.	T. Sweeney et al. #1
11.	Dow Chemical	Conoco Mineral Fee #1
12.	Humble Oil & Rfg. Co.	Cameron County Water Control & Improvement District 6 #1

Duval County

1.	C. C. Winn	Salinas Est. #2
2.	Shell Oil Co.	Stegall #A-1
3.	Humble Oil & Rfg. Co.	E. Garcia #1
4.	Taylor Rfg. Co.	Parr #T-2
5.	Pyramid Drlg. Co.	J. M. Luby Est. #1
6.	The Texas Co.	Gravis #1-A
7.	Humble Oil & Rfg. Co.	W. W. Garcia #1
8.	Hiawatha Oil & Gas Co.	Parr #D-1
9.	Quintana Petr. Corp.	Frank & Clyde Allen #1
10.	Hillcrest Oil Co.	K. Shaffer #1
11.	Hunt Oil Co.	Dechampa #1
12.	Arco Oil Corp.	Laura McBryde #1
13.	Texaco, Inc.	Canales #1
14.	Continental Oil Co.	Glasscock et al. #1

Hidalgo County

1.	Humble Oil & Rfg. Co.	McGill Bros. #416
2.	Shell Oil Co.	A. A. McAllen #9
3.	Shell Oil Co. et al.	Goldston Est. #1
4.	Humble Oil & Rfg. Co.	Santa Fe - Mula #7
5.	Pontiac Rfg.	Arrowhead Ranch #1
6.	Shell Oil Co.	A. A. McAllen et al. #1
7.	Shell Oil Co.	G. Coates-Newmont Oil Co. #1
8.	Taylor Oil & Gas Co.	K. J. Alexander #1
9.	Shell Oil Co.	A. W. Beaurline #1
10.	Magnolia Petr. Co.	G. Doughty #1
11.	Magnolia Petr. Co.	R. Garcia #1
12.	N. E. Hanson	S. Dobbins #1
13.	P. H. Welder	W. J. Davis #1
14.	Coastal States	G. H. Coates et al. #1
15.	Austral Oil Co., Inc.	R. Vela et al. #1
16.	Humble Oil & Rfg. Co.	B. Hanks #1
17.	Phillips Oil	Flores #1
18.	Sinclair Prairie Oil Co.	S. Geininger #1
19.	Humble Oil & Rfg. Co.	Texan Dev. Co. #1
20.	Coastal States	T. E. Murchison #1
21.	Houston Oil Co. of Texas	Hidalgo-Willacy #A-1
22.	Mokeen Oil Co.	J. T. Atwood #1
23.	Amerada Petr. Corp.	T. & N. O. RR. Co. #1
24.	Union Prod. Co.	Wysong Unit #2
25.	Continental Oil Co.	E. E. Johnson #1
26.	Standard Oil Co. of Texas	Rio Farms Inc. #1
27.	Houston Oil Co.	Hidalgo-Willacy Oil Co.
28.	Conoco	M. L. Talbot #1
29.	Tenneco Oil	McAllen Field Wide Unit #36
30.	LaGloria Corp.	South Weslaco Gas Unit #1
31.	Shell Oil Co.	H. W. Drawe #1
32.	Sinclair Oil	Houston Unit #2
33.	LaGloria Corp.	South Weslaco Gas Unit #11
34.	Bettis & Shepard	Schwartz #1

Jim Hogg County

1.	British American Oil Prod. Co.	Adams #1
2.	Humble Oil & Rfg. Co.	Mestena Oil & Gas Co. #C-2
3.	Cox Hamon	Armstrong #1
4.	W. Young	Mestina #3
5.	P. L. Davidson	Well Bros. #1
6.	G. C. Ayres	Mestena Oil & Gas Co. #4
7.	The Texas Co.	A. K. East #6
8.	Burns Trust #2	East #1
9.	E. R. Thomas	Holbein #1
10.	Sun Oil Co.	A. C. Jones #63
11.	Humble Oil & Rfg. Co.	A. M. Bass #30

Jim Wells County

1.	Carrl Oil et al.	Shaeffer Ranch #V-1
2.	O. Maclain	Rehmet #4-A
3.	Texas Southern Oil & Gas Co.	E. Monse #2
4.	Gulf Coast Minerals, Inc.	Robles Heirs #1
5.	W. E. Rowe	W. Meyer #2
6.	Sunray-Mid-Continental Oil Co.	C. Muil #1
7.	Appell Drlg. Co.	H. H. Chiles #1
8.	Carrl Oil & Shore Expl. Co.	A. C. Skinner #2
9.	Sid Katz Expl.	J. E. Morgan #1
10.	H. R. Smith	C. Driscoll Est. #1
11.	G. E. Chapman	Howell et al. Unit #1
12.	Sun Oil Co.	Canales #117
13.	Sun Oil Co.	A. T. Canales #43

Kenedy County

1.	Humble Oil & Rfg. Co.	S. K. East #B-18
2.	Gulf Oil Corp.	McGill Est. #2
3.	Humble Oil & Rfg. Co.	H. F. McGill #1
4.	Humble Oil & Rfg. Co.	S. K. East #B-15
5.	Humble Oil & Rfg. Co.	J. G. Kenedy, Jr. #"J"-2
6.	Humble Oil & Rfg. Co.	J. G. Kenedy, Jr. #G-1
7.	Pan Am.	Kenedy #1
8.	LaGloria Corp.	Kenedy Ranch #B-1
9.	Humble Oil & Rfg. Co.	R. J. Kleberg, Jr., Trustee, Patricio Pasture #10
10.	Humble Oil & Rfg. Co.	J. G. Kenedy, Jr. #C-2
11.	Humble Oil & Rfg. Co.	Kenedy #J-4
12.	Humble Oil & Rfg. Co.	S. K. East #D-1
13.	Humble Oil & Rfg. Co.	State Tract 249 #1
14.	Humble Oil & Rfg. Co.	R. J. Kleberg, Sacahuista Pasture #2
15.	Humble Oil & Rfg. Co.	S. K. East #41
16.	Humble Oil & Rfg. Co.	S. K. East #17
17.	Humble Oil & Rfg. Co.	C. M. Armstrong #20
18.	Humble Oil & Rfg. Co.	S. K. East #C-1
19.	Mobil Oil Corp.	State Tract 309 #1
20.	Mobil Oil Corp.	Texas Gulf 59202 State Tract 961L
21.	Humble Oil & Rfg. Co.	Santa Fe Ranch Julian Pasture #1
22.	Humble Oil & Rfg. Co.	C. M. Armstrong #22
23.	Humble Oil & Rfg. Co.	S. K. East "G" #1
24.	Humble Oil & Rfg. Co.	King Ranch-Saltillo #2
25.	Humble Oil & Rfg. Co.	State Tract 384 #1
26.	Texaco, Inc.	Yturria L and L A NCT - 2 #1
27.	Humble Oil & Rfg. Co.	King Ranch #2
28.	Humble Oil & Rfg. Co.	King Ranch - Tio Moya #1
29.	Gulf Oil Corp.	State Tract 427 #1
30.	Continental Oil Co.	State Tract 393 #1
31.	Humble Oil & Rfg. Co.	R. J. Kleberg, Jr., Frustel Stillman #7

Kleberg County

1.	Humble Oil & Rfg. Co.	King Ranch - Stratton #T-1
2.	Golden Trend Oil & Gas Corp.	Marshall-Michele #1
3.	Pure Oil Co.	State Tract 168 #A-1
4.	Humble Oil & Rfg. Co.	King Ranch - Seeligson #E-45
5.	Humble Oil & Rfg. Co.	King Ranch - Borregos #262
6.	Humble Oil & Rfg. Co.	King Ranch - Borregos #ME-5
7.	Meeker & Hass Bros.	O'Conner #1
8.	Lone Star Oil Co.	Mull #1
9.	Humble Oil & Rfg. Co.	King Ranch - Visnaga #8
10.	Mokeen Oil Co.	H. A. M. #A-1
11.	Humble Oil & Rfg. Co.	King Ranch - Alazan #3
12.	Humble Oil & Rfg. Co.	State Tract 197 #1
13.	Kelly Bell	State Tract 184 #1
14.	Humble Oil & Rfg. Co.	King Ranch - Laguna Larga #10
15.	Humble Oil & Rfg. Co.	King Ranch - Canelo #17
16.	Cities Service Petr.	R. B. Poteet #1
17.	Mokeen Oil Co. et al.	Yeargen #1
18.	Sun Oil Co.	Laguna Olmos Gas Unit 372 #1
19.	Humble Oil & Rfg. Co.	Baffin Bay State Tract 57 #1
20.	Shell Oil Co.	State Tract 206 #1

Nueces County

1.	Getty Oil Co.	Wilkerson #1
2.	Spartan Drlg. Co.	E. H. Granberry #1
3.	Southern Minerals Corp.	M. H. Griffith #1
4.	Getty Oil Co.	State Tract 275 #1
5.	Kirkpatrick Oil & Gas Co. & Natol Petr.	A. P. Regmund #1
6.	Gillring Oil	Winfield #8
7.	Southern Minerals Corp.	B. Sterns #1
8.	Glasscock Bros. & Puenticitas Oil Co.	La Rochelle #1
9.	Richardson Petr.	F. Nemec #1
10.	Forest Oil Corp. & Mobil Oil Co.	State Tract 786 #7
11.	Shell Oil Co.	State Tract 346 #1
12.	Champlin Oil & Rfg. Co.	B. Woffard #C-2
13.	Puenticitas Oil Co.	Simmons & Perry "B" #60
14.	The Atlantic Rfg. Co.	J. S. Womack
15.	Newman Bros.	W. W. Walton #1
16.	Coastal States	P. Kraft #1
17.	J. P. Driscoll et al.	F. D. Smith et al. #1
18.	Atlantic Richfield Co. & Tidewater Co.	St. 45-47 Unit, Tr. #470, #3
19.	Cities Service	State Tract 773L #1
20.	Humble Oil & Rfg. Co.	Laguna Madre State Tract 52 #1
21.	Gulf Oil Co., Humble Oil & Rfg. Co.	State Tract 772 #B-1
22.	Humble Oil & Rfg. Co.	State Tract 772 #1
23.	Union Oil of Calif.	State Tract 775-L #1
24.	G. N. Graham	Al. Dorsogna #1
25.	The Chicago Corp.	Chapman Ranch #3
26.	A. O. Morgan & Southern Minerals Corp.	Chapman Heirs #43-1
27.	Humble Oil & Rfg. Co.	State Tract 173 #1
28.	Cherryville Corp.	B. Dunn et al. #1

Starr County

1.	Richardson Petr. Enterprise	E. Yzaguirre #B-1
2.	Oil Operations, Inc.	Margo Est. #A-1
3.	Sun Oil Co.	A. C. Jones #55
4.	Sun Oil Co.	J. F. Hall-State #1-A
5.	Humble Oil & Rfg. Co.	D. Olivarez #1
6.	Magnolia Petr. Co.	F. B. Guerra #5
7.	Sun Oil Co.	O. B. Simpson State #1
8.	Sun Oil Co.	G. H. Coates State #A-4
9.	Owen & Moss	W. S. Parks #4
10.	Lockhart Oil Co. of Texas	J. D. Brock #2
11.	Sun Oil Co.	Reilly #A-1

Willacy County

1.	Humble Oil & Rfg. Co.	M. F. Garcia #2
2.	Texaco Inc.	Hurria L & L Co. #A-10
3.	Humble Oil & Rfg. Co.	Sauz-Ranch-Jardin #1
4.	Pan Am.	Coleman #1
5.	Sun Oil Co.	Scott #1
6.	Shoreline Petr. Corp.	Lorena Walker #1
7.	Humble Oil & Rfg. Co.	Williamar Unit #1
8.	Humble Oil & Rfg. Co.	Sauz-Ranch-Nopal #2
9.	Phillips Petr. Co.	Livingston #1

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 thus 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. 6b), a pattern which parallels very closely the updip limit of foraminiferal markers.

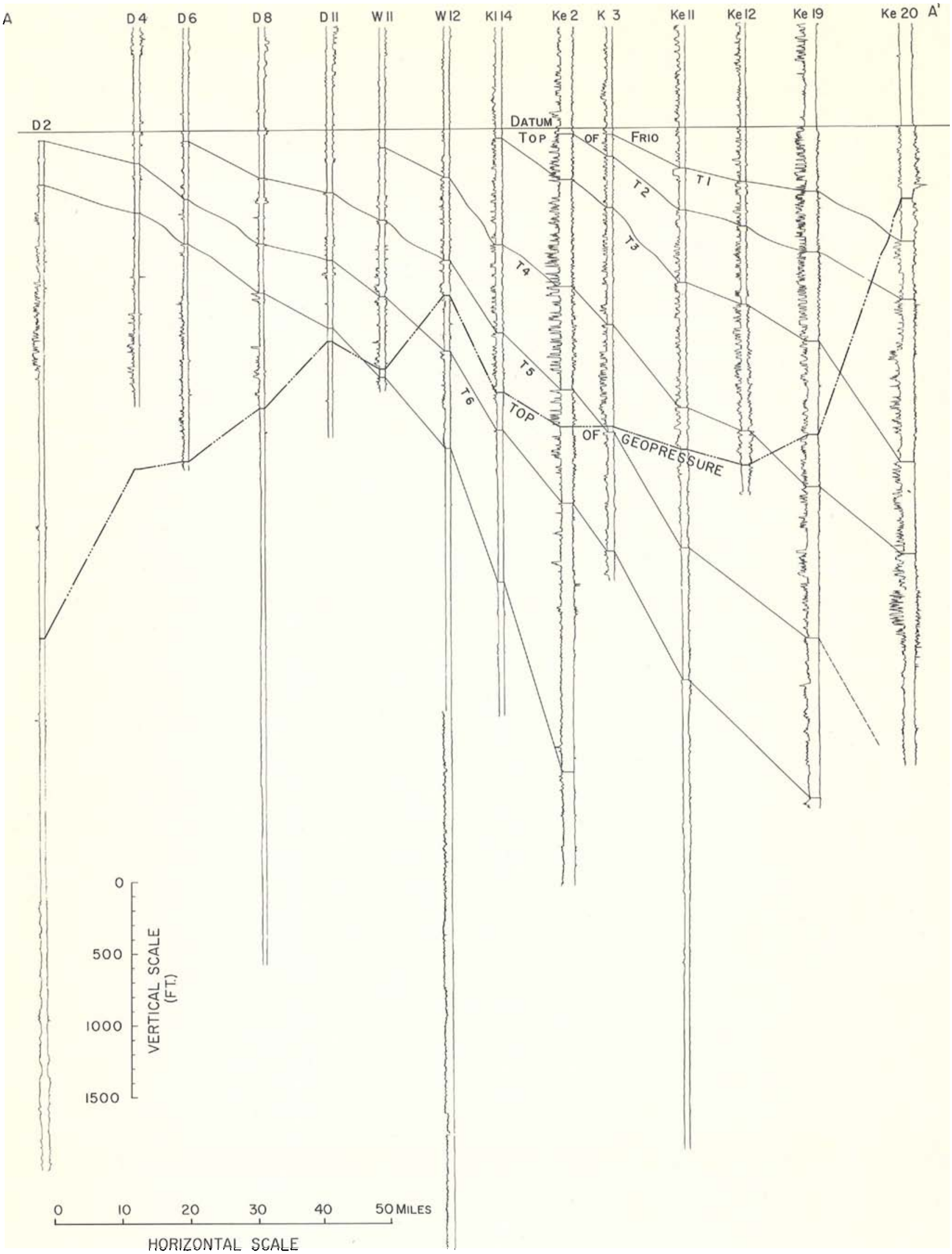


Fig. 12. Sand facies distribution along section A-A', datum on top of the Frio. "T" markers indicate correlation points interpreted by using major shale beds and foraminifer zones. The top of the geopressured zone is indicated by the broken line.

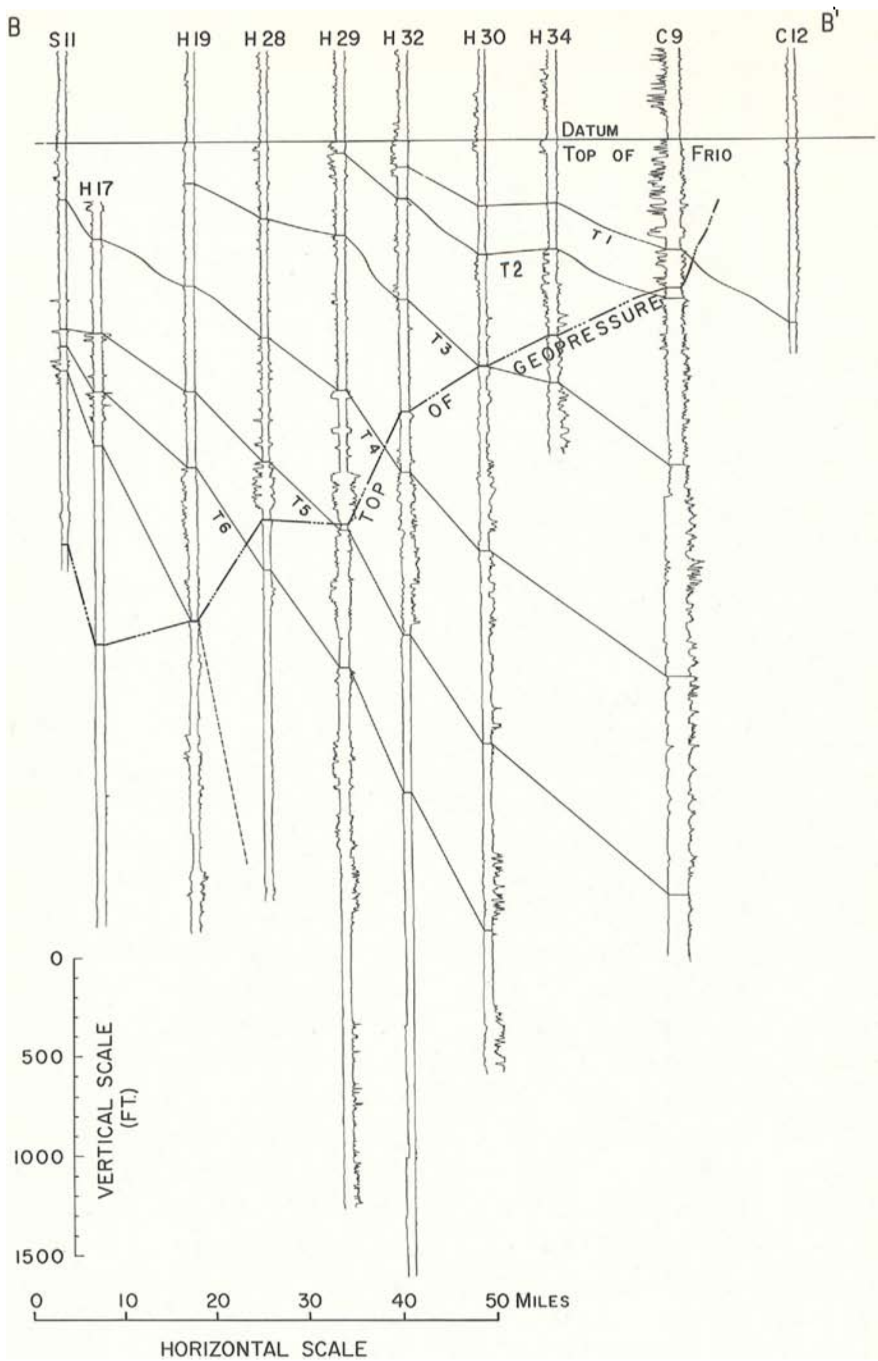


Fig. 13. Sand-facies distribution along section B-B', datum on top of the Frio. "T" markers indicate correlation points interpreted by using major shale beds and foraminifer zones. The top of the geopressured zone is indicated by the broken line.

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 strandplain.

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 by using sand-percentage maps, in addition to 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 strandplain. 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 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 suggest 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.

Strandplain systems--Strandplain 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 longshore 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.

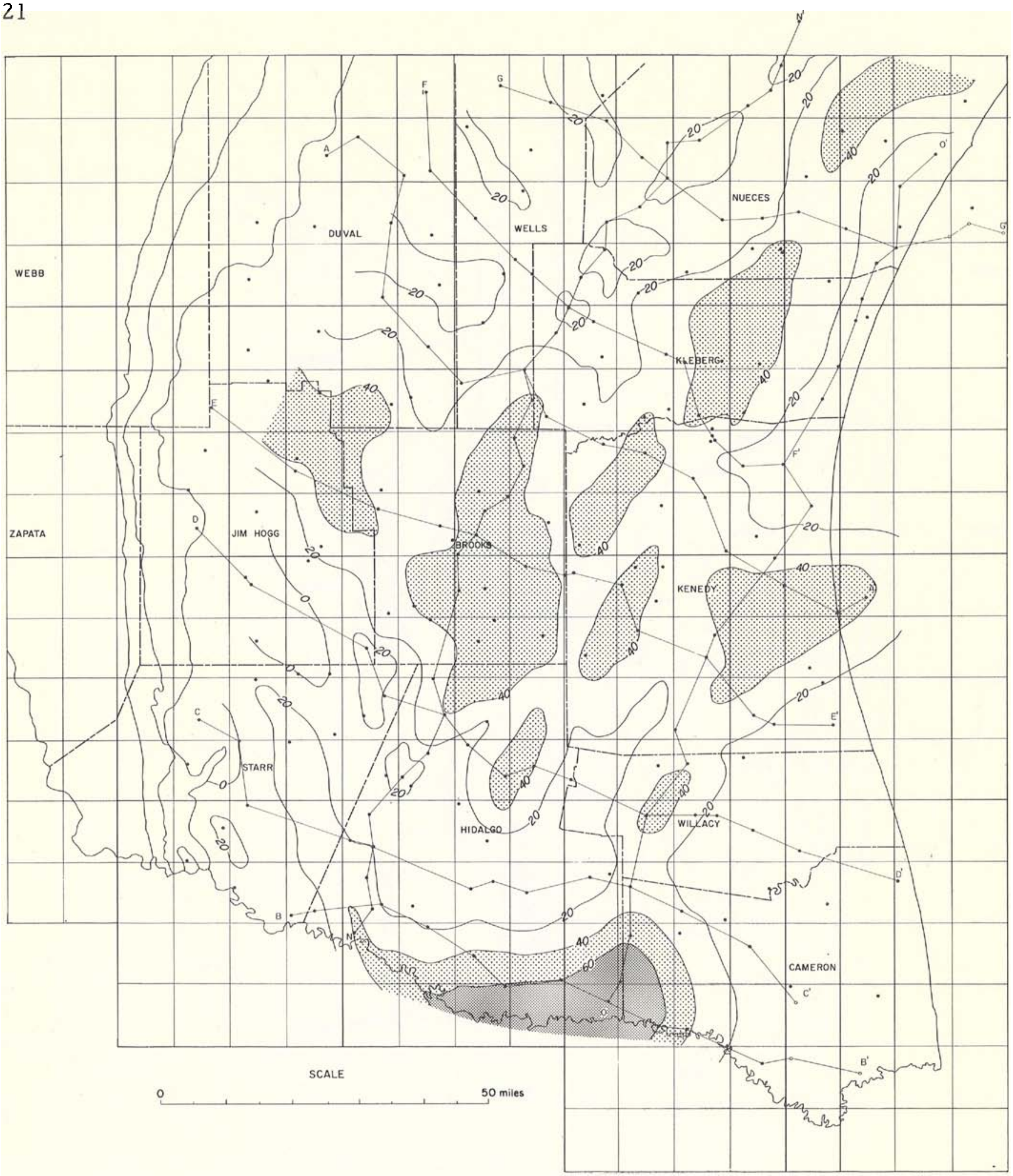


Fig. 15. Sand percentage in zone T4-T5.

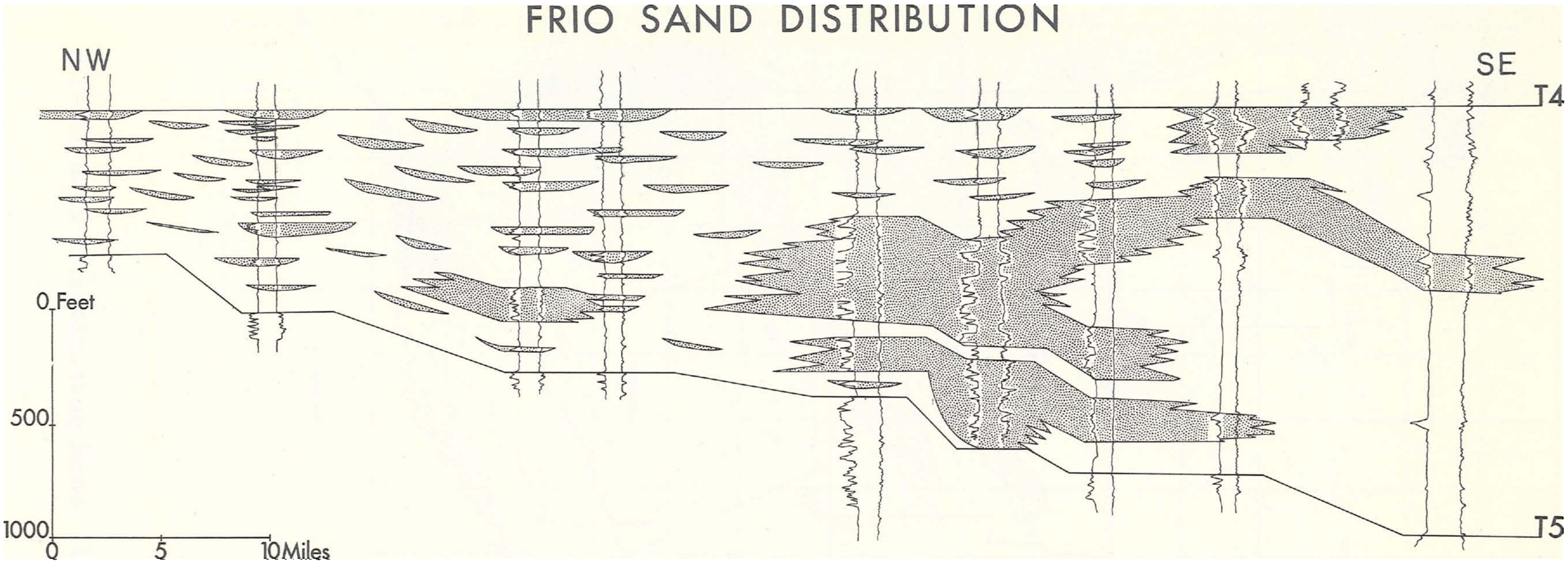


Fig. 16. Sand distribution between T4 and T5 along section F-F'.

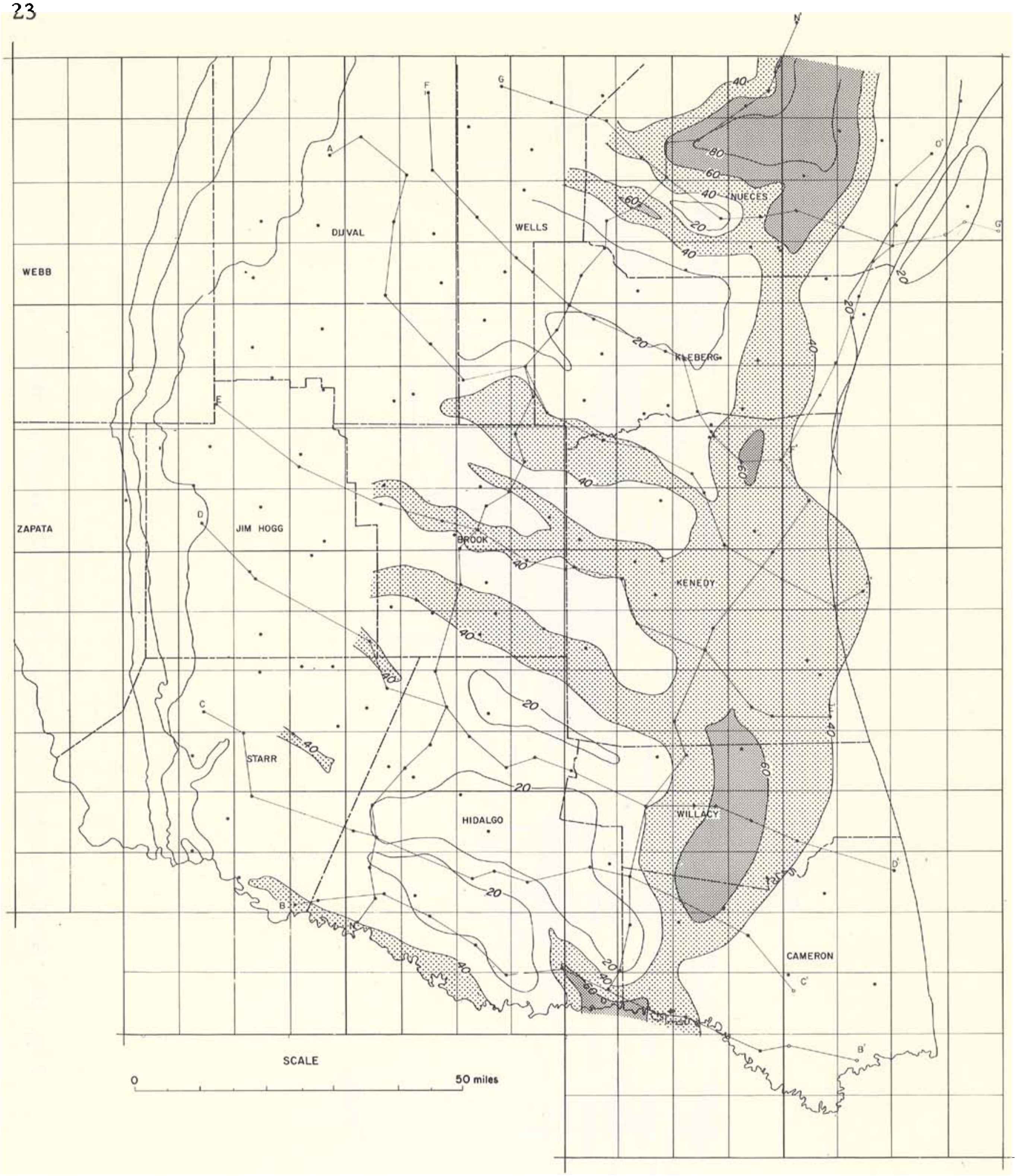


Fig. 17. Sand percentage in zone T3-T4.

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

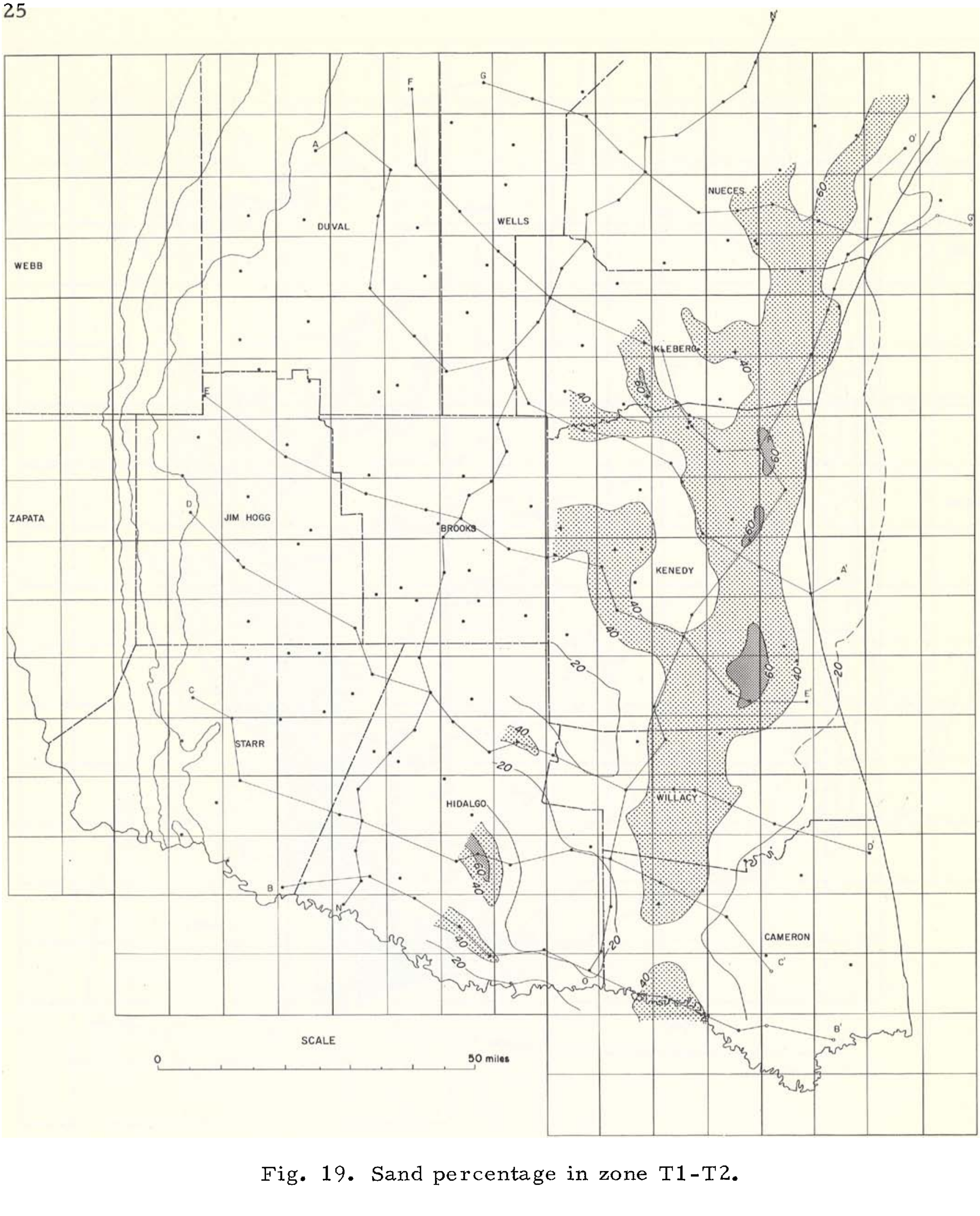


Fig. 19. Sand percentage in zone T1-T2.

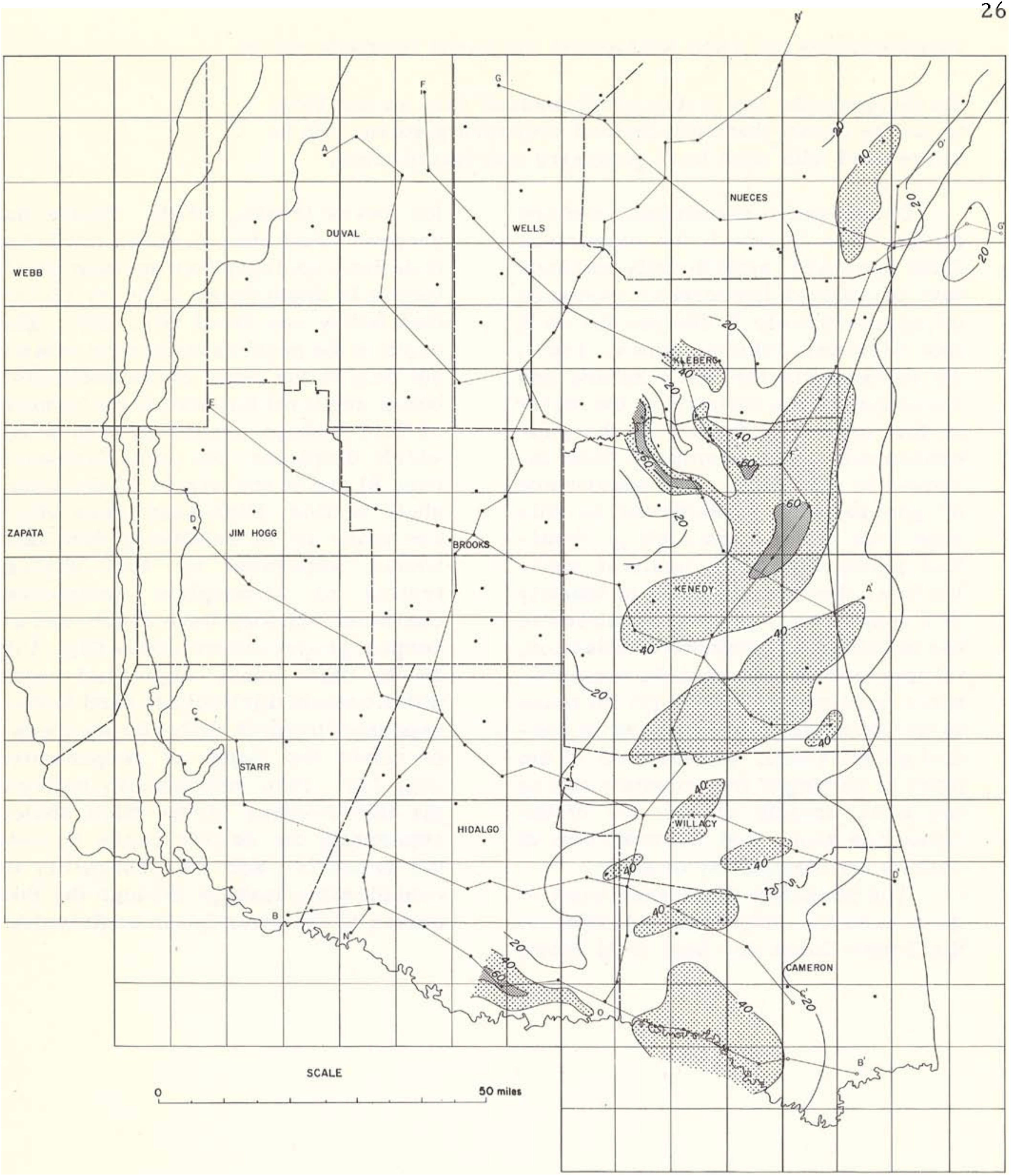


Fig. 20. Sand percentage in zone T0-T1.

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 geopressured 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. 8) 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 strandplain 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 strandplain sediments.

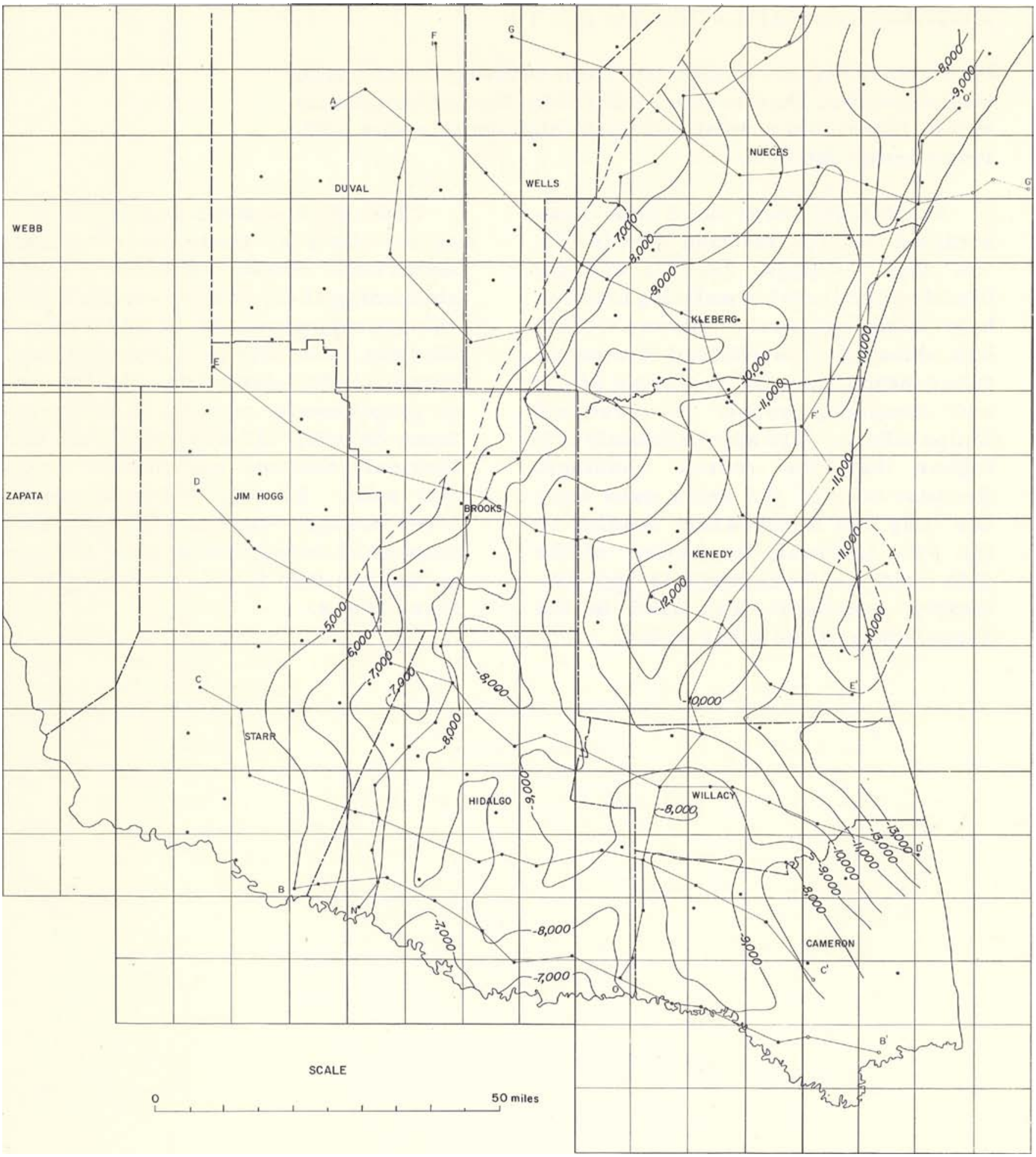


Fig. 21. Top of the geopressured zone, South Texas.

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 and 240°F and that thermal gradients may double below this zone. Second, lower temperatures seem to occur in areas of maximum sand deposition because the geopressured zone is displaced deeper in these areas.

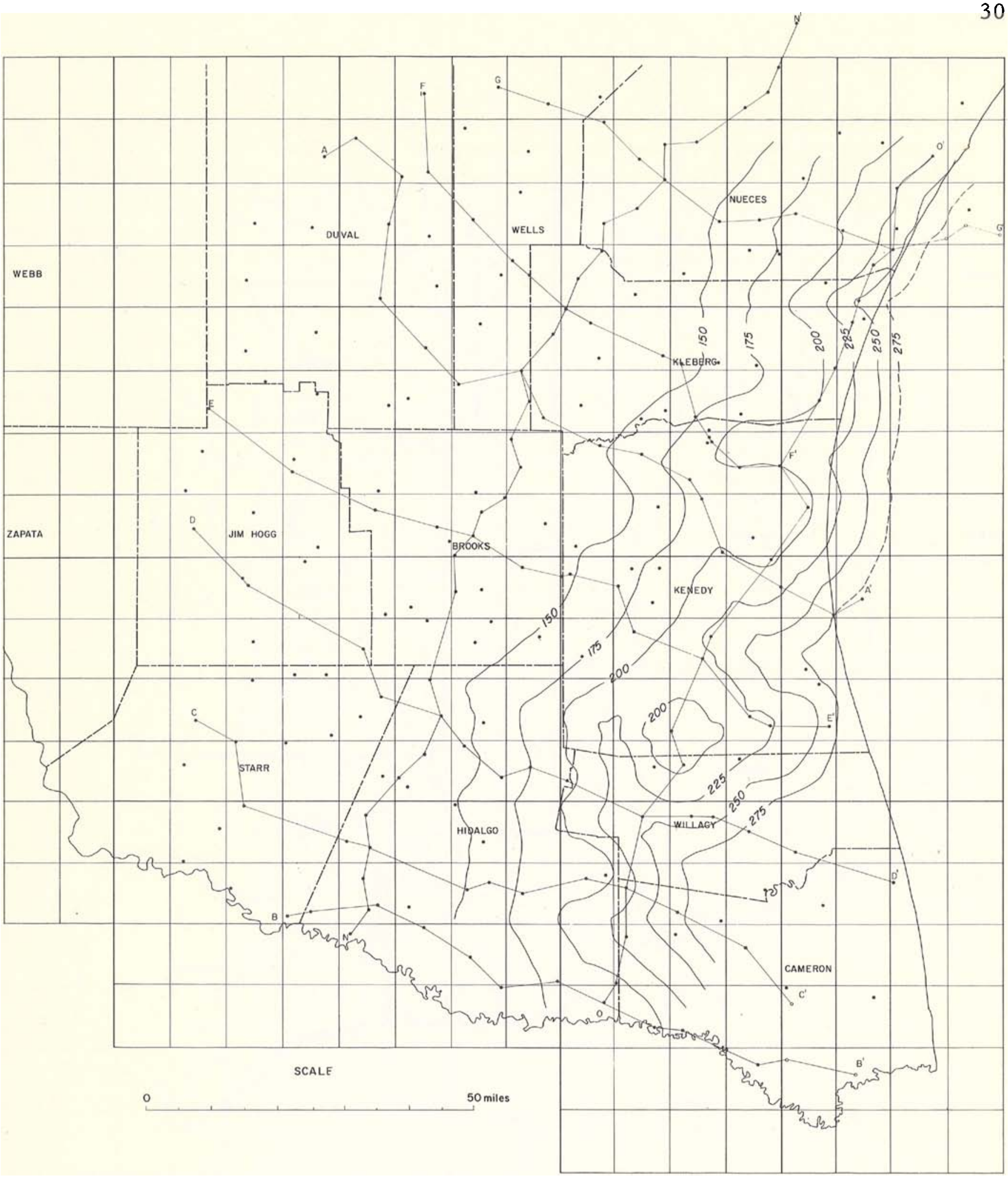


Fig. 22. Isothermal map on T3 datum.

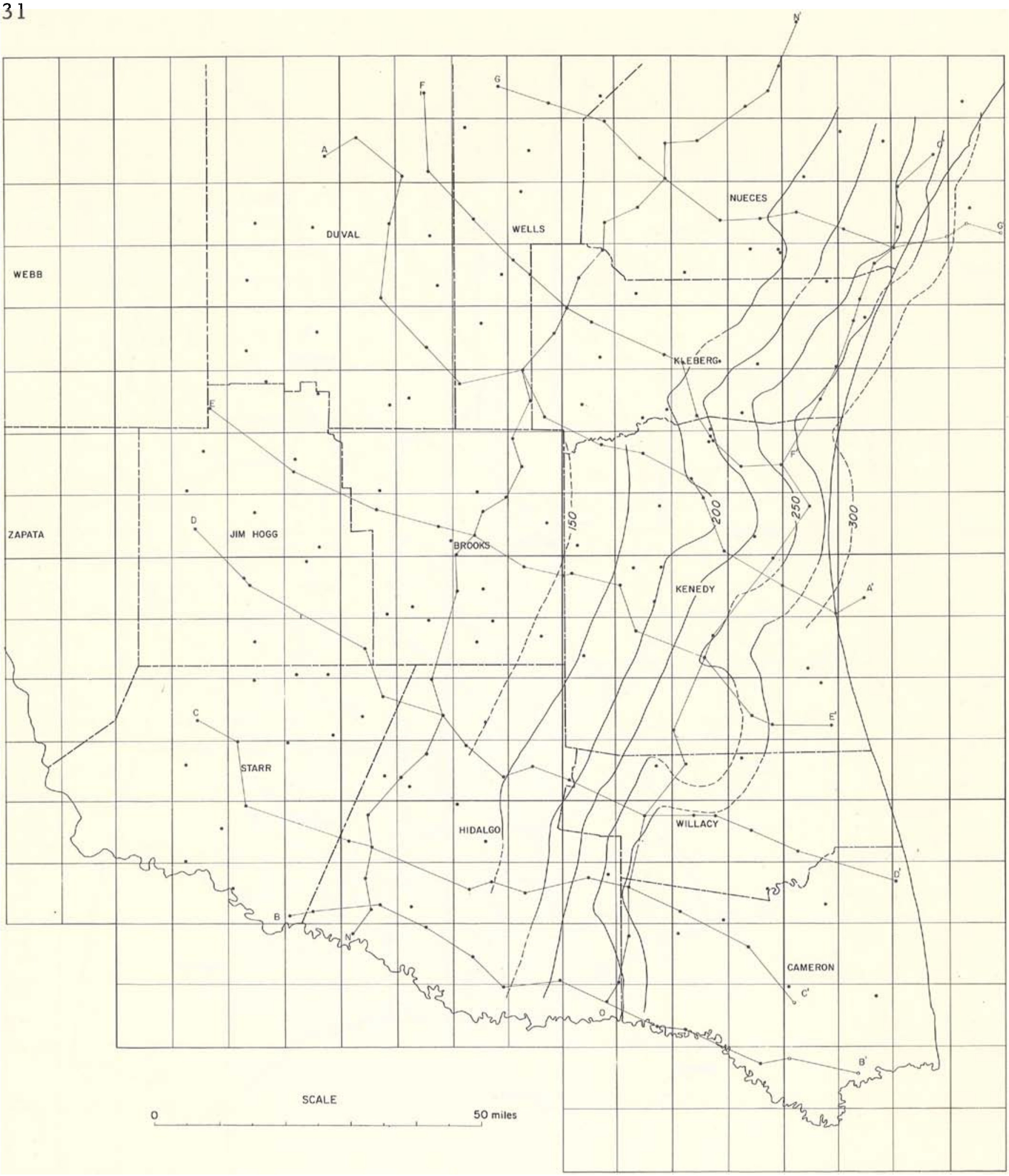


Fig. 23. Isothermal map on T4 datum.

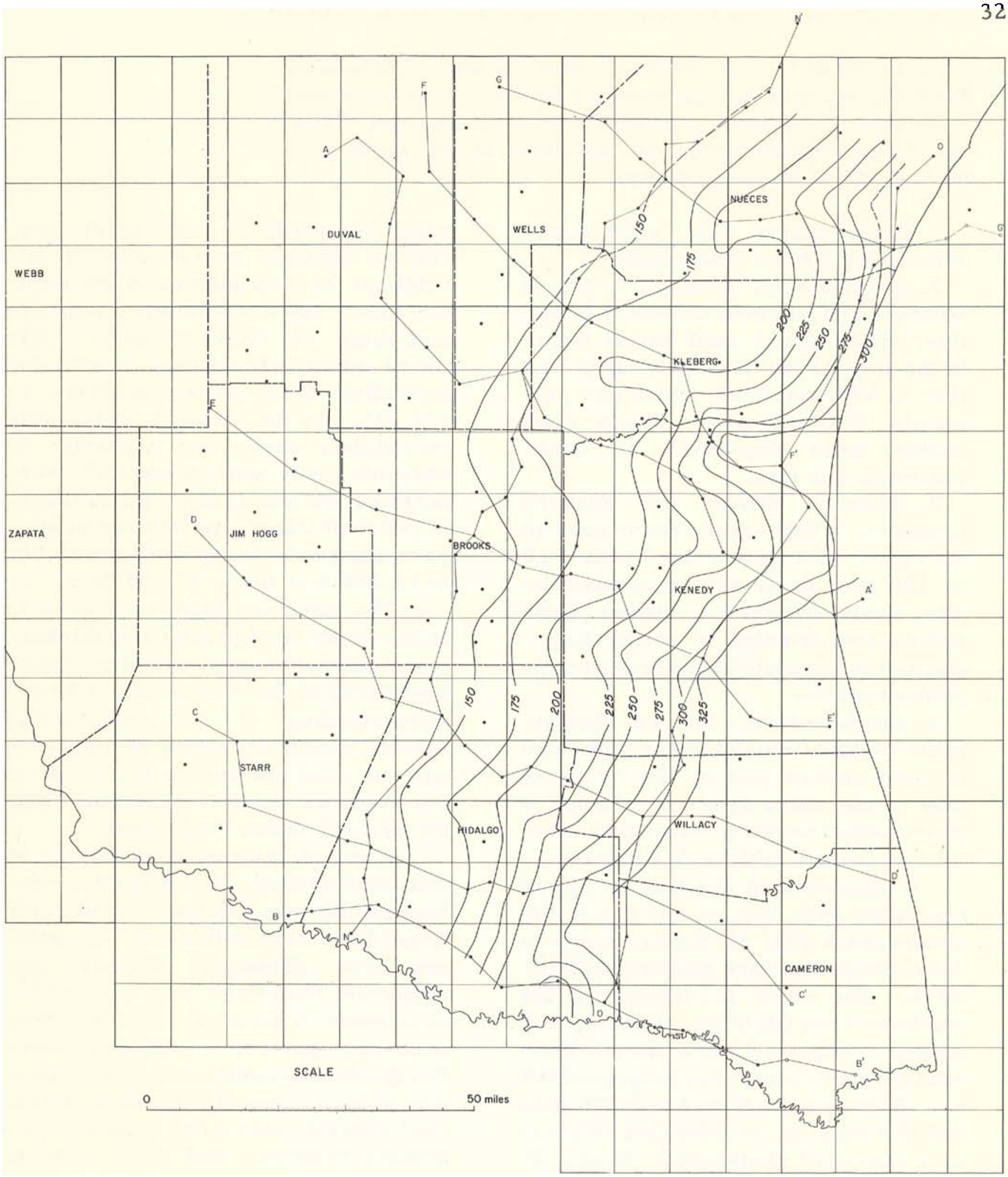


Fig. 24. Isothermal map on T5 datum.

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 occur in the lower Frio in 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 strandplain 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-percentage 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 geopressured 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 geopressured. Thus, the central area is not as prospective for geothermal energy in the Frio section. The contrast in prospectiveness between 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 strandplain 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).

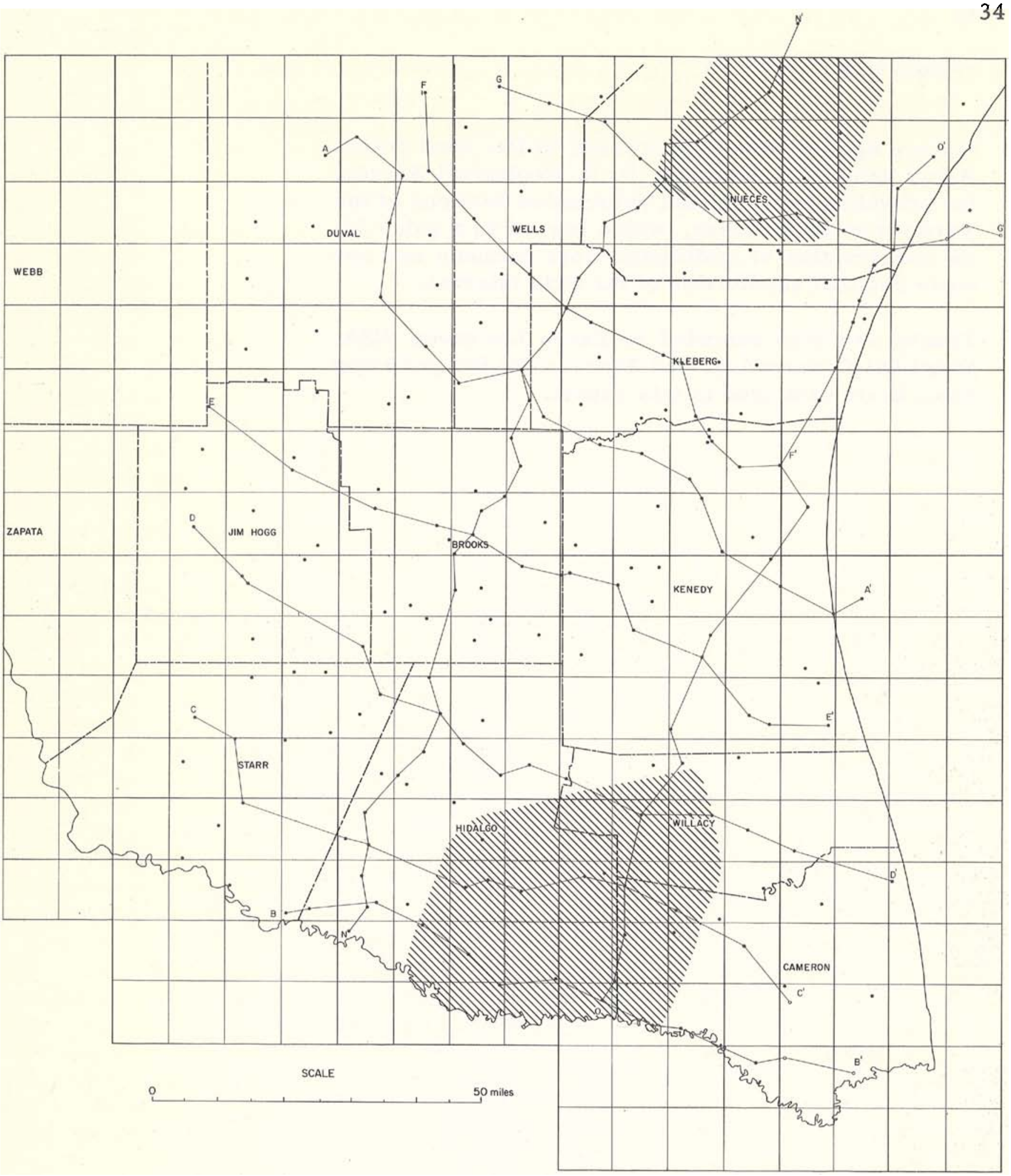


Fig. 25. Potential geothermal fairways.

ACKNOWLEDGMENTS

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Thanks are also extended to Exxon Company, USA, Mobil Oil Corporation, and Tenneco Oil for providing some basic data used in this report.

Cover Map - total thickness of
Frio Formation, South Texas

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