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GEOTHERMAL RESOURCES: FRIO FORMATION, UPPER TEXAS GULF COAST

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KNOWLEDGE OF REGIONAL SAND TRENDS AIDS IN IDENTIFICATION OF GEOTHERMAL FAIRWAYS

The objective of this study is to identify major sand trends, which, along with subsurface temperatures and pressures, aid in evaluating the potential of producing geothermal energy from the Frio Formation, Upper Texas Gulf Coast.

During the Tertiary, huge quantities of terrigenous sediments were deposited as gulfward-thickening sedimentary wedges along the Texas Gulf Coast. The sand and shale making up these wedges were transported across a broad fluvial plain and deposited in deltaic complexes or were reworked by marine processes into strandplains and barrier islands. Growth faults developed contemporaneously at the site of maximum deposition as a result of rapid loading of large quantities of deltaic and strandplain sands onto previously deposited prodelta and shelf muds. These growth faults allowed the accumulation of extremely thick sections of sand and also caused the isolation of many of these sand bodies from porous updip sands; pressured reservoirs developed after further loading and compaction (Bruce, 1973; Jones, 1975).

This study is investigating geopressured geothermal reservoirs in this setting. Limited data obtained from deep wells drilled for oil and gas indicate that many of these large sand reservoirs are filled with water which has high temperature, is relatively low in total dissolved solids, and is saturated with methane gas. To be suitable for electric power generation, the reservoir should have a volume greater than 3 cubic miles (which is equivalent to 300 feet of sand distributed areally over more than 50 square miles), permeability greater than 20 millidarcies, and subsurface temperatures higher than 300°F.

This report reviews the results of the Bureau of Economic Geology regional study of the Frio Formation (fig. 1) in the Upper Texas Gulf Coast (fig. 2). It is a continuation of two similar studies of the Frio in the Lower and Middle Texas Gulf Coast (Bebout, Dorfman, and Agagu, 1975; Bebout, Agagu, and Dorfman, 1975). The objective of these reports is to outline areas (fairways) which appear the most prospective for producing geothermal energy and which therefore deserve further, more detailed study.

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 by the dot pattern.

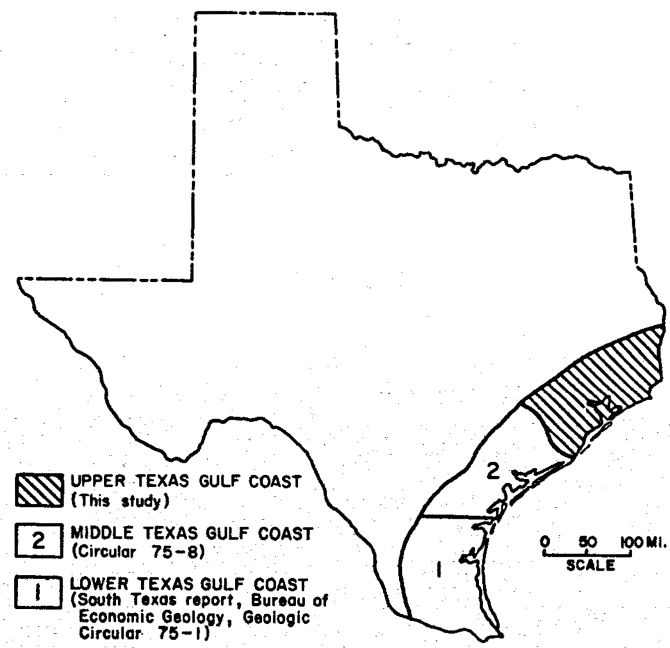


Figure 2. Upper Texas Gulf Coast study area of this report and Lower and Middle Texas Gulf Coast areas reported on previously by Bebout, Dorfman, and Agagu (1975) and Bebout, Agagu, and Dorfman(1975).

FRIO REGIONAL DEPOSITIONAL PATTERNS--UPPER TEXAS GULF COAST

The Frio Formation forms a basinward-dipping wedge of sand and shale which thickens abruptly toward the Gulf.

The Tertiary formations along the Texas Gulf Coast form a number of wedges of sand and shale which dip and thicken toward the Gulf of Mexico (fig. 3). Major growth faults occur toward the downdip end of each wedge. The Frio Formation makes up one of the thicker of these wedges. The Frio is believed to outcrop as the Catahoula Formation which consists largely of terrigenous clay and volcanic ash and of local lenses of sand. At the outcrop, of course, the top of the Frio equivalent is several hundred feet above sea level; at the present-day Gulf Coast, the top of the Frio is deeper than 10,000 feet below sea level (figs. 4 and 6). The Frio is less than 500 feet thick near the outcrop and greater than 8,000 feet thick at the coast (figs. 4 and 7).

The Frio wedge is very similar to other younger and older wedges and is distinguished from these primarily on the basis of marker foraminifers (fig. 5). Foraminifer recognition is dependent upon many factors such as depositional environment (depth of water, temperature, nature of substrate, light, etc.), nature of samples, experience of micropaleontologist, and method of processing samples. In spite of the problems involved, micropaleontological zones aid in gross subdivision of the Tertiary section and provide a general correlation fabric. The base of the Frio, then, is recognized to begin at the first occurrence of Textularia warreni; the top begins at the first occurrence of Marginulina vaginata and below the first occurrence of Heterostegina texana.

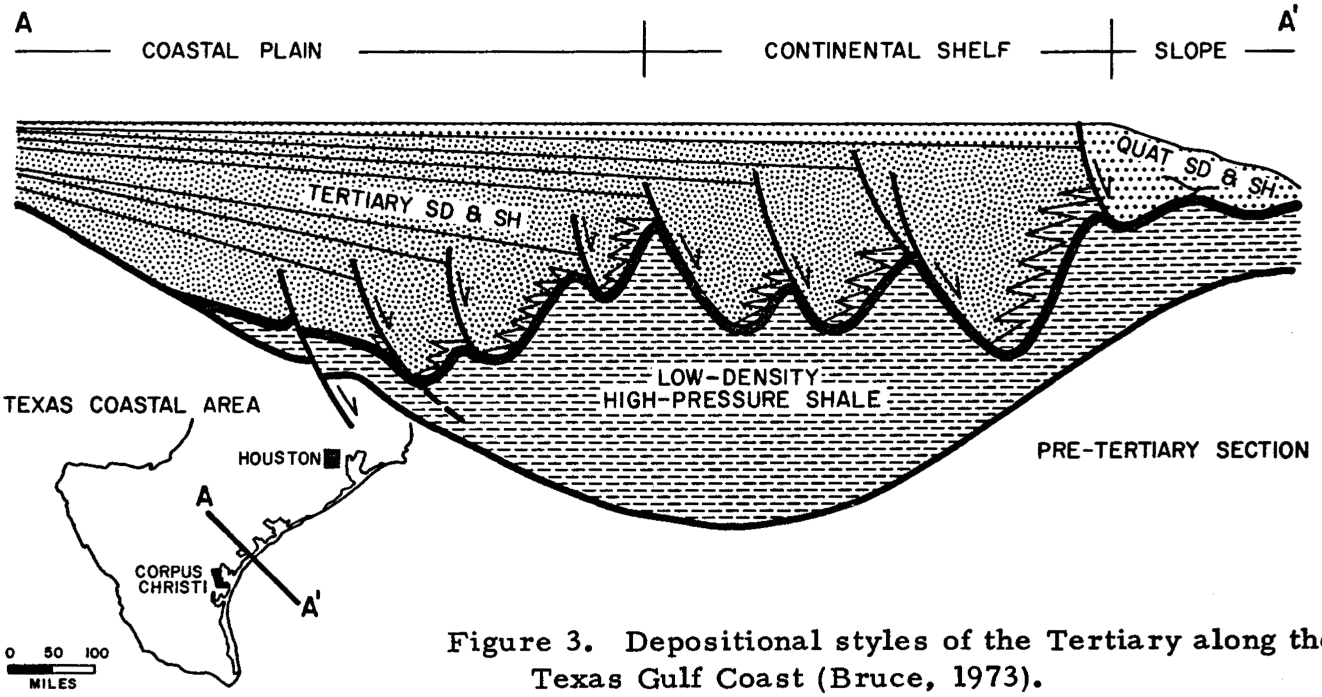


Figure 3. Depositional styles of the Tertiary along the Texas Gulf Coast (Bruce, 1973).

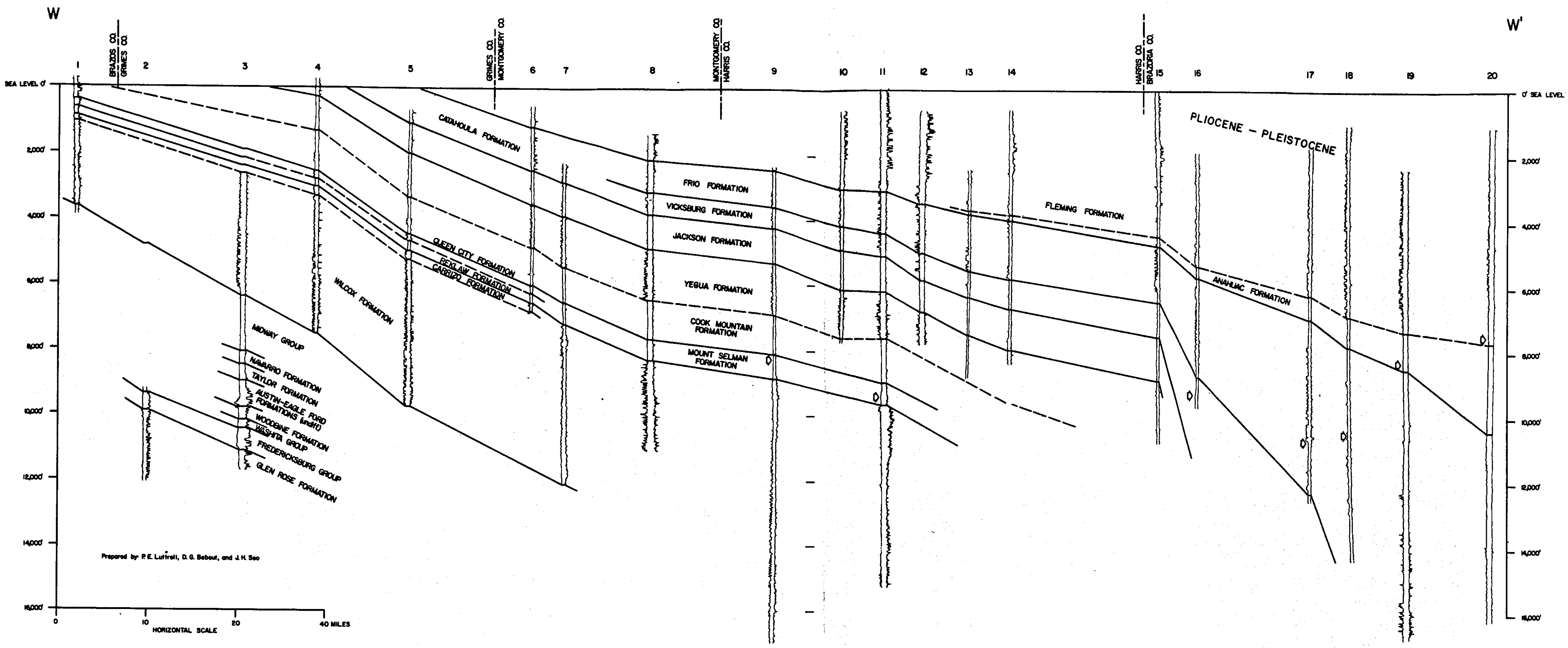


Figure 4. Regional cross section W-W'. The arrow on the left side of most well logs indicates the top of geopressure. The several growth faults which cross this section are omitted in order to maintain continuity of the depositional patterns.

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 5. Foraminifer markers, Texas Gulf Coast Miocene and Oligocene.

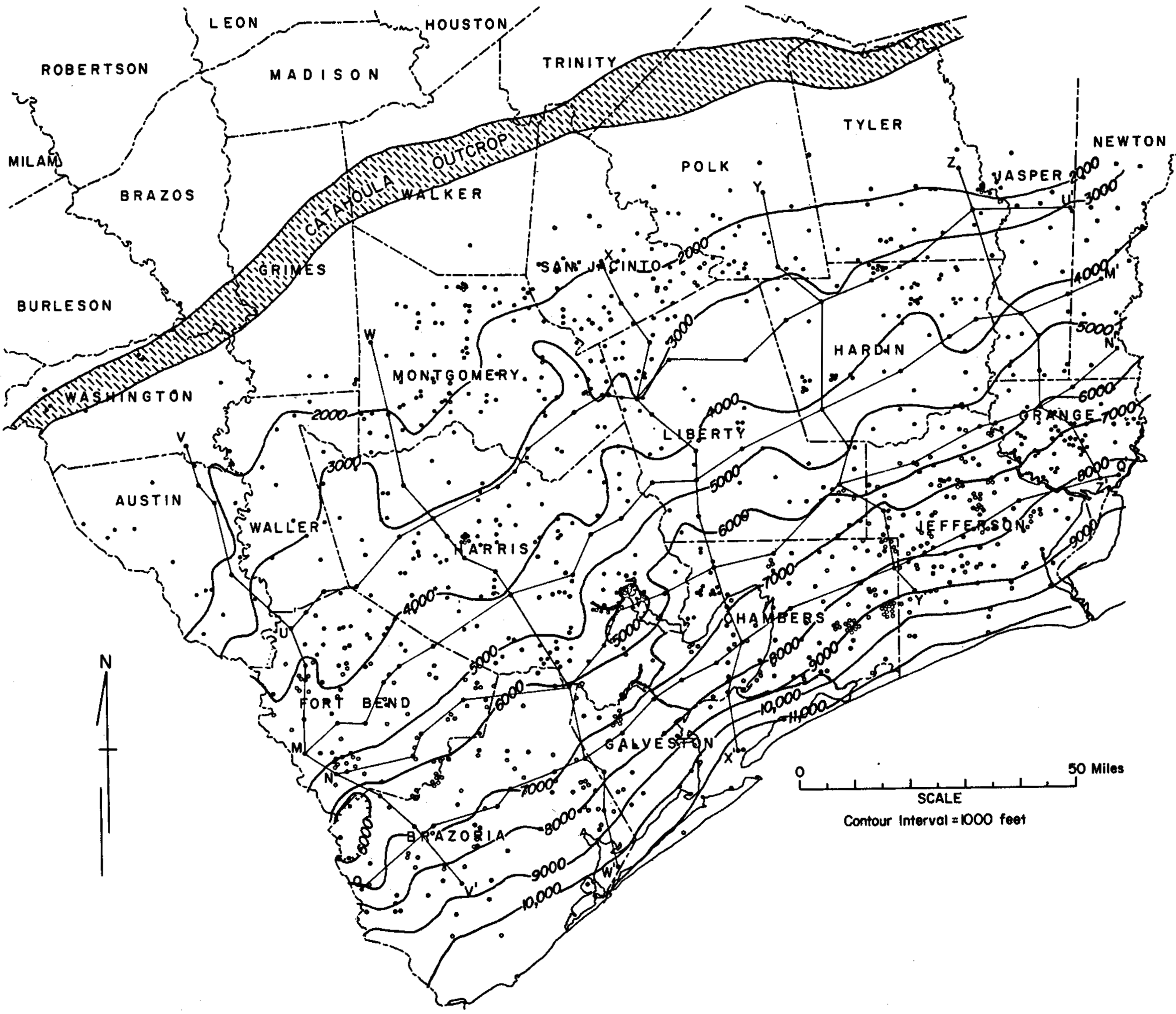


Figure 6. Structure on top of the Frio Formation.

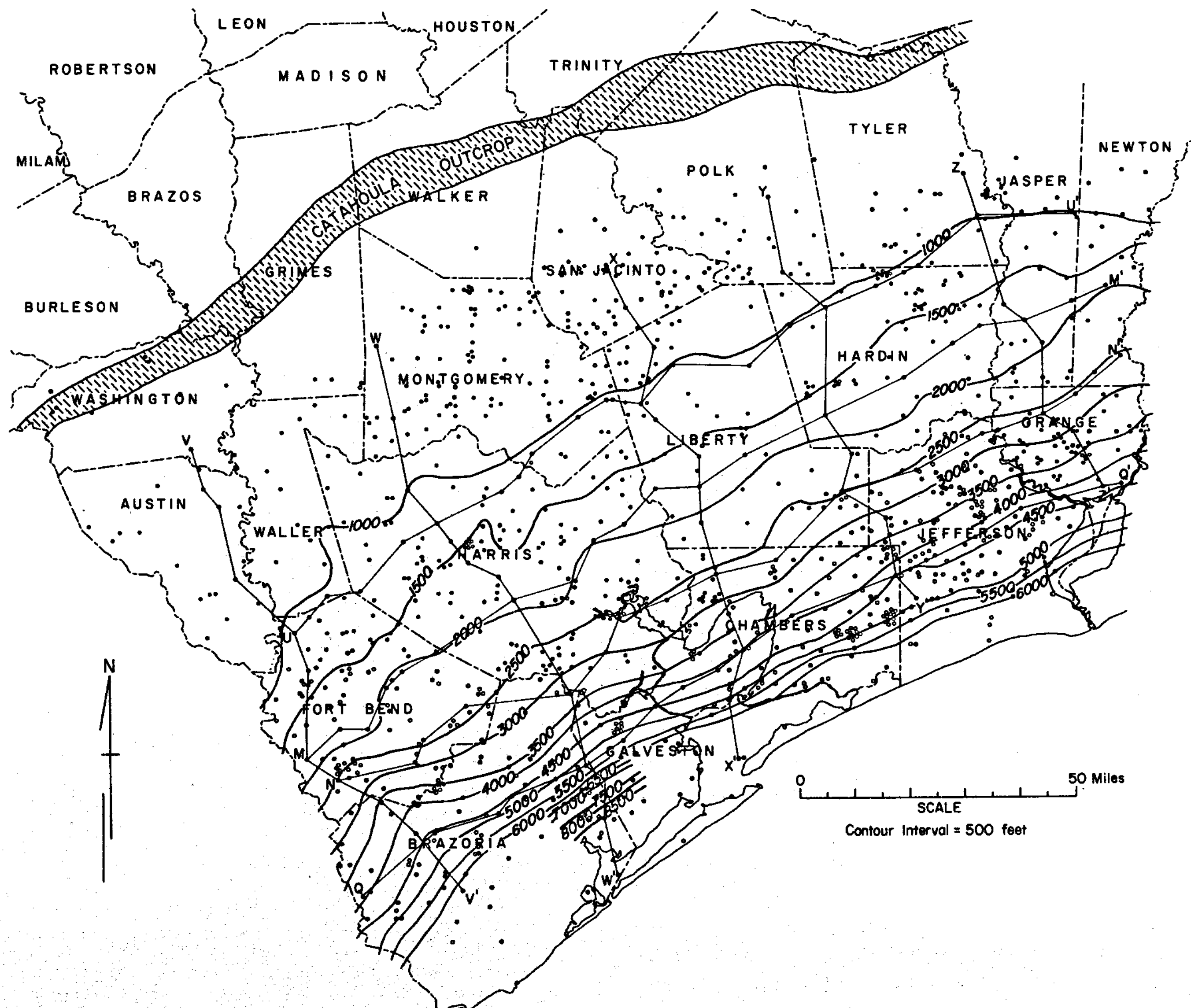


Figure 7. Total thickness of the Frio Formation.

GROWTH FAULTS AND SALT DOMES AFFECT REGIONAL DEPOSITIONAL PATTERNS

Movement of growth faults and salt domes contemporaneous with deposition of Frio sands and shales caused abnormal local thickening and thinning of the section.

Oil and gas exploration along the Texas Gulf Coast has traditionally centered around structures associated with growth faults and salt domes. Contemporaneous downward movement on the downdip or Gulf side of growth faults resulted in the abnormal thickening of sand and shale units and in the development of rollover structures and associated tensional faults which provide closure for many oil and gas reservoirs (fig. 8). Salt domes present during deposition of the Frio caused abnormal thinning of the formation over the structure (fig. 9); later movement of the dome resulted in complex folding and faulting of the formation (Halbouty, 1967). Thickness data from wells so affected are not reliable for regional study; therefore, care was taken to select wells far removed from such structures.

Growth faults which significantly affect Frio sediments are located near the present-day coast (fig. 10). Most of the faults are arcuate shaped in map view and extend laterally along strike approximately 20 to 30 miles. Here, along the Upper Texas Gulf Coast, the growth faults do not have as great a lateral extent or vertical displacement as do those along the Lower and Middle Texas Gulf Coast. Growth faults included on Figure 10 have been highly generalized to show major zones of faulting, and many faults with less than 300-foot displacement have been omitted.

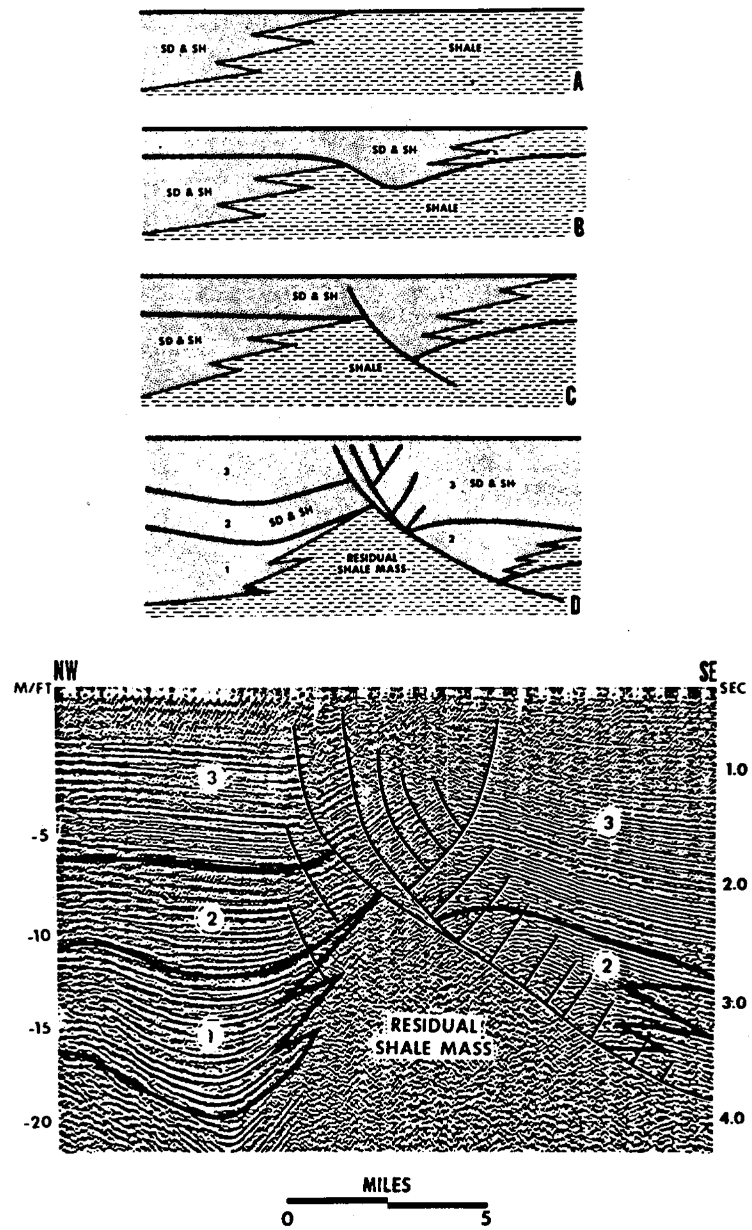


Figure 8. Growth-fault development interpreted from a seismic section and shown sequentially by diagrams (Bruce, 1973).

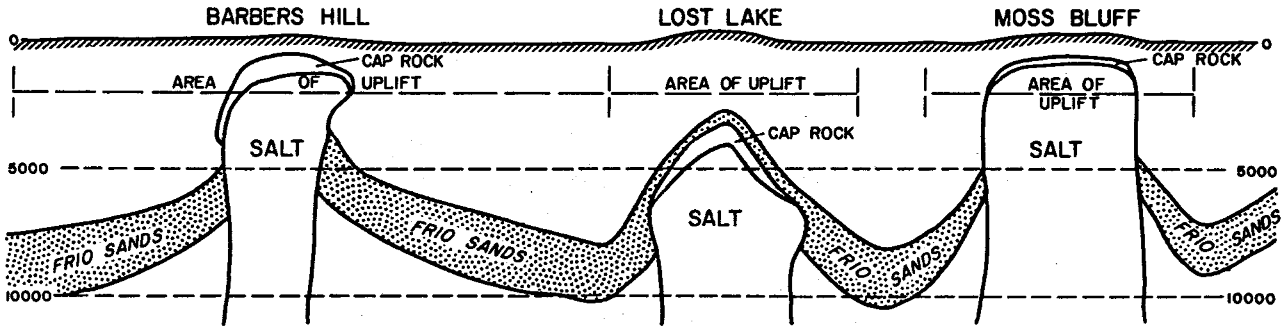
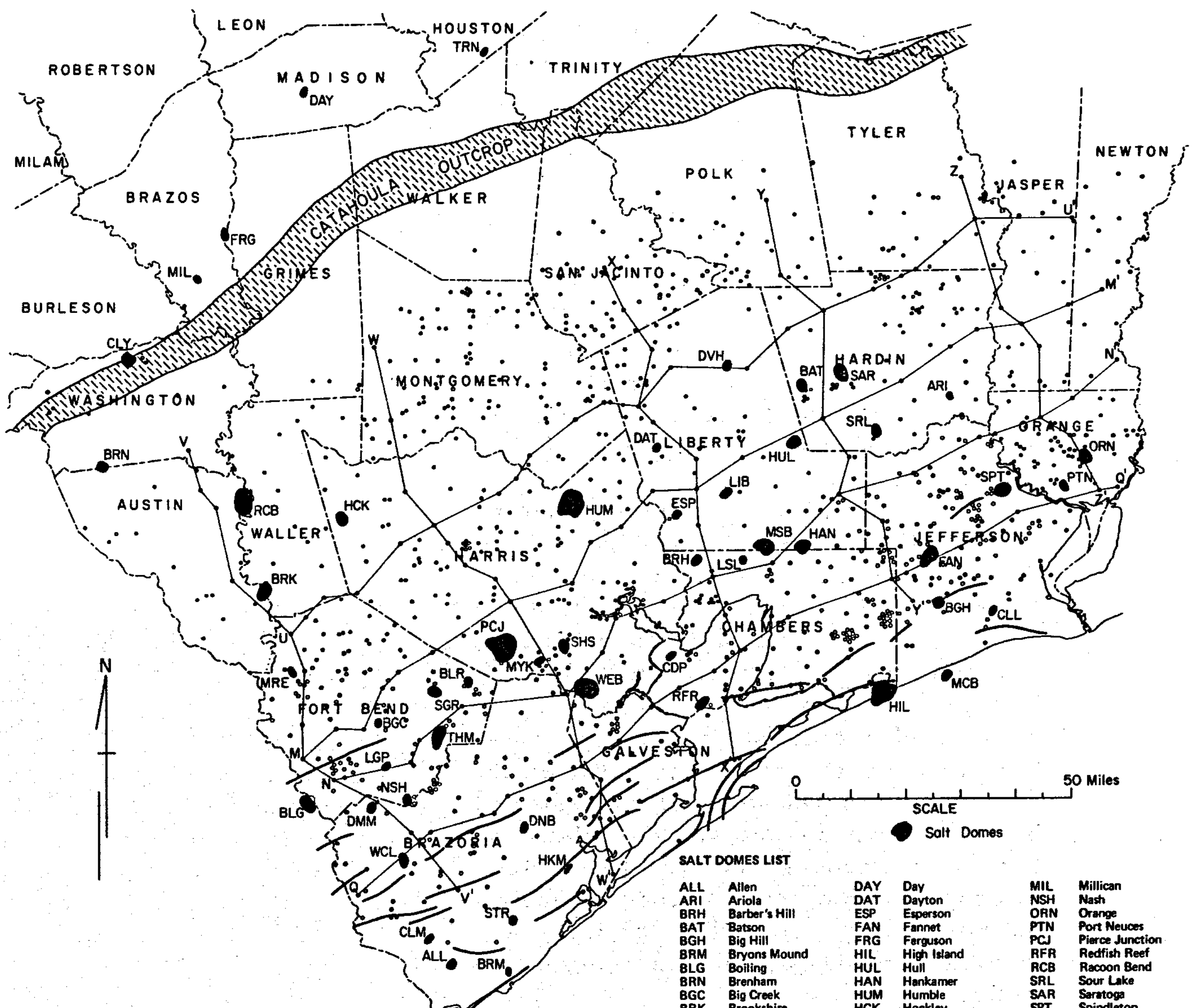


Figure 9. Relationship of Frio thickness to salt-dome structures. Cross section is located on Figure 10 (after Halbouty, 1967).



SALT DOMES LIST

ALL	Allen	DAY	Day	MIL	Millican
ARI	Ariola	DAT	Dayton	NSH	Nash
BRH	Barber's Hill	ESP	Esperson	ORN	Orange
BAT	Batson	FAN	Fannet	PTN	Port Neuces
BGH	Big Hill	FRG	Ferguson	PCJ	Pierce Junction
BRM	Bryons Mound	HIL	High Island	RFR	Redfish Reef
BLG	Boiling	HUL	Hull	RCB	Racoon Bend
BRN	Brenham	HAN	Hankamer	SRL	Sour Lake
BGC	Big Creek	HUM	Humble	SAR	Saratoga
BRK	Brookshire	HCK	Hockley	SPT	Spindletop
BLR	Blue Ridge	HKM	Hoskins Mound	SHS	S. Houston
CLL	Clam Lake	LIB	Liberty	SGR	Sugarland
CDP	Cedar Point	LSL	Lost Lake	STR	Stratton Ridge
CLY	Clay Creek	LGP	Long Point	TRN	Trinity
CLM	Clemens	MCB	McFaddin Beach	THM	Thompsons
DVH	Davis Hill	MSB	Moss Bluff	WCL	W. Columbia
DMM	Damons Mound	MYK	Mykama	WEB	Webster
DNB	Danbury	MRE	Moore		

Figure 10. Major growth faults and salt domes, Upper Texas Gulf Coast. Salt-dome data from Halbouty, 1967.

CONTROL DATA--ELECTRICAL LOGS

Electrical logs from deep wells spaced 5 to 10 miles apart provide control for recognition of sand and shale and for construction of regional sections.

Abundant control for determining the distribution of sand and shale is available from electrical logs from the enormous number of wells drilled in the search for oil and gas along the Upper Texas Gulf Coast. Previous studies by Fisher and McGowen (1967), Fisher and others (1970), Guevara and Garcia (1972), Bebout, Dorfman, and Agagu (1975), and Bebout, Agagu, and Dorfman (1975) indicate that well spacing of 5 to 10 miles apart is optimal for regional studies. Closer control involves complex correlation problems caused by minor facies changes or local structure near growth faults and salt domes. Wells which penetrate the entire Frio were selected in all cases except along the downdip portion near the coast where few wells penetrate the whole formation.

Data from 465 wells were used in this study of the Upper Texas Gulf Coast (fig. 11). A grid of 5 dip and 4 strike sections was constructed in order to develop the basic correlations between wells. Then, "infill" wells between the cross sections were correlated into the sections. Correlation into cross sections is believed to be superior to well-to-well correlation because cross-section correlations take into account regional facies and micropaleontological trends updip, downdip, and laterally as well as vertical trends within the individual wells.

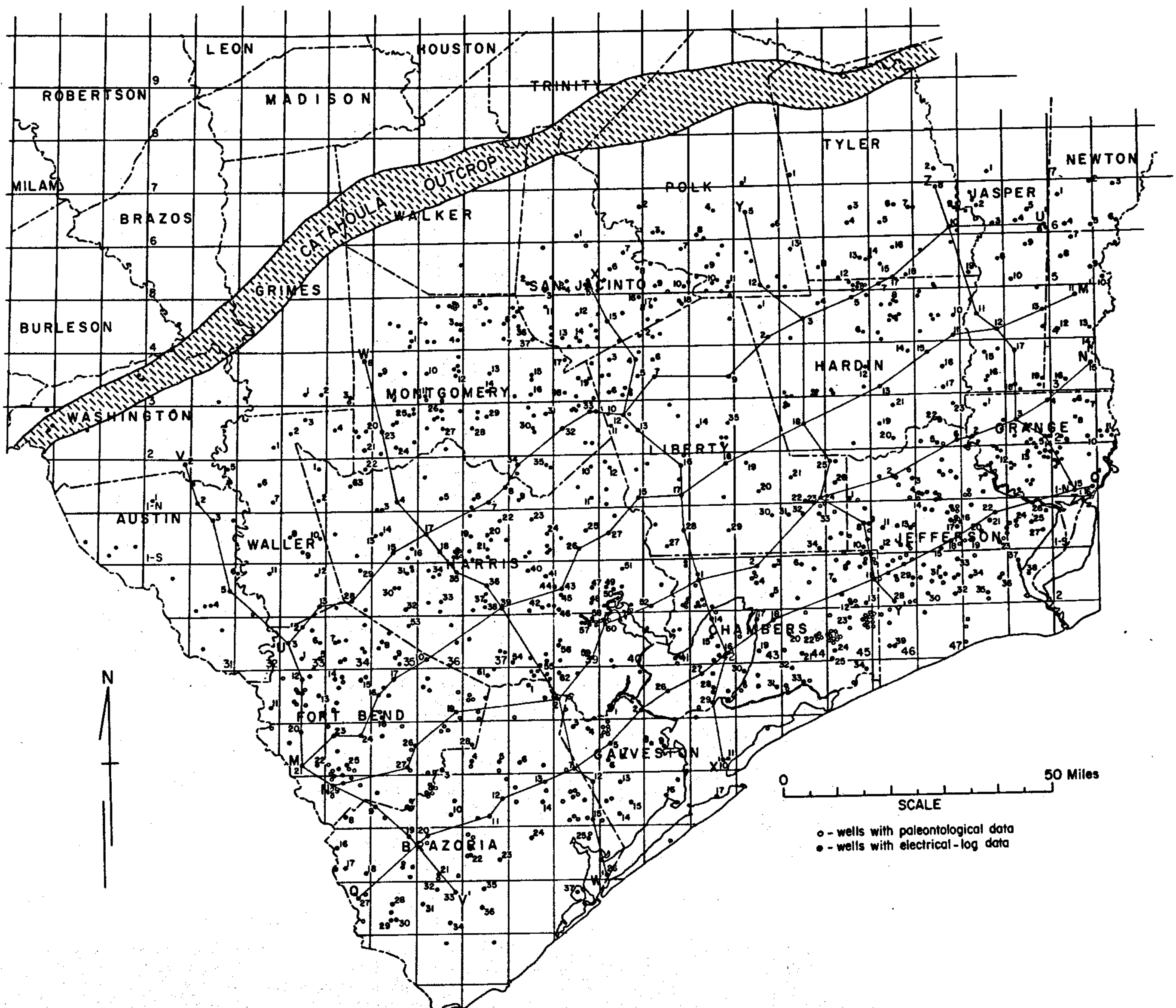


Figure 11. Well-log control and cross sections constructed for the Upper Texas Gulf Coast study. Wells are identified on pages 11 through 14.

LIST OF WELLS

Austin County

1. Sun Oil Co. — Von Rosenburg #1
2. Skelly Oil Co. — Zander #1
3. H. L. Hawkins — Mewis #1
4. Shell Oil Co. — Cole #1
5. Lueth & Robishaw — O. C. Kurtz #1
6. N. L. Causey — Ernest Steck #1

Brazoria County

1. Willard Gill Petroleums — Mitchell et al. Unit #1
2. Gulf Coast Leaseholds, Inc. — Yost #1
3. Beck Oil Co. & Oil Properties, Inc. — Sara West Heirs #1
4. Texas City Refining Co. — Sharp Corporation #1
5. Hargrave Oil Corp. — Fred Klobouk #1
6. Skelly Oil Co. — A. W. Adam #1
7. The Superior Oil Co. — Conklin Oil Unit #1
8. Rowan Drilling Co. — Krause #1
9. Pan American Prod. Co. — N. W. Hopkins #1
10. Southern Minerals Corp. — Ramsey State Farm #1
11. Davis Oil Co. — R. J. Loatracco #1
12. Union Texas Petr. Corp. — J. T. Garrett #1
13. Brown & McKenzie, Inc. — Clark Estate #1
14. Pan American Prod. Co. — Callihan Unit #1
15. Phillips Petr. Co. — Houston "JJ" #1
16. Caroline Hunt Trust Est. — Minot T. Pratt #1
17. Humble Oil & Refining Co. — M. McFarland #2
18. Southwest Gas Producing Co. — McDonald #1
19. Kirby Petr. Co. & Russell McFarland — Kittie Nash Groce #1
20. Pan American Petr. Corp. — T. L. Smith Heirs #1
21. F. A. Callery, Inc. — Houston C. Munson #A-1
22. Monsanto Co. & Pan American Petr. Corp. — Stashy #1
23. Pano Tech Expl. Corp. — Jaminson #1
24. Humble Oil & Refining Co. — J. M. Skrabanek #1
25. Phillips Petr. Co. — Houston "LL" Well #1
26. Phillips Petr. Co. — State Lease 51000 Bl. 32 Well #1
27. Lone Star Prod. Co. — H. A. Frede #1
28. Michel T. Halbouty — Marie O. Ellis #1
29. Pan American Petr. Corp. — B. R. L. D. Co. #A-1
30. Davis Oil Co. — Miller #1
31. Pan American Petr. Corp. — Ida Hobbs #1
32. Humble Oil & Refining Co. — Ward-Byers #1
33. Mobil Oil Corp. — Retrieve State Farm Tract 1 Well #1
34. Monsanto Co. — Austin #1
35. Humble Oil & Refining Co. — Retrieve State Farm Tract 4 Well #1
36. Continental Oil Co. — White-Frost Unit #1
37. Gulf Oil Corp. — Texas State Lease 53034 Well #2

Chambers County

1. Kirby Petr. Co. — Kirby Petr. Co. Fee Tract 8 #1
2. Earl T. Mackey — J. R. Tompkins #1
3. Superior Oil Co. — J. T. White #1
4. John F. Anderson — Turtle Bay State Tract 39 Well #1
5. Pel-Tex, Inc. — Curtis Penick et al. #1
6. Sunray DX Oil Co. — James C. Hall #1
7. Texas Consolidated Petr. Co. — Copper #1
8. Sun Oil Co. — Moore Estate #2
9. Humble Oil & Refining Co. — W. Winnie Oil Unit #1, Well #1
10. McCarthy Oil & Gas Corp. — Klein et al. #1
11. Belco Petr. Corp. — Ruby Taylor #1
12. Windsor Oil Co. — R. L. White #1
13. Skelly Oil Co. — W. M. Wangler #1
14. Skelly Oil Co. — Gulf J #1
15. Getty Oil Co. — State Tract 48 #1
16. McMoran Expl. Co. — State Tract 64, Well #1
17. Al Brown — #1 Fahring Est. Unit
18. Pan American Petr. Corp. — C. A. Kierke #1
19. Pel-Tex Petr. Co. — Henry Gau Estate #1
20. Coastal States Gas Prod. Co. — D. J. Cline #1

Chambers County (cont'd.)

21. Continental Oil Co. — Pearl R. Jackson #3
22. Occidental Petr. — T. Middleton #1
23. Texaco, Inc. — O. H. Acom #1
24. Shell Oil Co. — Barrow Ranch #2
25. Skelly Oil Co. — #1-A Barrow Ranch
26. Superior Oil Co. — State Tract 252, Well #1
27. Pennzoil Prod. Co. — State Tract 100, Well #2
28. Exxon — Galveston Bay State #A-173
29. Humble Oil & Refining Co. — State Tract #244, #A-103
30. Getty Oil Co. — State Tract #80, Well #1
31. Humble Oil & Refining Co. — Moody Foundation #2
32. Placid Oil Co. — G. R. Canada #1
33. Humble Oil & Refining Co. — G. C. Jackson #1
34. John W. Mecom — T. Middleton et al. #1

Fort Bend County

1. Scurlock Oil Co. — McMillan Farms #1
2. Scurlock Oil Co. — Virginia J. Meek #1
3. W. S. Boyle et al. — Spencer #1
4. Continental Oil Co. — Bruner #1
5. Russell Maguire — Averill #2
6. Meredith & Co. — Lulu Lloyd #1
7. Magnolia Petroleum & Seaboard Oil Co. — Elizabeth McKennon #1
8. Standard Oil Co. of Texas — W. G. Wing et al. 1 - #1
9. Falcon Seaboard Drilling Co. — A. R. Dillard #1-A
10. M. P. S. Production Co. — Sugarland Ind. #1
11. Warren Petr. Corp. — A. Kelner #1
12. Titanic — Mazola #1
13. Russell Maguire — Moore #2-A
14. Lenoir M. Josey Inc. — Foster Farms #1
15. Fort Bend Oil Co. — George & Collins #1
16. Sorelle & Sorelle — Wessendorff #1
17. H. C. Cockburn — Clayton Foundation #1
18. Fort Bend Oil Co. — Thomas R. Booth #1
19. Pure Oil Co. — N. B. Knight #1
20. Scurlock Oil Co. & M. T. Halbouty — Dennis Krause #1
21. Fort Bend Oil Co. — J. M. Moore Estate #1
22. General Crude Oil Co. — Stavinoha #1
23. Windward & H. B. Ownby — F. W. Sims #1
24. Gulf Coast Leaseholds — Frank Chaloupka #1
25. Grover J. Geiselman — Schendel Gas Unit #1
26. Atlantic Refining Co. — Julius M. Gurbels #1
27. Slade Oil & Gas, Inc. — Sallie Brown Kennelly #1
28. J. K. Dorrance — J. E. Foster #1
29. The Oil & Gas Co. — Byrne #1

Galveston County

1. Sparta Oil Co. — W. W. Landrum et al. #1
2. Russell Maguire — Ed Taylor #1
3. Pan American Petr. & Wesley West — Jockusch Oil Unit #1
4. Patrick R. Rutherford — F. K. Miller #1
5. Cities Service Petr. Co. — Stewart #B-2
6. Rowan Oil Co. & Texas Gulf Prod. — Mrs. Corine Scott #1
7. Placid Oil Co. & The Texas Co. — H. D. Cross #1
8. Humble Oil & Refining Co. — Bayou Dev. Co. Well "B" #14
9. Superior Oil Co. — Superior Oil Co. Fee #1
10. Houston Oil & Minerals — E. W. Boyt #1
11. Houston Oil & Minerals — State Tract 342 #1
12. The Texas Company — J. W. Harris #B-1
13. Hassie Hunt Trust Co. — Benn Sass #1
14. Mobil Oil Corp. — Halls Bayou Ranch #1
15. Texas Eastern Transmission — S. L. Henck #1
16. Humble Oil & Refining Co. — State Tract #81 Well #1
17. George Mitchell & Assoc. — Galveston Townsite Unit 2, Well #1

Grimes County

1. Gulf Oil Corp. — Wm. Gardner #2
2. Millican Oil Co. — Mike Harris #2
3. Glenn H. McCarthy — Gibbs-Elgin et al. #1

LIST OF WELLS (cont'd.)

Hardin County

1.	Austral Oil Co.	A-S 6731 #1
2.	A. A. Spidle	#1 A. A. Spidle Kirby Unit #1
3.	International Nuclear Corp.	Harris #1
4.	Belco Petr. Corp.	Atlantic Fee #3
5.	Atlantic Refining & Sinclair Oil & Gas	Hardin Co. School Land #1-A
6.	Atlantic Refining & Sinclair Oil & Gas	P. A. Works Fee #1
7.	Prairie Prod. Co. & Convest & Macpet	Nona Fletcher et al. #1
8.	Pan American Prod. Co.	Sternenberg #B-1
9.	Gordon Street & Ada Oil Co.	Sternenberg "X" #1
10.	International Nuclear Corp.	Atlantic #1
11.	Sinclair Oil & Gas Co. & Atlantic Refining Co.	H. McGill #4
12.	Dominion Corp.	William Seale et al. #1
13.	Cyprus Oil Co.	Dishman #1
14.	Neches Expl. Corp.	Harvey #1
15.	Mobil Oil Corp.	#1 Arco Fee Block "D" Hardin Co.
16.	Prudential Drilling Co.	#1-A Arco Bradley Fee
17.	Kelly-Brock	Fee #1 Arco Montgomery
18.	Sun Oil Co.	Alexander #2
19.	The Texas Co.	F. M. Carpenter Jr. #1
20.	Pel-Tex-McMoran-Equitable	Kirby Lumber Co. #1
21.	J. C. Chance Well Service	Nona Mills #1
22.	Clegg & Hunt	The Keith Co. #1
23.	Dow Chemical Co.	Kirby-Hosford #1-A

Harris County

1.	Sinclair Oil & Gas Co.	Henry Krezdorn #1
2.	Zeni Oil Co.	Perkins #1
3.	Austral Oil Expl. Co.	Wm. A. Schuenmann #1
4.	Texaco, Inc.	M. H. Mergele #1
5.	Slick Oil Corp.	Paul H. Jackson #1
6.	Sorelle & Sorelle	P. E. Smith #1
7.	Houston Natural Gas Prod. Co.	H. W. Tanneberger #1
8.	William K. Davis	Alvina Couch Unit #1
9.	Ginther, Warren & Ginther	J. N. Taub Est. #1
10.	B. M. Hester	U. S. Plywood-Champion Paper #1
11.	Humble Oil & Refining Co.	Foster Lumber Co. #1
12.	Lone Star Prod. Co.	Janet House Auchincloss #1
13.	Standard Oil Co. of Texas	H. J. Longenbaugh #1-1
14.	Standard Oil Co. of Texas	Lenoir M. Josey et al. #1
15.	Standard Oil Co. of Texas	G. J. Mellinger et al. 4-#1
16.	Pan American Petr. Corp.	Gus S. Wortham #1
17.	Oil Properties Inc.	Anna M. Gaylor #1
18.	Pan American Petr. Corp.	Dorothy D. Brown #1
19.	Texaco, Inc.	#1 Sharman Gas Unit No. 1
20.	Currie B. Davis	Carry House #1
21.	Kilroy Co. of Texas	Mary L. Ingersoll #1
22.	Kilroy Co. of Texas	Merrill #1
23.	Texland Prod. Corp. & H. L. Dillon	Grossman #1
24.	Noble Ginther	Ginther Fee et al. #1
25.	Russell Maguire	Scanlan A #1
26.	Houston Oil Co.	Swilley #1
27.	Woodward & Co.	Annie Pechanec #1
28.	Scurlock Oil Co.	James C. Arnold #1
29.	Salt Dome Oil Corp.	David R. Rorick #1
30.	Artex Oil Corp.	Lillian W. Fleming #1
31.	Jack W. Frazier	H. J. Marks #1
32.	E. B. Cox & J. L. Hamon	Lydia Marquart #1
33.	Moran Oil Co.	Hayes #1
34.	Hankamer Investment Co.	G. H. Spencer #1
35.	Carl Casey	R. H. Austrey #1
36.	Jack Frazier	Laura Lackner #1
37.	Tidewater	Roy #1
38.	Sparta Oil Co.	J. Harvey Suttles #1
39.	Carrie B. Davis	Susholtz #1
40.	Rutherford & Royal	First Natl. Bank of Houston #1
	Eddy Refining Co.	Goodrich #3
	Stanolind	D. A. Oates #1

Harris County (cont'd.)

43.	Goby	Hunt #1
44.	Eddy Refining Co.	County of Harris #1
45.	Stanolind Oil & Gas Co.	John W. Van #1
46.	Sun Oil Co.	Oates #1
47.	Humble Oil & Refining Co.	M. O. Furr #1
48.	Inexco Oil Co.	H. C. & H. S. C. Navigation Dist. #1
49.	M. N. Stafford	R. H. Weiss #B-1
50.	Macdonald Oil Corp.	#B-1 R. H. Weiss
51.	Petroleum Corp. of Texas	Meyer Est. #2
52.	The Texas Co.	Mrs. Emma K. Busch Est. #1
53.	J. C. Wynne & R. H. Hedge	Winkleman #1
54.	J. P. Petkas	Lucien Bukowski #1
55.	Commerce Oil Co.	Meadowbrook #1
56.	Stanolind Oil & Gas Co.	Staiti #1
57.	Tenneco Oil Co.	Shell Oil Co. #1
58.	Inexco Oil Co.	Kelly Brock #A-1
59.	Bradco Oil & Gas Co.	Bishop & Sowden #1
60.	Midwest Oil Corp.	Rohn Haas No. 1
61.	Jack W. Frazier	Louis #1
62.	Humble Oil & Refining Co.	#1 Second National Bank of Houston
63.	N. B. Hunt	August E. Hegar #1

Jasper County

1.	Sun Oil Co.	Kirby Lumber Co. #1
2.	Mayo	Cartwright #1
3.	Prudential Drilling Co.	Arc-Blount #1
4.	Hanson	Arco-Sec 8 #1
5.	Conroe	Van Pelt #1
6.	Davis Oil Co.	Arco Fee #1
7.	Kerr-McGee	Atlantic-Sinclair #1-B
8.	International Nuclear Corp.	#1 Arc-Allen
9.	Prudential Drilling Co.	Arco Section 29 Fee #1
10.	Kelly-Brock	A. R. C. O. Medrano #1
11.	Gulf Oil Corp.	Temple Lumber Co. Well #1
12.	Mobil Oil Co.	Atlantic-Richfield Sec. 77 #1
13.	Apache Corp. et al.	Martin Foley Gas Unit #1
14.	Prudential Drilling Co.	Arco Section 93 Fee #1
15.	International Nuclear Corp.	A. R. C. Craig #1
16.	Kelly-Brock	Miller-Vidor #1
17.	White Shield Oil & Gas Co.	Southwest Timber #1
18.	Phillips Petr. Co.	Vidor #1
19.	Lacoastal Petr. Corp.	Kirby Lumber Co. #2

Jefferson County

1.	Lawrence J. Kelley	B. H. Willis Estate #1
2.	Texaco, Inc.	P. R. Leger #1
3.	Rowan & Nichols	Melancon #1
4.	Crown Central Petr. Corp.	M. Guiterman "A" #1
5.	Amoco Prod. Co.	Caswell Trust #4
6.	Sun Oil Co.	H. E. Winn #1
7.	Atlantic Refining Co.	Willer Vidor #1
8.	Glenn H. McCarthy	Bauer #1
9.	Cyprus Oil Co.	Lonman-Howth Unit #1
10.	McCarthy Oil & Gas Co.	Klein et al. #1
11.	Petroleum, Inc. & J. M.	Gilbert Estate #1
12.	Prudential Drilling Co. et al.	Robertson-Lohmann Unit #1
13.	Placid Oil Co.	Alexander Wolbert #1
14.	Rebel Corp.	No. 1 Weed, Side Track #1
15.	Macpet and Dow Chemical Co.	G. D. Clubb et al. #1
16.	Gulf Oil Corp.	Rake #1
17.	Humble Oil & Refining Co.	Broussard #B-1
18.	Prudential Drilling Co.	Floyd C. Smith #1
19.	Dan J. Harrison, Jr.-Ferguson & Bosworth	State Gaulding Gas Unit #1
20.	Texaco, Inc.	#1 Bordages State Gas Unit #1
21.	Humble Oil & Refining Co.	J. E. Klaver #1
22.	Kirby Petr. Corp.	S. Wedgeworth et al. Unit #1
23.	Shell Oil Co.	Tyrrell-Combest Realty Co. #1
24.	Trice Prod. Co.	Lum C. Edwards #1
25.	Meredith & Co.	
26.	Sun Oil Co.	#1 Howeth Fee
27.	Michel T. Halbouty	Flanagan #1
28.	Belco Petr. Corp.	Crawford 161 #2

LIST OF WELLS (cont'd.)

Jefferson County (cont'd.)

29.	William K. Davis	Eunice Arceneaux #1
30.	General Crude Oil Co.	Nold #1
31.	Tenneco Oil Co. & Humble Oil & Refining Co.	Mamie McFaddin Ward #1
32.	Amoco Prod. Co.	API No. 42-245-30186
33.	Sohio Petr. Co.	B. C. Hebert Heirs #1
34.	Houston Natural Gas Co.	Broussard Heirs #1
35.	Amoco Prod. Co.	McFaddin Ranch B-#1
26.	Magnolia Petr. Co.	McFaddin #B-1
37.	Gulf Oil Corp.	Port Arthur Refinery Fee #1
38.	Humble Oil & Refining Co.	State Tract 38 Well #1
39.	McDonald Oil Co.	Hebert #1

Liberty County

1.	Floyd L. Karsten	English #1
2.	Oil Reserves Corp.	#1 Ed Jefferson
3.	George Mitchell & Assoc.	#1 H. R. Cherry
4.	Gulf Oil Corp.	Kirby Lumber Co. #C-1
5.	General Crude Oil Co.	Davis Hill #1
6.	Superior Oil Co.	T. J. Hightower #1
7.	H. J. Porter & Phillips Petr. Co.	Champion #1
8.	Cherryville Corp.	Thelma Jackson #1
9.	Texas Gas Expl. Corp. & Dodgen Oil & Gas	Nona Mills #1
10.	Acorn Oil Co.	C. C. Berry #1
11.	General Crude Oil Co.	McClain #1
12.	Humble Oil & Refining Co.	B. E. Quinn #B-1
13.	James B. Fuller et al.	Foster Lumber Co. #1
14.	The Texas Co.	Blanding #1
15.	T. G. Anderson & E. L. Bowman	Kovalcik #1
16.	Peninsula Exploration Co.	Creel #1
17.	Amerada Petr. Co.	R. C. Brown #1
18.	General Crude Oil Co.	Brauer #1
19.	Lamar Hunt Trust Est.	Carr Development Co. #1
20.	Bankline Oil Co.	W. D. Gordon #1
21.	Texaco, Inc.	Price Daniel #1
22.	National Assoc. Petr. Co.	B. H. Willis #1
23.	Stan Pyndus	#1 Hope I. Able
24.	Texaco, Inc.	Curtis Hankamer #1
25.	Sun Oil Co.	Stone #1
26.	Humble Oil & Refining Co.	M. E. Pickett #1
27.	Michel T. Halbouty	Kirby Petr. Co. #E-1
28.	General Crude Oil Co.	Moore's Bluff #D-1
29.	John W. Mecom	Lacy Armour #1
30.	Tarpon Oil Co.	Bailey Unit #1
31.	Group Oil Co.	Elkins #1
32.	Shell Oil Co.	B. H. Willis Estate #1
33.	Herbert Hunt Trust Estate	E. W. Boyt #1
34.	Wesley West	C. K. Boyt #1
35.	David C. Bintliff	C. C. Edge et al. #1

Montgomery County

1.	Capitol Co.	Alliance Trust #1
2.	G. C. Garvey	Foster Estate #1
3.	Superior Oil Co. & C. D. Speed	James B. Sykes #1
4.	B. B. Burke	Ferguson #1
5.	The Moran Corp.	W. T. Hooper #1
6.	Oil Reserves Corp.	Foster Estate #1
7.	Texmo Oil Co.	Hutchings-Sealy Natl. Bank #3
8.	Petroleum Management Co.	Jones & Shands #1
9.	Emanuel Lester	Earl White #1
10.	Socony-Mobil Oil Co.	Sealy-Smith Foundation #1
11.	George Mitchell & Assoc.	Fred B. Asche et al. #1
12.	General Crude Oil Co.	Sealy-Smith #1
13.	Hagan & Litchfield	Harris & Freeman #1
14.	Skelly Oil Co.	Gertrude Tipton #1
15.	Texaco, Inc.	B. D. Griffin #1
16.	Floyd L. Karsten	Knapp #1
17.	J. S. Abercrombie	Glenna M. Aylor #1
18.	Head & Welsh & Loftin	#1 Southland Paper Mills
19.	Amerada Petr. Co.	Foster Lumber Co. #1

Montgomery County (cont'd.)

20.	Glenn McCarthy	Tucker #1
21.	Ralph A. Johnston	J. M. Frost III et al. #1
22.	Sinclair Oil & Gas Co.	McCrabb #1
23.	Steve Gose	K. K. Kramer #1
24.	Commercial Petr. & Transport Co.	Pills & Leyle #1
25.	Pan American Prod. Co.	#1 Winslow
26.	Stanolind Oil & Gas Co.	McMahon #1
27.	Moran Corp. - Columbia Drilling Co.	M & M Minerals #1
28.	Sinclair Oil & Gas Co.	Grogan-Cockran Lumber Co. #1
29.	N. B. Hunt	Agnes Bridgett Doyle #1
30.	Standard Oil Co. of Texas	Dorothy Anderson et al. Unit #1
31.	Atlantic Refining Co.	So. Texas Development Co. #1
32.	Sinclair Oil & Gas Co.	Foster Lumber Co. #1
33.	Samedan Oil Corp.	C. E. Coleman #1
34.	Mobil Oil Co.	Bender Estate Farm #1
35.	C. E. Gates	C. G. K. & M. #11
36.	The Moran Corp.	Browder #1
37.	Hassie Hunt Trust	Adriance #1

Newton County

1.	White Shield	Kirby et al. #1
2.	Cain	Kirby Lumber #1
3.	Atlantic	T & NO RR #1
4.	Pure Oil Co.	West #1
5.	PDC-Sentinel	1-ARC et al.
6.	Atlantic	Moore #1
7.	Meredith & Co.	1-Strawther
8.	Bright et al.	1-Arco et al.
9.	Mac. Pet.	1-Harrison Un.
10.	Oil Reserves	1-K Kirby et al.
11.	Humble Oil & Refining Co.	E. C. Hankamer #13
12.	Kilroy Oil Co. of Texas	B. E. Quinn #1
13.	Slick Oil Corp. et al.	Hankamer #1-D
14.	Republic Prod. Co.	Sabine Tram #1
15.	Ancil T. Fuller	#1 Earl C. Hankamer
16.	W. L. Sinclair Dev. Co.	E. C. Hankamer #1

Orange County

1.	Humble Oil & Refining Co.	Paraffine Oil Corp. #1
2.	Sun Oil Co.	East Beaumont Townsite #1
3.	Prairie Producing Co.	Edgar Brown #1
4.	T. G. Anderson	Champion Paper Co. #1
5.	Kelly-Brock	#1 Arco Fee
6.	Davis Oil Co.	B. D. Orgain #1-A
7.	Penton & Penton & Union Prod. Co.	#6 Powell Lumber Co.
8.	Texas Pacific Coal & Oil Co. et al.	Luther-Moore Lumber Co. #1
9.	Midwest Oil Corp.	Starks #2
10.	Tenneco Oil Corp.	H. L. Stark #1-A
11.	Edwin Allday et al.	George Henderson et al. #1
12.	John W. Mecom	N. N. Adcock #1
13.	T. G. Anderson & E. L. Bowman	Lutcher-Moore Lumber Co. #1
14.	Phillips Petr. Co.	Boise "A" #1
15.	John W. Mecom	E. W. Brown #2
16.	John W. Mecom	E. W. Brown #1

Polk County

1.	Shell Oil Co.	Southland Paper #2
2.	Harper	Brock #1
3.	William K. Davis	#1 Douglas McCardell et al. Unit
4.	Tribal Oil Co. et al.	Carter Camden #1
5.	Hassie Hunt Trust	Wirt Davis #1
6.	Jordon Drilling Co.	Kirby Lumber Co. #1
7.	A. O. Phillips	M. E. Barnes #1
8.	Gem Oil Co.	Carrier #1
9.	Continental Oil Co.	W. T. Carter & Bro. #B-1
10.	Jordon Drilling Co. et al.	Lafollette #1
11.	Shell Oil Co.	Bailey #1
12.	Oil Reserves Corp.	W. T. Carter #1
13.	Oil Reserves Corp.	W. T. Carter Bros. #C-1

LIST OF WELLS (cont'd.)

San Jacinto County

1.	Hunt	1 - Foster Estate
2.	Cities Service	1 - Melvin
3.	Burke	1 - Elmore et al.
4.	Reserve Oil & Gas Co.	Polk #1
5.	Standard Oil Co. of Texas	Foster Lumber Co. #1
6.	The Texas Company	Foster Lumber Co. #1
7.	William K. Davis	#1 Anna Hale et al. Unit
8.	Viking Drilling Co. et al.	Langham Gas Unit #1
9.	Amoco Prod. Co.	W. W. Langham #1
10.	Sparta Oil Co. et al.	#1 Humble & Moore
11.	Continental Oil Co.	Gibbs Bros. & Co. #1
12.	Amerada Petr. Co.	Foster Lumber Co. #A-1
13.	Fain Drilling	Baldwin #1
14.	Shell Oil Co.	Central Coal & Coke #1
15.	Magnolia Petr. Co.	Hinchliff-Simms #1
16.	Stanolind	Roberts #1
17.	San Jacinto Petr. Co.	Ogletree #1
18.	Continental Oil Co. et al.	Frost Lumber Co. #1

Tyler County

1.	Justiss-Mears	G-2
2.	Spidle	International Paper #1
3.	Nebo Oil Co., Inc.	Ethyl Sawyer #1
4.	Pel-Tex, Inc. et al.	Humble Fee #1
5.	Humble Oil & Refining Co.	M. L. Davis #1
6.	Kent Exploration	Pope #1
7.	American Republics et al.	H. G. Sutton #1
8.	San Patricio Oil Co.	Cain #1
9.	Grubb & Hawkins	Kirby Lumber Co. #1
10.	Wolf Exploration Co.	Atlantic-Sinclair Fee #1
11.	Sinclair Oil & Gas Co. et al.	T. W. Chambers #1
12.	Shell Oil Co.	Kirby Lumber Co. Tract 165A, Well #1
13.	Humble Oil & Refining Co.	East Texas Oil Co. Fee #B-1

Tyler County (cont'd.)

14.	Atlantic Refining & Sinclair Oil & Gas	Smyth Walden #1
15.	Basin Petr. Corp.	Kirby-Wurts #1
16.	P. T. Sharples	D. D. Swearingen #1
17.	American Republic Corp. et al.	S. E. Wilson Fee #1
18.	Rex Reynolds	Kirby #1
19.	Prudential Drilling Co.	ARC Fisher Fee #1

Waller County

1.	Sinclair Oil & Gas Co.	R. C. McDade #1
2.	Mana Oil Corp. & Associated Oil & Gas Co.	J. H. Smith #1
3.	Brazos Oil & Gas Co.	Corine Connell No. 1-A
4.	The Texas Co.	Rice Institute #1
5.	Miami Oil Producers, Inc.	Arch H. Rowan #1
6.	Sumas Prod. Co.	J. J. Menke #1
7.	H. L. Hunt	C. M. Menke #1
8.	Pfeffer & Hogue	Pfeffer & Hogue Fee #1
9.	Michel T. Halbouty	John W. Harris et al. Well #1
10.	Humble Oil & Refining Co.	T. E. Sparks #1
11.	Mound Co.	L. F. Fuqua #1
12.	Exxon Co., USA	K. G. F. U. No. 2 Well #W-45
13.	Union Prod. Co.	Ida Clarey Unit #1

Washington County

1.	R. J. Whelan	Solomon #1
2.	Magnolia Petroleum Co.	Giddings Estate #1

Cameron Parish, Louisiana

1.	The California Co.	State Lease 3463 Well #1

REGIONAL FRIO CROSS SECTIONS FORM A RELIABLE CORRELATION GRID

Correlations developed on regional dip and strike cross sections take into account paleontological markers, similar electrical-log patterns, and regional dip and thickening into the Gulf.

The entire Frio Formation is several thousand feet thick over most of the study area; this thickness is too great to be used as a mapping unit in order to identify sand trends and depositional environments. Therefore, it is necessary to subdivide the Frio into several subunits. Recognition of this problem led to the subdivision of the Frio into six subunits in the Lower and Middle Texas Gulf Coast studies (Bebout, Dorfman, and Agagu, 1975; Bebout, Agagu, and Dorfman, 1975). This subdivision was based on several assumptions: (1) micropaleontological or foraminifer markers which always occur in the same vertical sequence within the Frio (fig. 12) are time dependent as well as environmentally controlled, and they define a gross correlation fabric; (2) on a regional scale, the Frio thickens and dips uniformly downdip toward the Gulf; and (3) shale zones are more reliable correlation markers than are thick sands because they are more widespread and represent longer periods of time for deposition.

On the regional cross sections of the Frio from the Upper Texas Gulf Coast (figs. 13-21), the formation has been subdivided into the six subunits using "T" markers as in the two previous Frio reports. On all dip sections, each unit shows a main sand depocenter which shifts gulfward in successively younger units, a predominantly shale area with numerous thin, discontinuous sands updip of the high sand area, and a predominantly shale area with sparse, thin sands downdip.

In the southern part of the study area, the main sand depocenter is very narrow; for example, along the "W" dip section (fig. 14), only one well (Br2) penetrated the sand trend. The sand bodies are stacked and very little gulfward progradation occurred. In contrast, to the north the sand trend is wide; along the "Z" dip section (fig. 17), it is penetrated by six wells (J11, J12, J17, J18, 03, and 05). This wide trend is the result of progradation of the sand depocenter progressively seaward in each younger correlation unit.

Local exceptions to this vertical stacking occur downdip of the main sand depocenter along narrow bands on the seaward side of growth faults.

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 12. Foraminifer markers, Texas Gulf Coast Miocene and Oligocene.

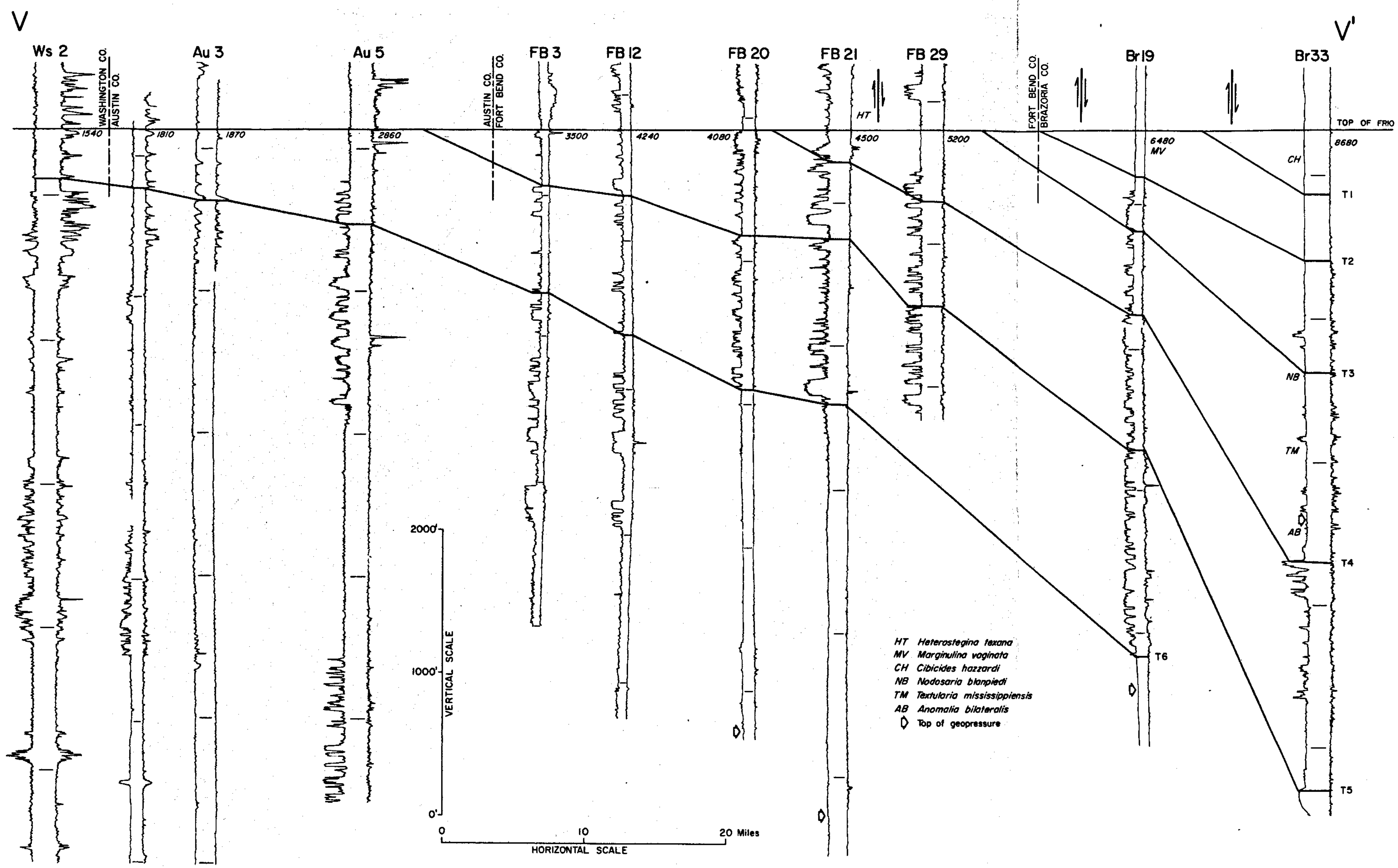


Figure 13. Dip section V-V'. The locations of this section and those which follow are given on Figure 11. The occurrence of marker foraminifers is shown by the letter abbreviations. The subdivision of the Frio into six correlation units is shown by the arrow on most wells.

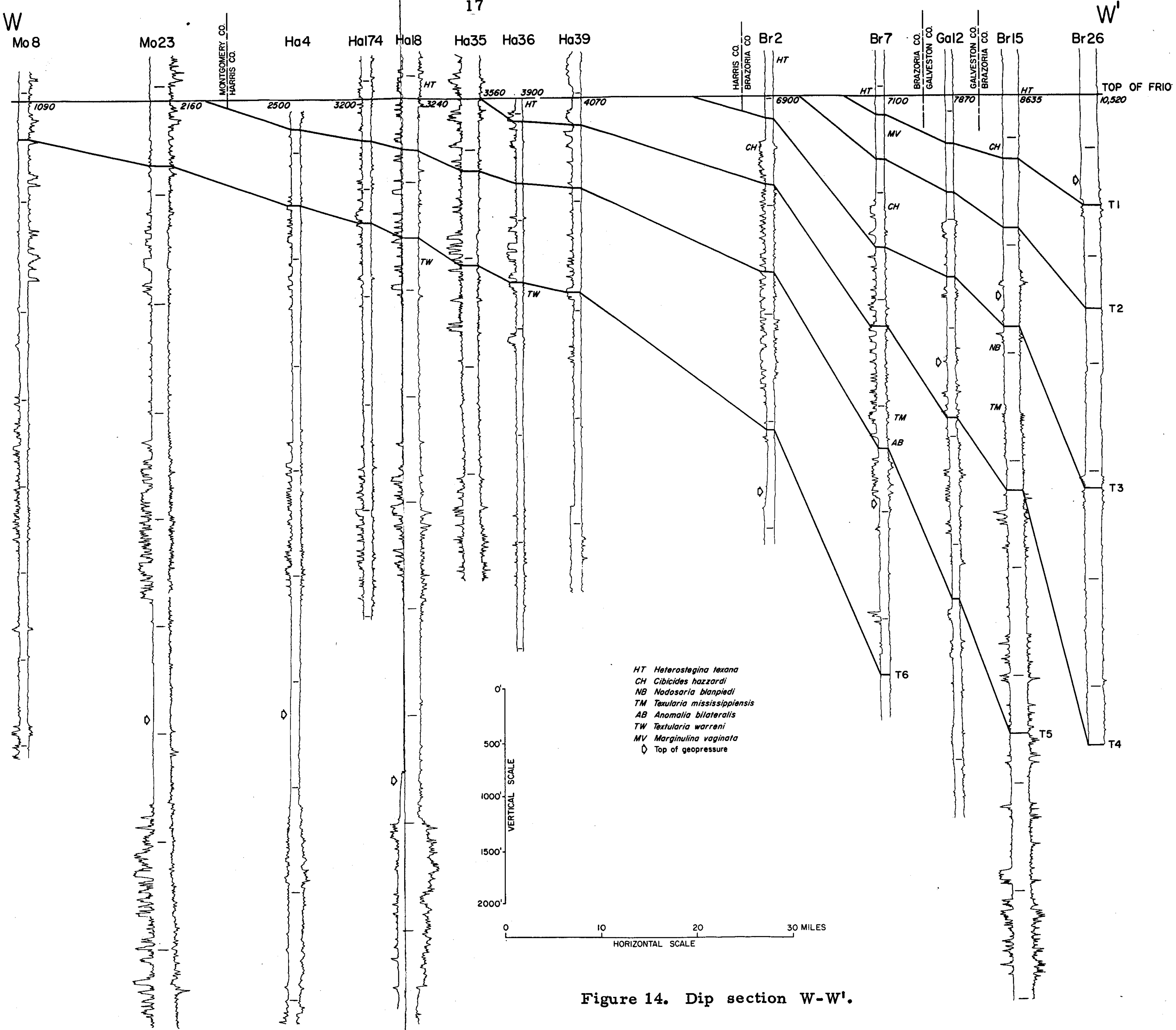


Figure 14. Dip section W-W'.

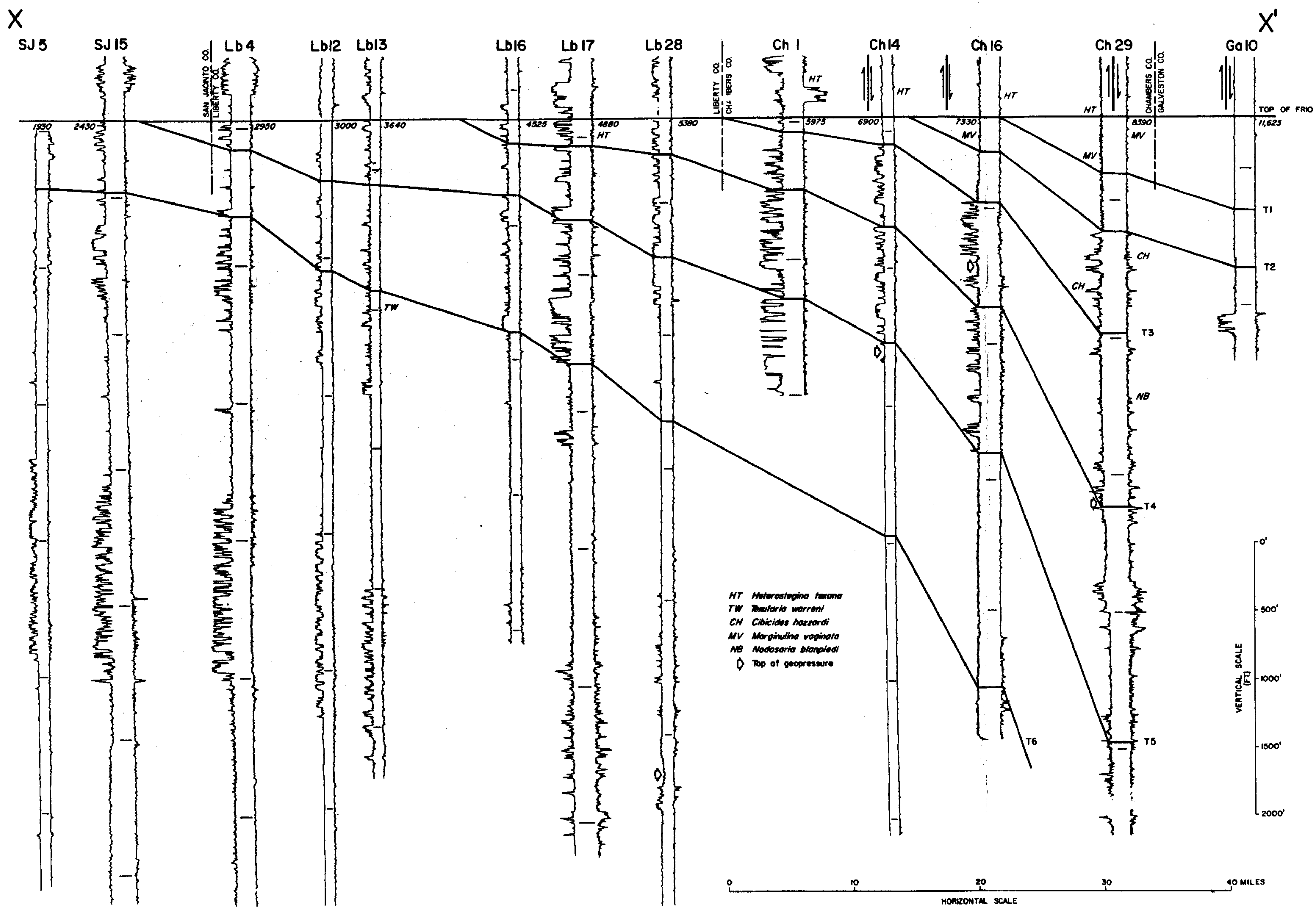


Figure 15. Dip section X-X'.

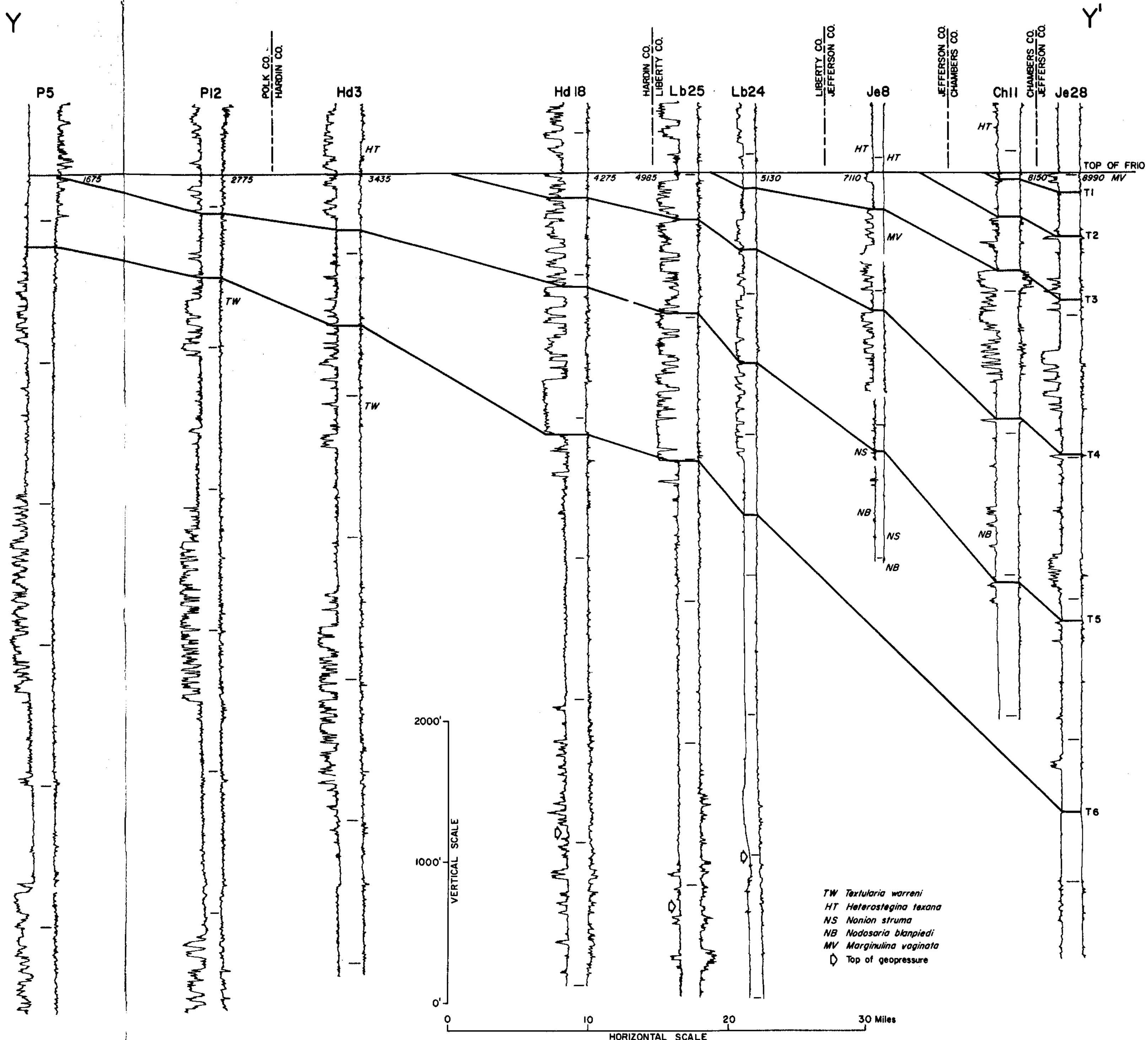


Figure 16. Dip section Y-Y'.

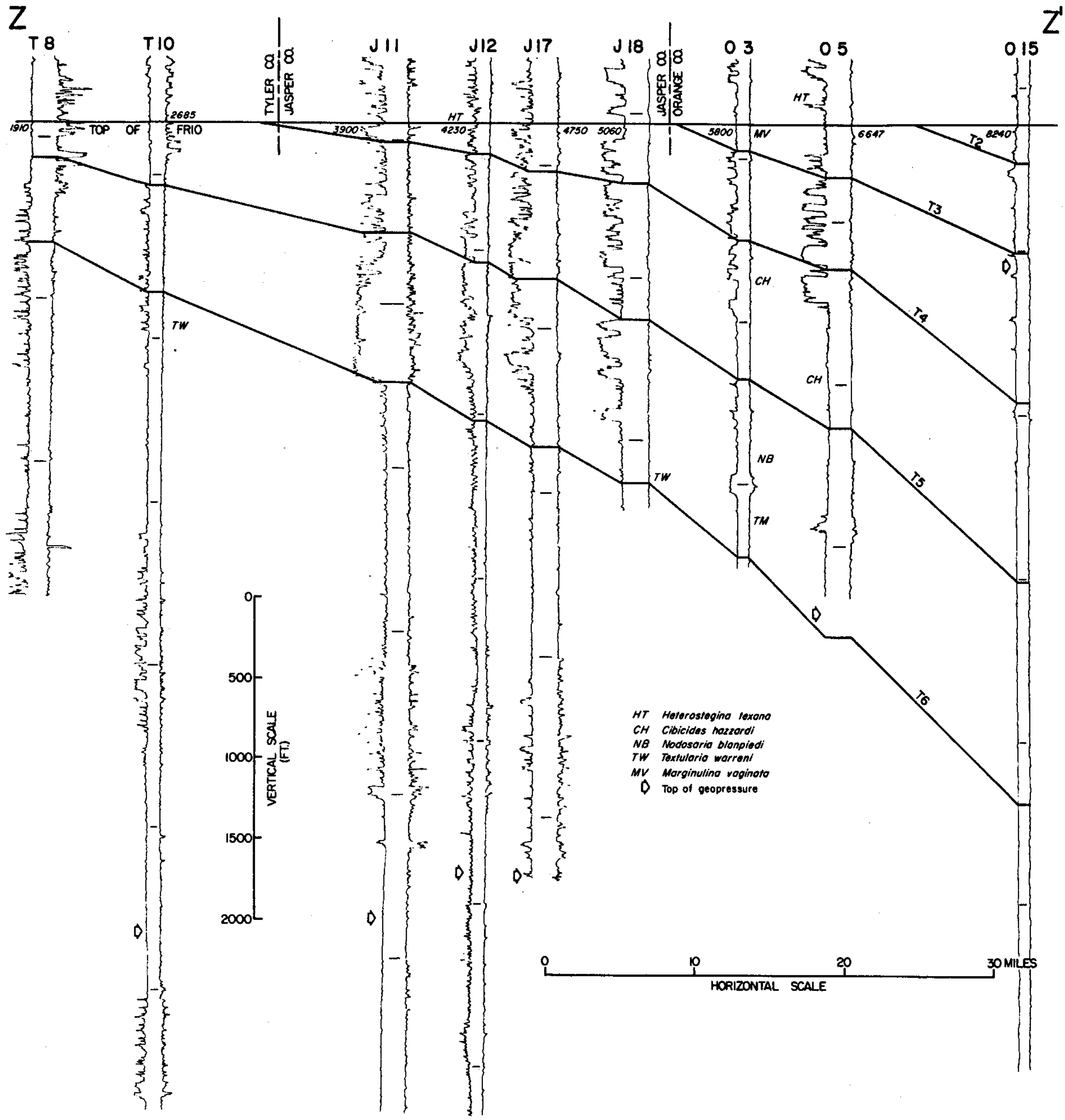


Figure 17. Dip section Z-Z'.

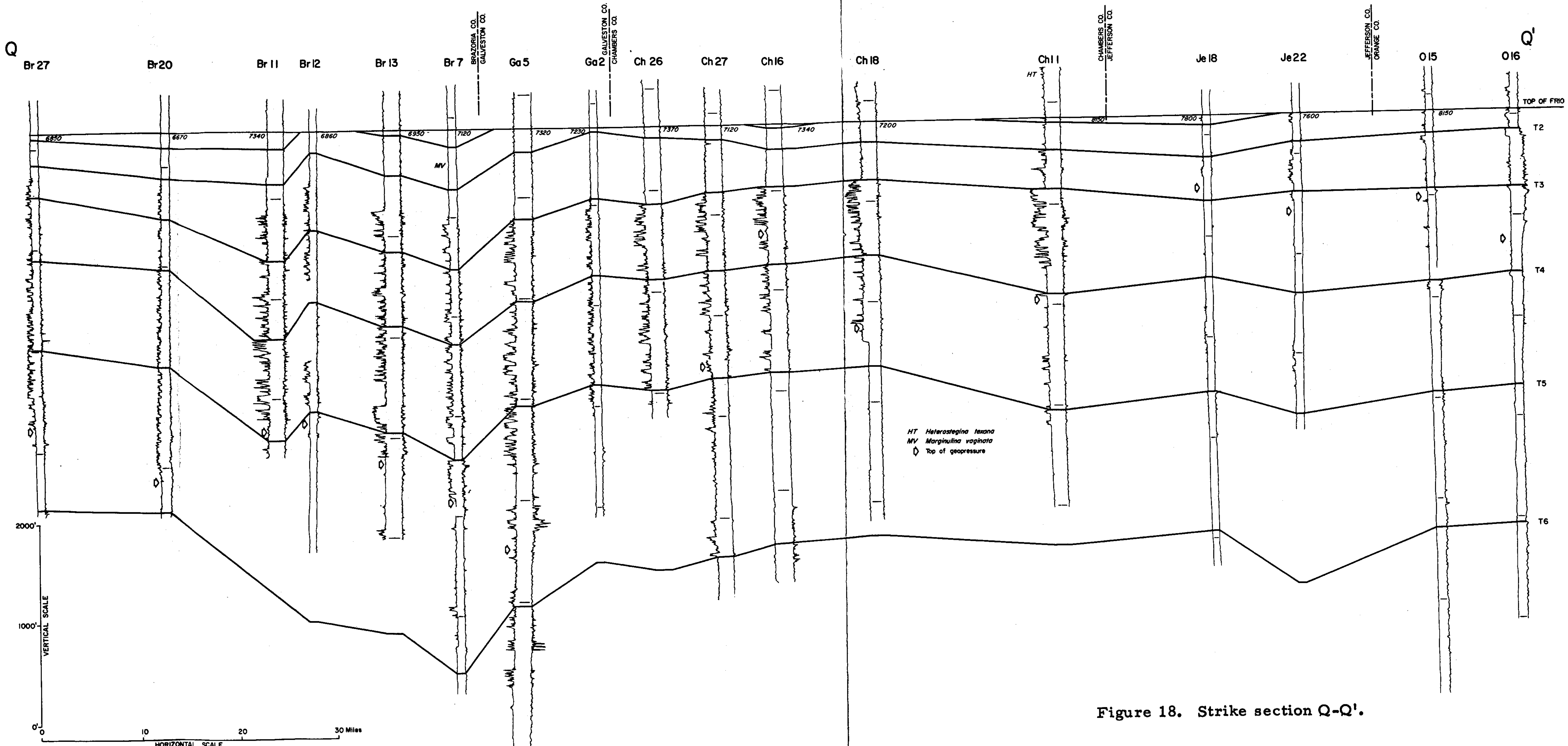


Figure 18. Strike section Q-Q'.

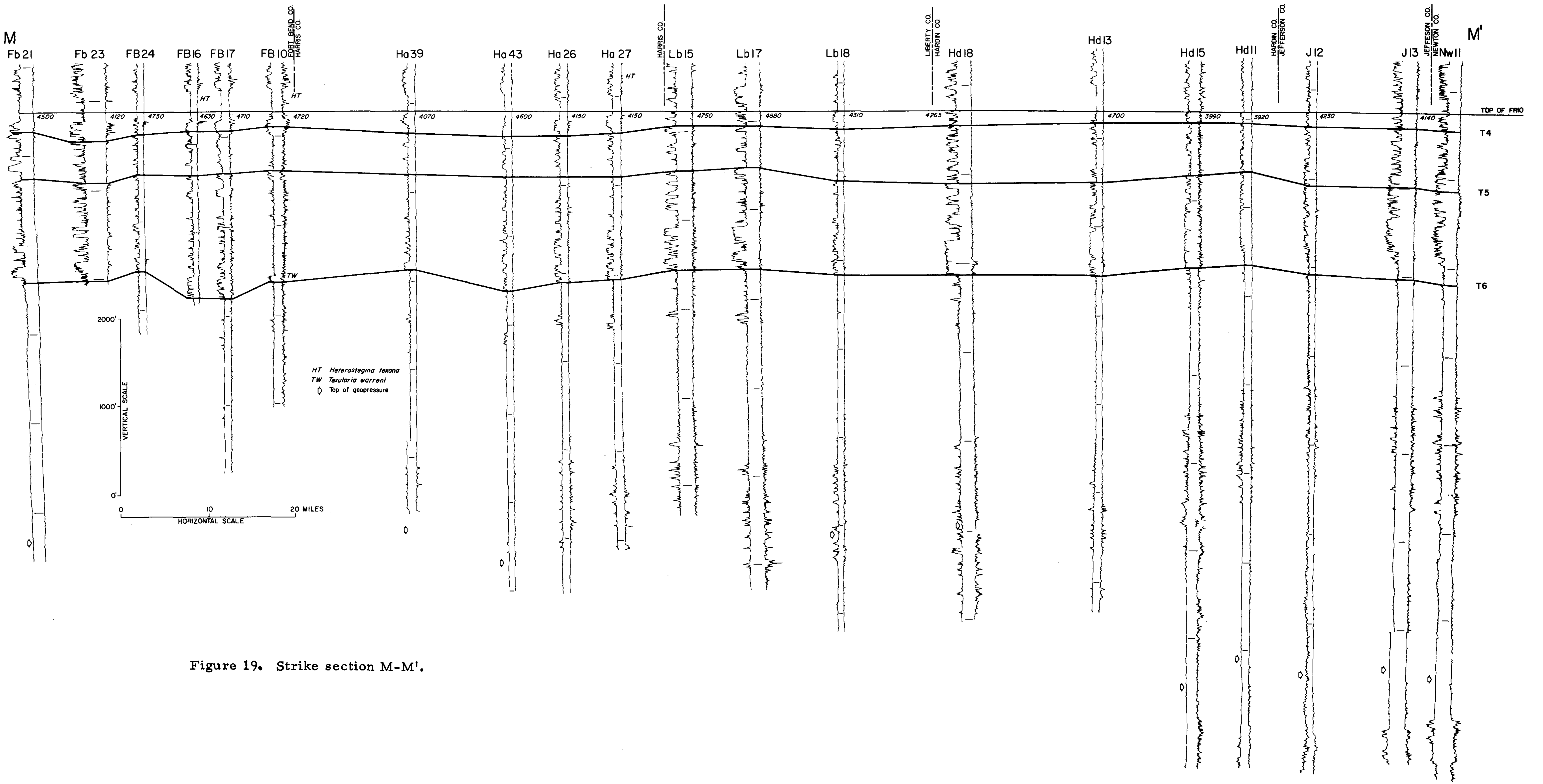


Figure 19. Strike section M-M'.

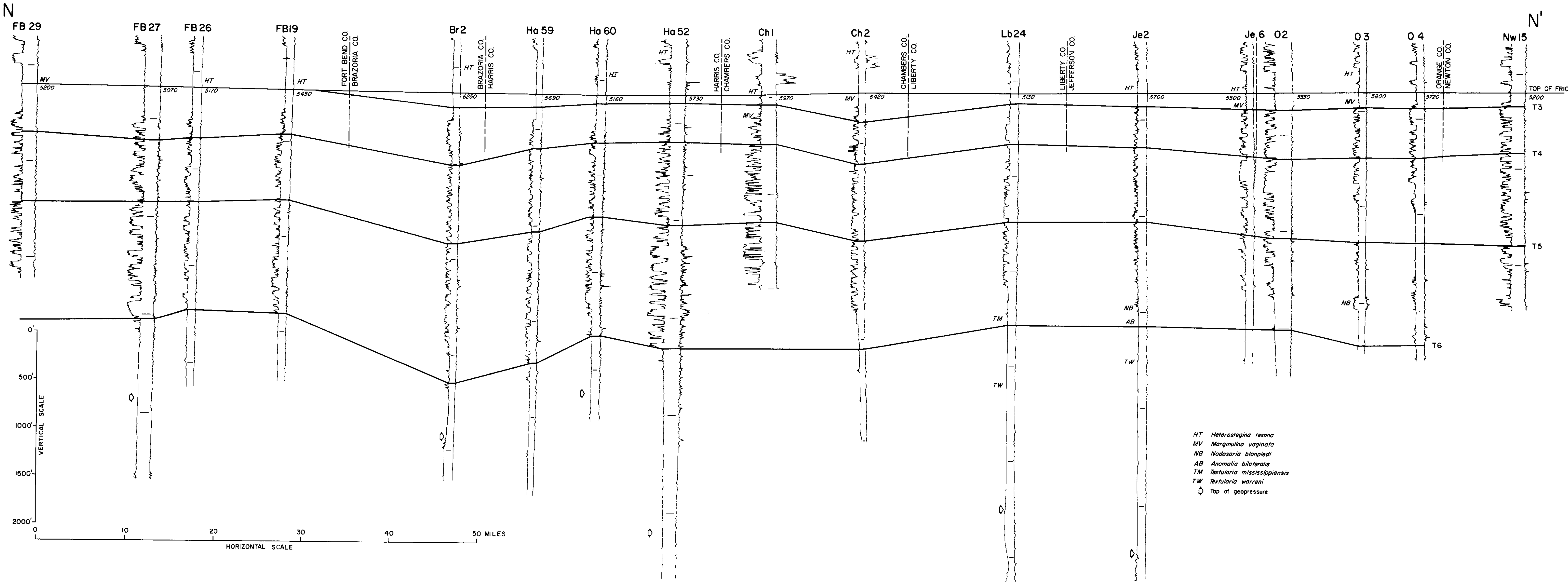


Figure 20. Strike section N-N'.

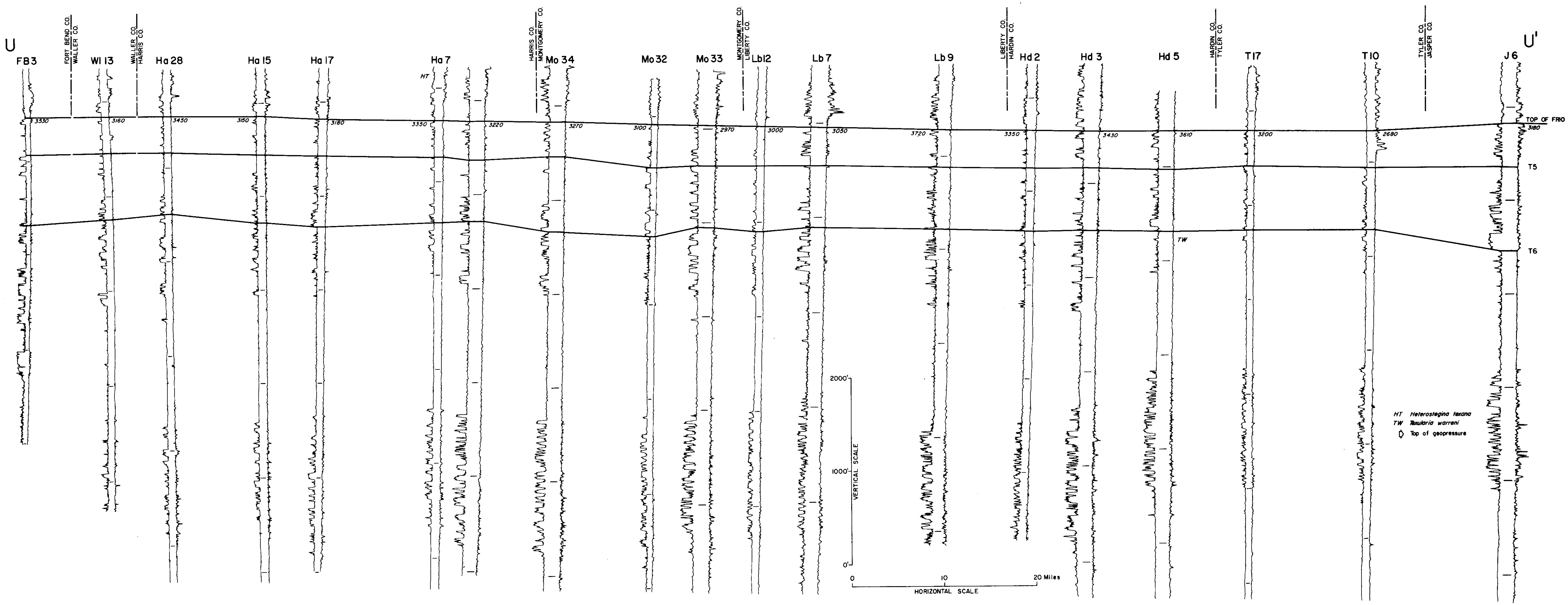


Figure 21. Strike section U-U'.

INTERPRETATION OF DEPOSITIONAL SYSTEMS FROM SAND-PERCENT AND NET-SAND MAPS

Areal distribution of sand bodies obtained from sand-percent and net-sand maps, along with the vertical relationships obtained from electrical-log cross sections, is an essential element in developing reliable interpretations of the depositional systems which deposited the sand/shale sequences.

Interpretation of the depositional system in which sands and shales were deposited is based (1) on areal distribution of the sand bodies and (2) on vertical textural variations within the sand bodies and their relationship with interbedded shale. The main sand depocenter is readily recognized on both total net-sand and sand-percent maps (figs. 22 and 23). As shown by the 800-foot contours on the total net-sand map (fig. 22), this high-sand trend is narrow in the southern part of the study area, a continuation of the pattern recognized in the Middle Texas Gulf Coast (Bebout, Agagu, and Dorfman, 1975), but widens somewhat to the north. The wider trend to the north is the result of more gulfward progradation in this area. The main sand trend is approximately parallel to and about 30 to 40 miles inland from the present-day Gulf Coast. Cumulative thickness of sand along this band averages 1,600 feet and locally exceeds 2,000 feet; sand percentage ranges between 40 and 60 percent. Most of the sand bodies are from 100 to 200 feet thick. They are commonly in sharp contact with the overlying and underlying shale as is shown by the blocky spontaneous-potential curve on the dip cross sections (figs. 13-17). Because of their dominant strike alignment and sharp upper and lower contacts, most of these sand bodies are interpreted to have been deposited mainly by marine processes as strandplain systems and barrier islands (Fisher and others, 1969). Local high-constructive lobate deltas accumulated in the upper part of the Frio on the northern half of the study area, as indicated by the lobate shape on the maps and the gradational upward-coarsening sequence on the electrical logs.

Updip from the main sand depocenter is a broad belt consisting predominantly of shale with less than 400 feet of total sand (fig. 22) and generally lower than 30 percent sand (fig. 23). The tendency toward dip alignment of some of the contours reflects the presence of sand-feeder systems. The log patterns, for the most part, show a sharp basal contact and a tendency within individual sand bodies toward fining and becoming shalier upward. In addition, these sand bodies have limited areal extent and cannot be correlated from one well to another more than a few miles distant. This updip band is interpreted as a fluvial plain with numerous areas in which fluvial channels were preferentially located.

Downdip from the strandplain system is a narrow belt along which cumulative net sand and sand percent abruptly decrease to 0. Numerous sand bodies occur here, but they are commonly thinner than 50 feet and of limited areal extent. Lack of adequate deep well control in this downdip area makes difficult the determination of the sand configuration. In addition, because of poor log response in the deeper portions of many wells, sands are difficult to recognize. These downdip sands and shales were deposited in the shelf system.

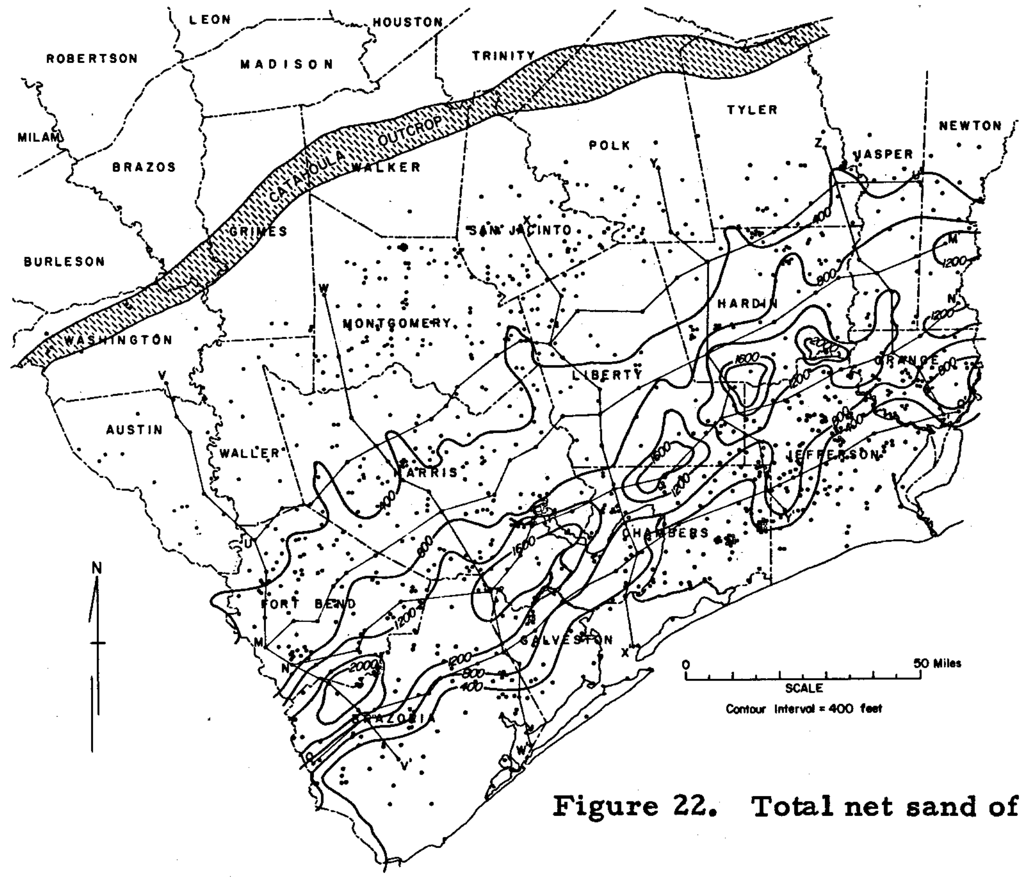


Figure 22. Total net sand of the Frio Formation.

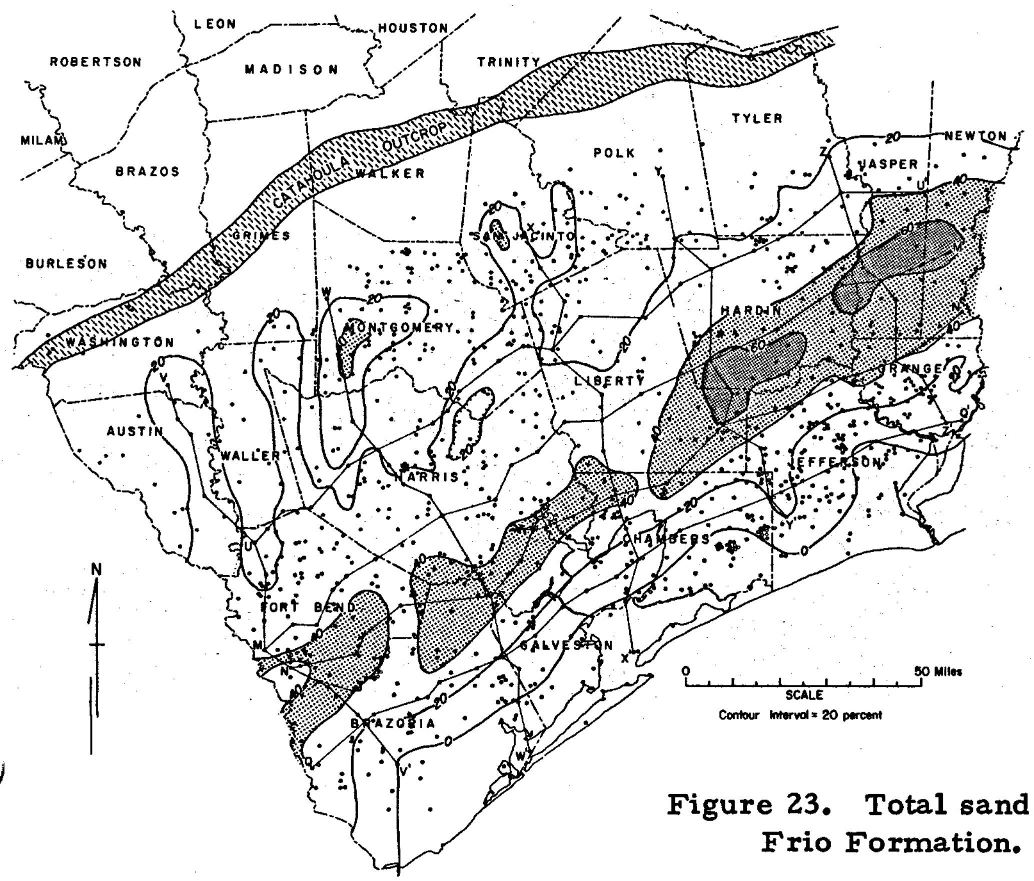


Figure 23. Total sand percentage of the Frio Formation.

UPDIP LIMIT MAPS ILLUSTRATE OFFLAPPING SEDIMENTARY PATTERN

The updip-limit maps of "T" markers and marker foraminifers show progradation by the offlapping pattern of each successive zone.

The offlapping or progradational pattern of the Frio is well illustrated by the map showing updip limits of "T" markers (fig. 24); the oldest or lowest marker (T5) is located furthest updip, and successively younger markers are gulfward. The map of the undip limits of marker foraminifers (fig. 25) shows that Textularia warreni, index of the top of the underlying Vicksburg Formation, and Heterostegina texana, index of the overlying Anahuac Formation, extend furthest updip, indicating more extensive marine encroachment both below and above the Frio. Markers within the Frio, Marginulina vaginata and Nodosaria blanpiedi, do not show a consistent trend probably because of the predominance of vertical stacking of the main sand depocenter particularly in the southern part of the study area.

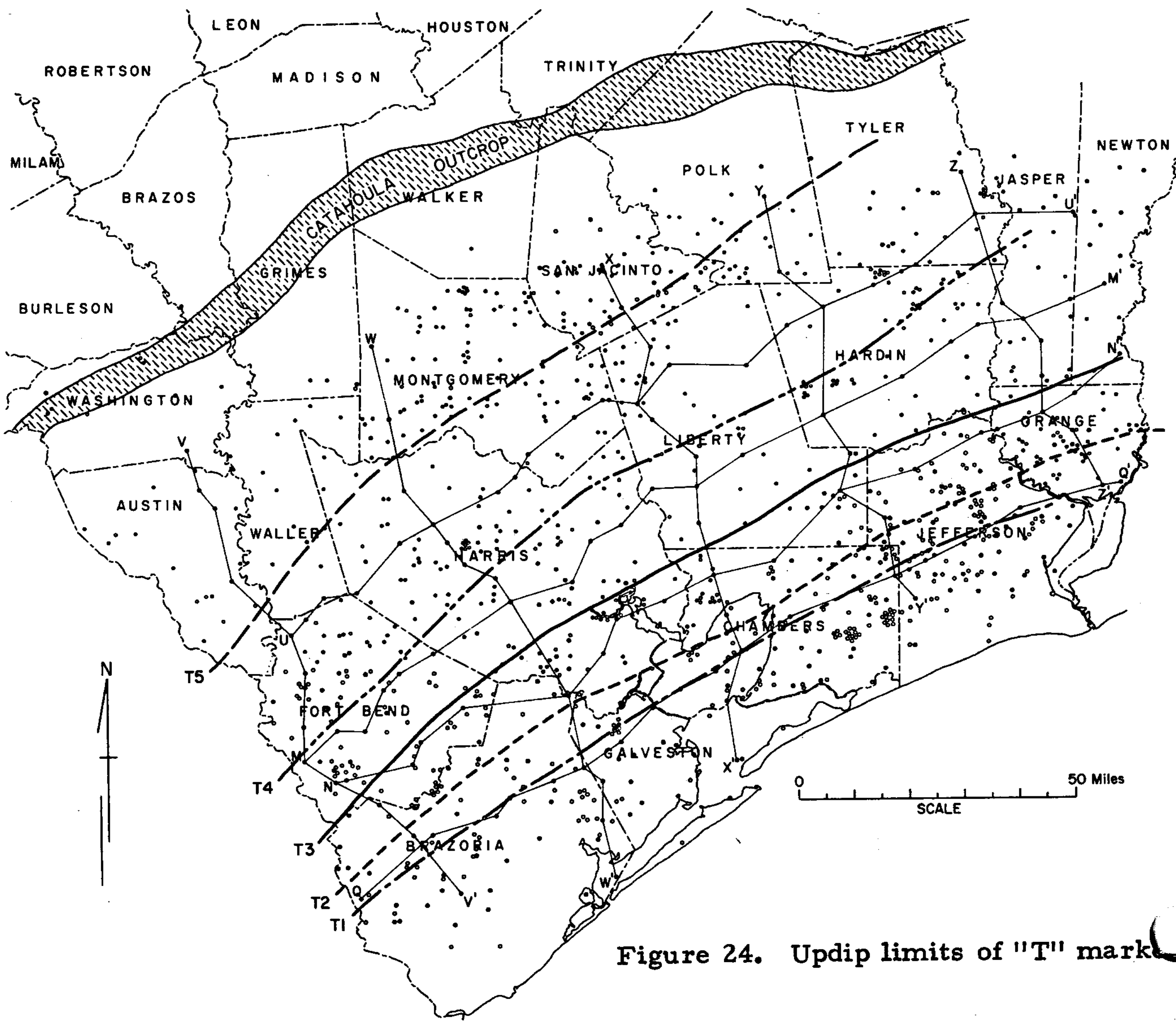


Figure 24. Updip limits of "T" mark

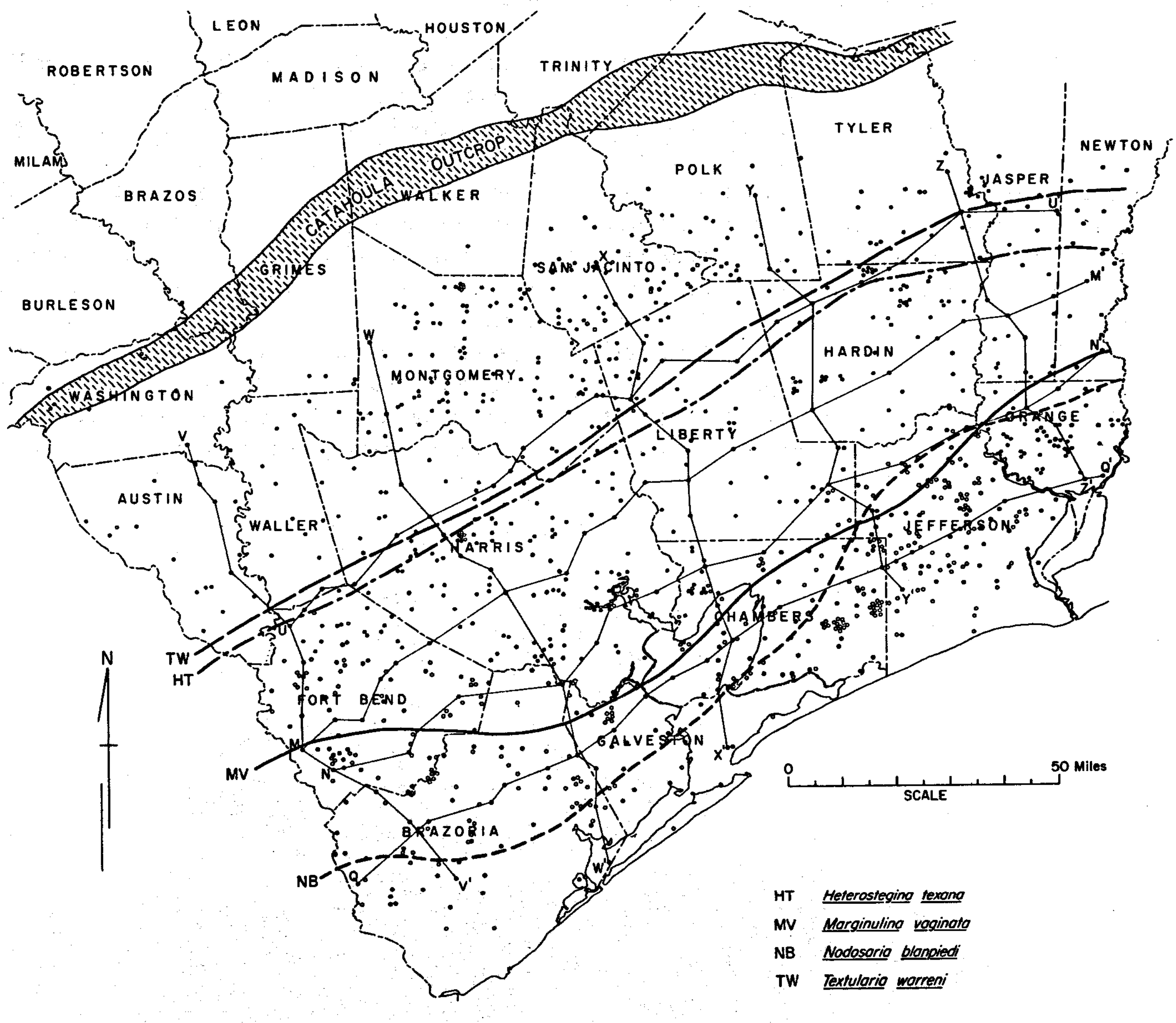


Figure 25. Updip limits of foraminifer markers.

SAND DISTRIBUTION--T5-T6

Greater than 600 feet of sand accumulated in the T5-T6 interval in a dominantly strike-oriented trend.

The sand-percent map for T5-T6 (fig. 26) shows a narrow high-sand belt (10 to 30 miles wide) which consists of greater than 40 percent sand and extends the length of the Upper Texas Gulf Coast area; this belt is broken only for a short distance in northwestern Chambers County. More than 600 feet of sand occurs throughout the trend (fig. 27), and locally in Brazoria County cumulative thickness exceeds 1,000 feet. The sand bodies along this trend commonly range from 20 to 150 feet thick (fig. 28) but are locally greater than 350 feet thick.

Updip of the main sand depocenter, the sand decreases to between 10 and 30 percent except along well-developed dip-oriented bands where 40 percent sand occurs locally. Downdip of the main sand depocenter, the sand uniformly decreases to 0 in a short distance; scattered sand bodies are between 10 and 35 feet thick and cumulate to several hundred feet thick on the downdip side of growth faults.

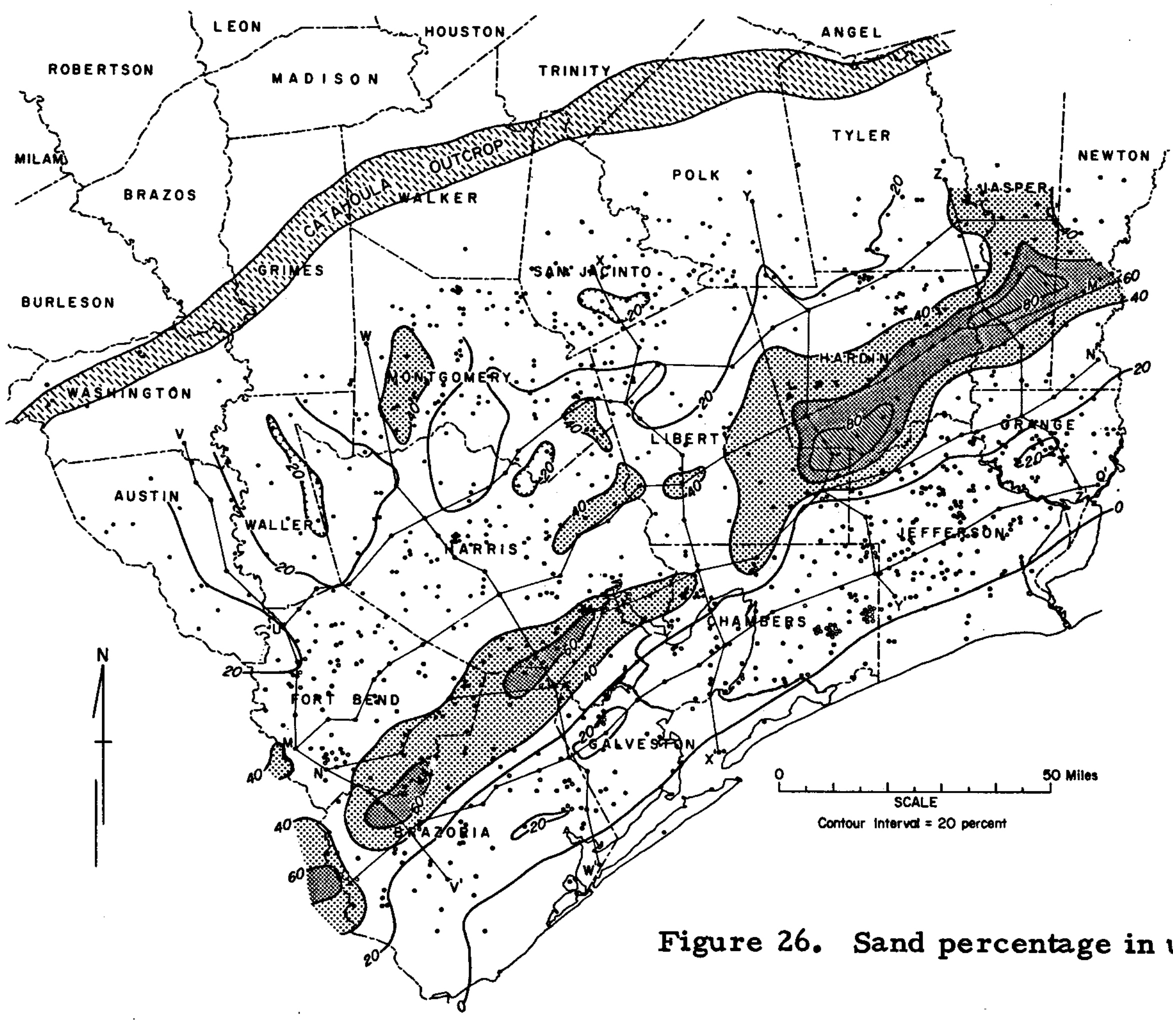


Figure 26. Sand percentage in unit T5-T6.

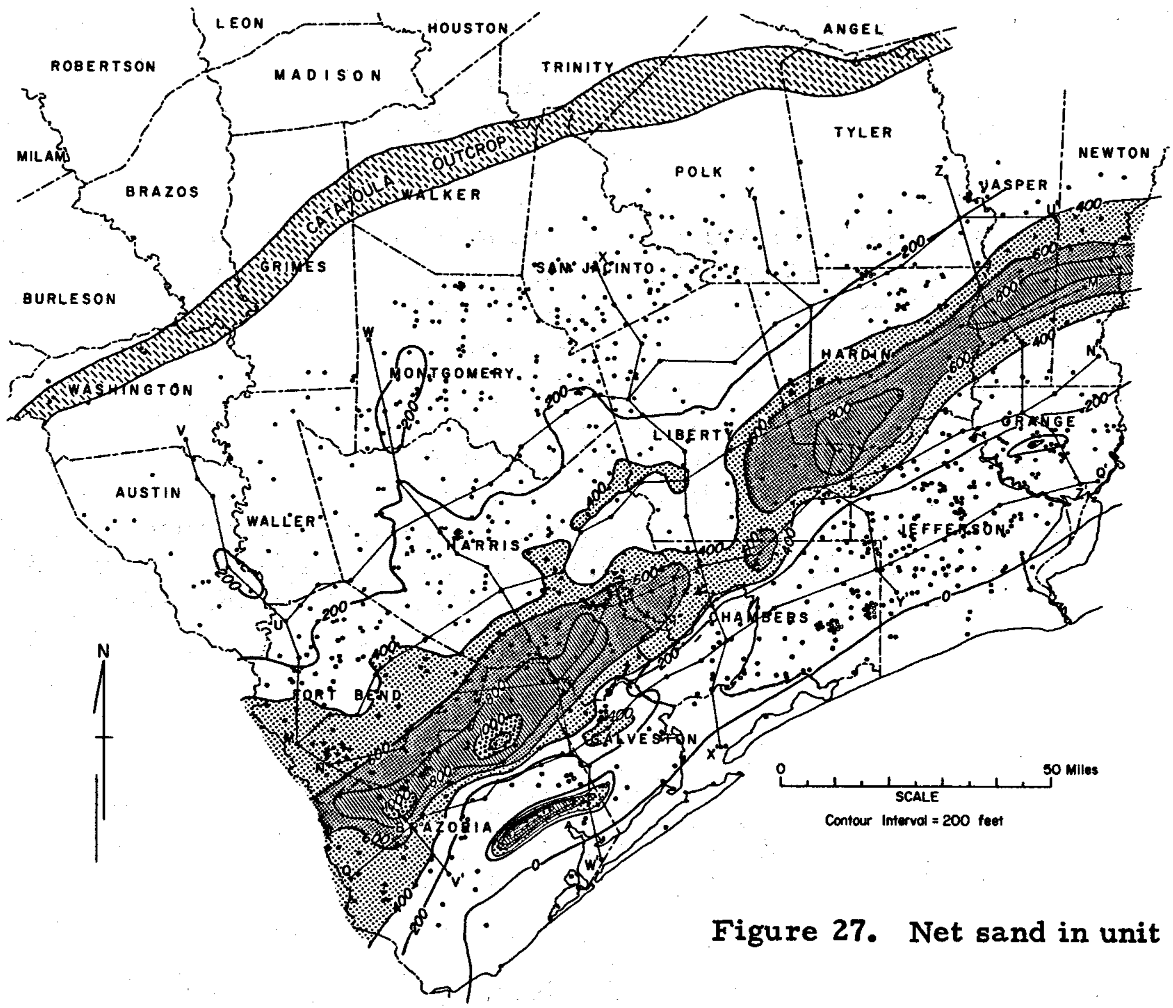


Figure 27. Net sand in unit T5-T6.

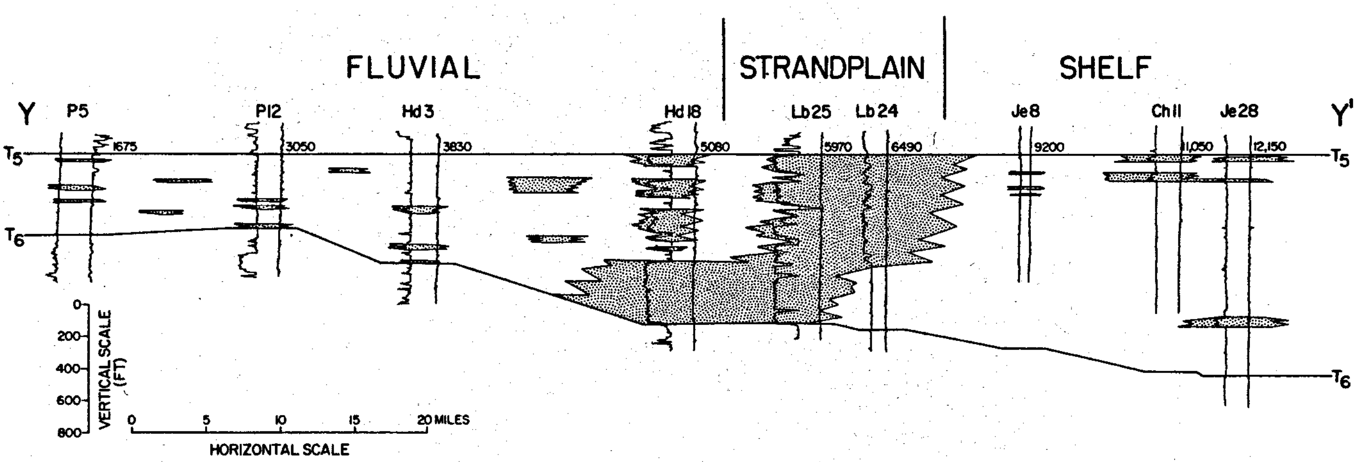


Figure 28. Sand distribution and interpreted depositional environments in unit T5-T6 along section Y-Y'.

SAND DISTRIBUTION--T4-T5

Strike-aligned sand bodies form a nearly continuous band of sand greater than 400 feet thick parallel to the Gulf Coast.

The strike-aligned main sand depocenter forms a 10- to 15-mile-wide unbroken band of 40 to 60 percent sand (fig. 29); total sand thickness reaches 400 feet throughout most of the trend and exceeds 600 feet in north-central Brazoria County (fig. 30). Individual sand bodies range in thickness from 20 to 200 feet (fig. 31).

Updip of this trend, sand percentage drops to less than 30 percent except locally along dip-oriented feeder systems where up to 40 percent sand occurs. Several such feeder systems are recognizable. Sand bodies range from 20 to 100 feet thick. Downdip of the main sand depocenter, sand-percent and net-sand maps both show a marked decrease in sand. The several small sand pods which appear on both maps are the result of the vertical stacking of sand bodies 10 to 50 feet thick.

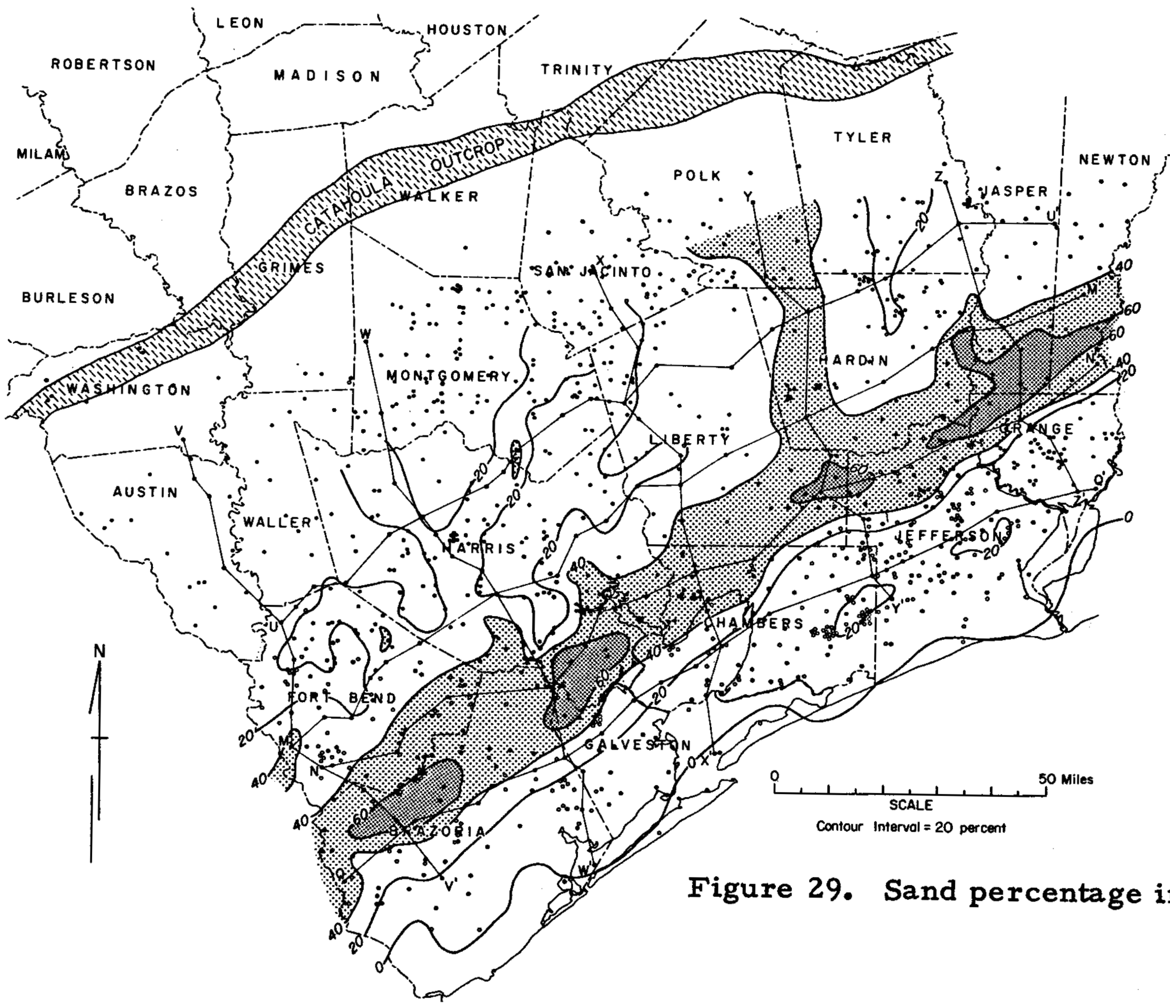


Figure 29. Sand percentage in unit T4-T5.

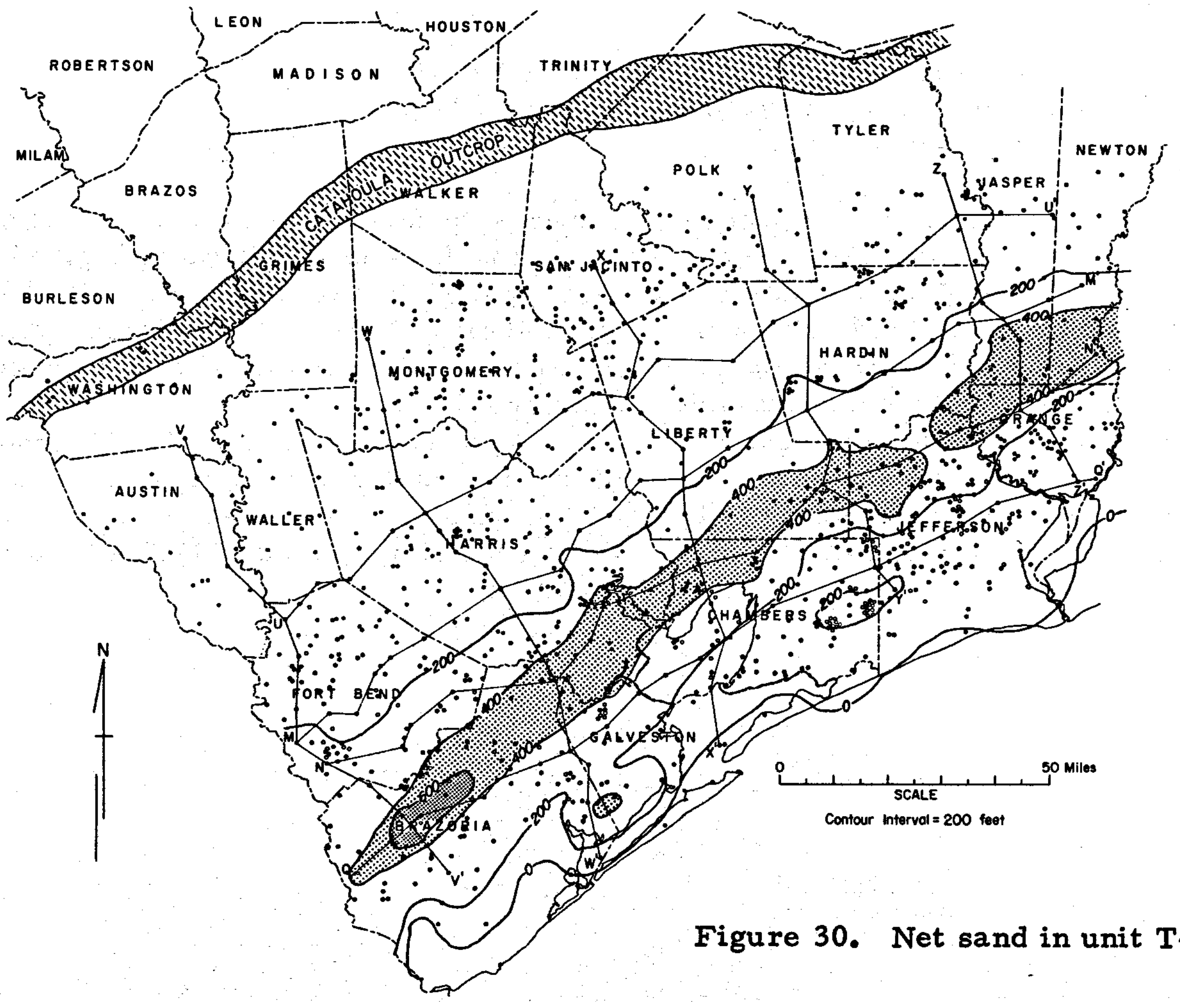


Figure 30. Net sand in unit T4-T5.

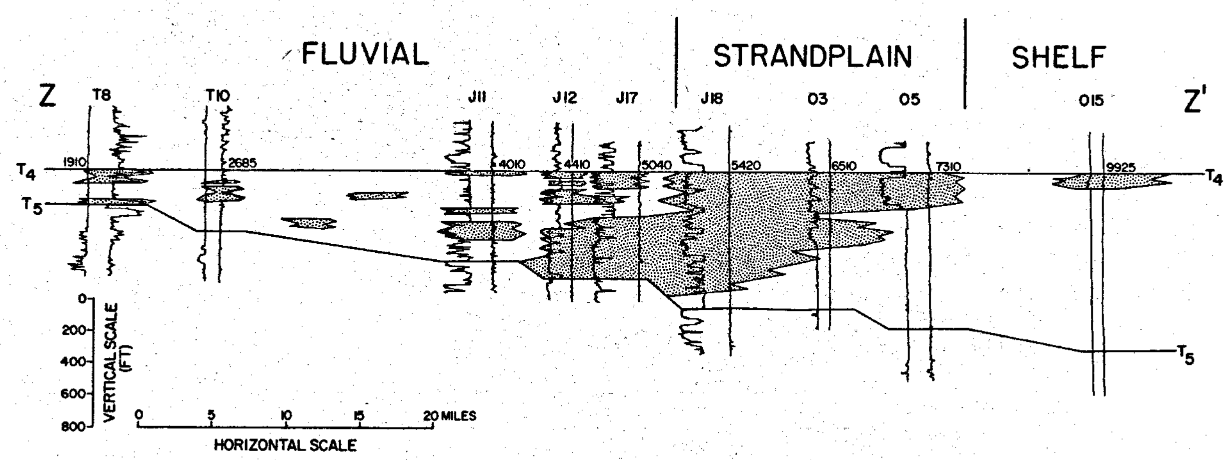


Figure 31. Sand distribution and interpreted depositional environments in unit T4-T5 along section Z-Z'.

SAND DISTRIBUTION--T3-T4

The lobate shape of unit T3-T4 in the northern part of the area is in marked contrast to the strike-aligned trends of the two older units (T4-T5, T5-T6).

The strike alignment so prominent in the previous two units (T4-T5, T5-T6) is not well developed in unit T3-T4. The sand-percent and net-sand maps (figs. 32 and 33) show a lobate-shaped sand pattern in the northern part of the study area rather than the strike-aligned sand trends in the southern part and in older, previously described Frio units. The spontaneous-potential curve shows a tendency toward coarsening or becoming less shaley upward (fig. 34), also typical of deltaic systems (Fisher and others, 1969). Associated dip-oriented feeder systems are strongly developed.

Sand content in unit T3-T4 drops off a short distance downdip of the main deltaic sands. These sands are very thin, 10 to 30 feet, and of limited lateral extent.

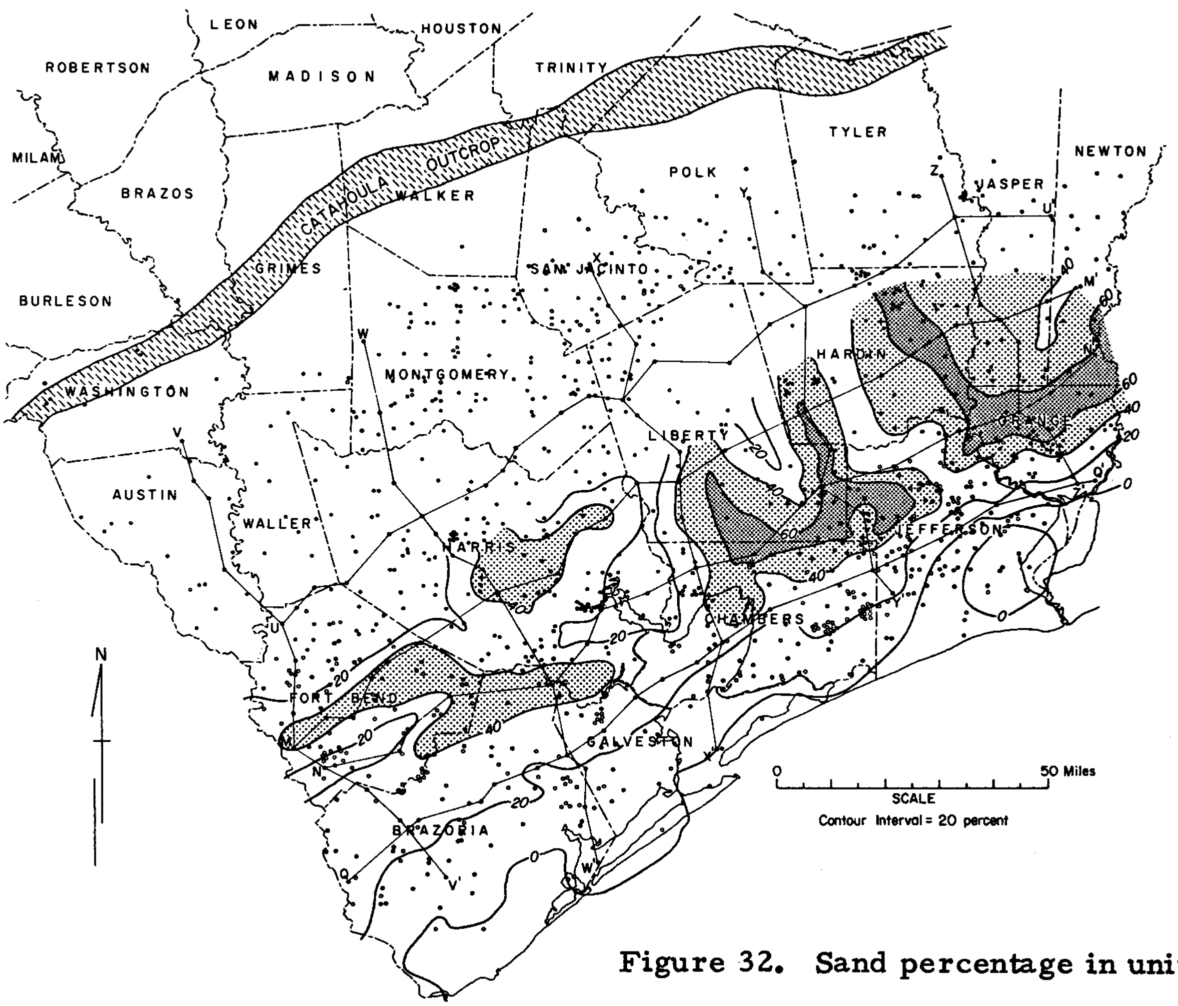


Figure 32. Sand percentage in unit T3-T4.

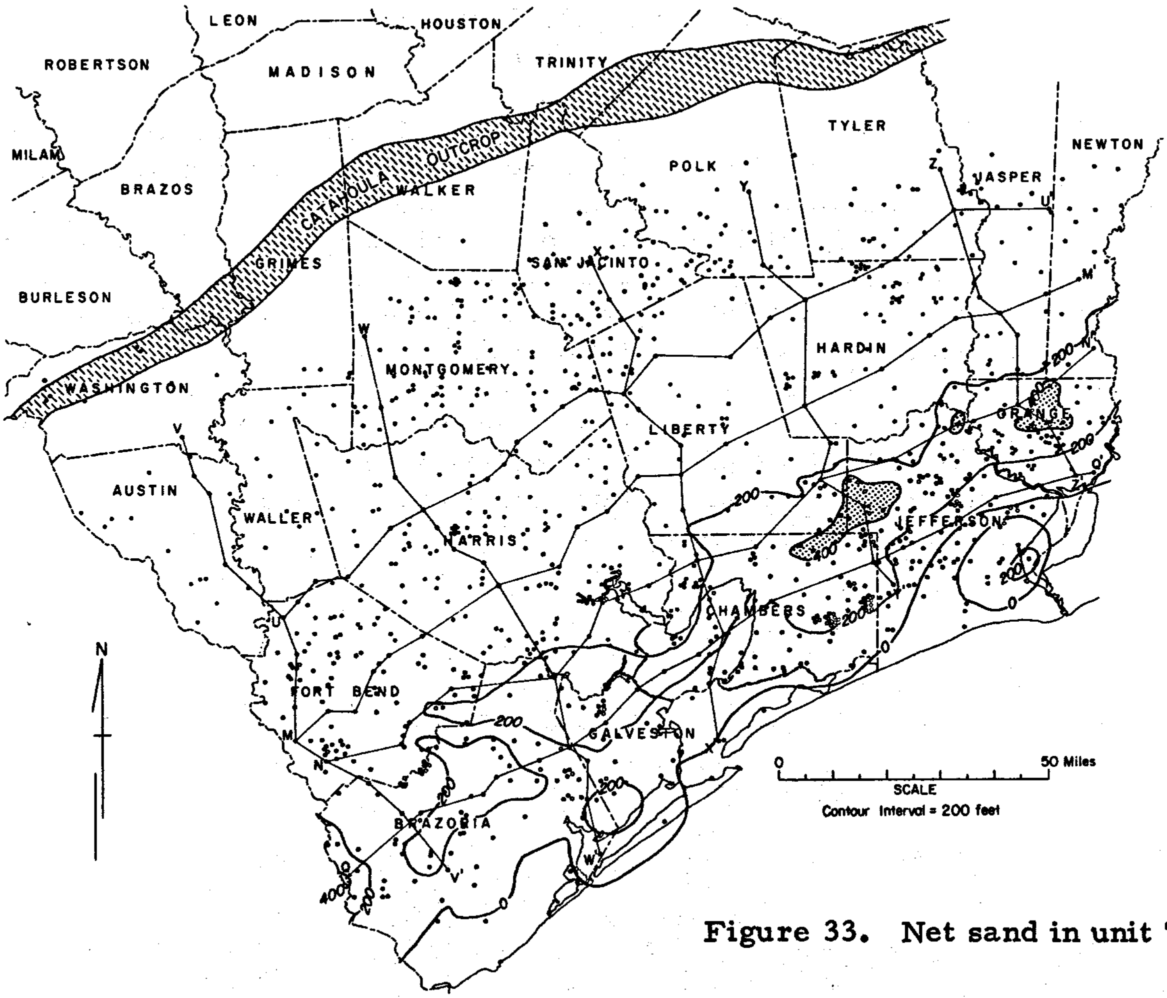


Figure 33. Net sand in unit T3-T4.

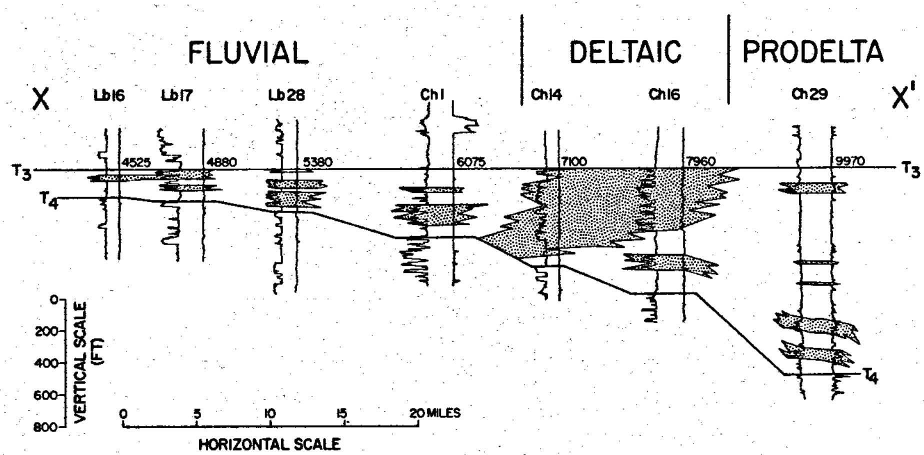


Figure 34. Sand distribution and interpreted depositional environments in unit T3-T4 along section X-X'.

SAND DISTRIBUTION--T2-T3

The lobate pattern of T3-T4 is present but poorly developed in unit T2-T3 in the northern part of the study area.

The T2-T3 unit appears as a continuation of the patterns established in unit T3-T4. Strike alignment of sand bodies is not developed; on the other hand, the sand bodies are irregular to lobate shaped (figs. 35 and 36) in the northern part of the study area. The main sand depocenter is represented by 20 to 40 percent sand (fig. 35) and cumulative thickness of slightly more than 200 feet net sand (fig. 36). Individual sand bodies are thin, 10 to 50 feet thick, and show a tendency toward coarsening or becoming less shaley upward (fig. 37). Updip, the dip-aligned feeder systems are well developed but are short because of the proximity of the updip limit of this unit.

Downdip, net sand and sand percent decrease in a short distance. Sand bodies here are thin, 10 to 20 feet thick, in a very thick shale section.

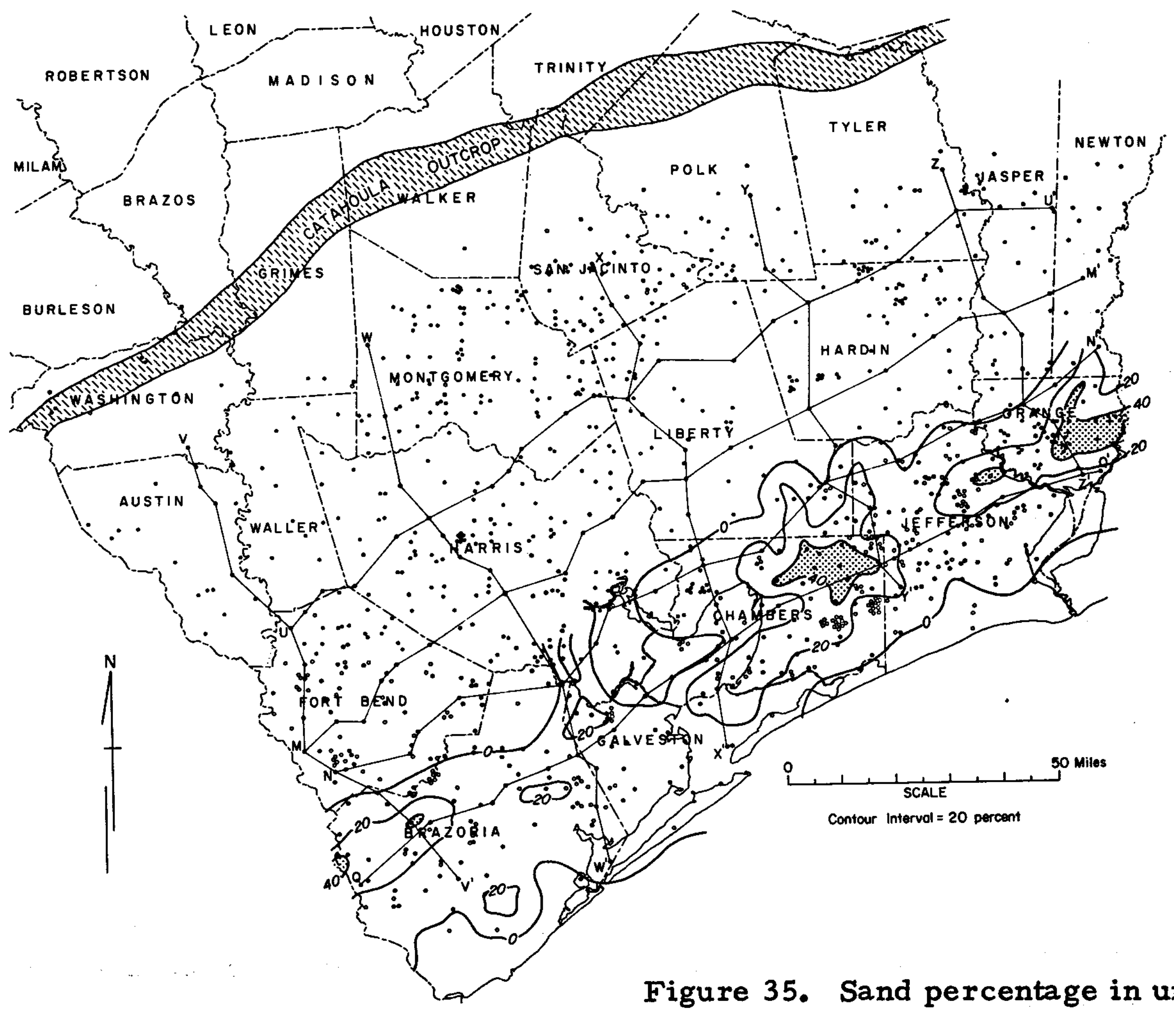


Figure 35. Sand percentage in unit T2-T3.

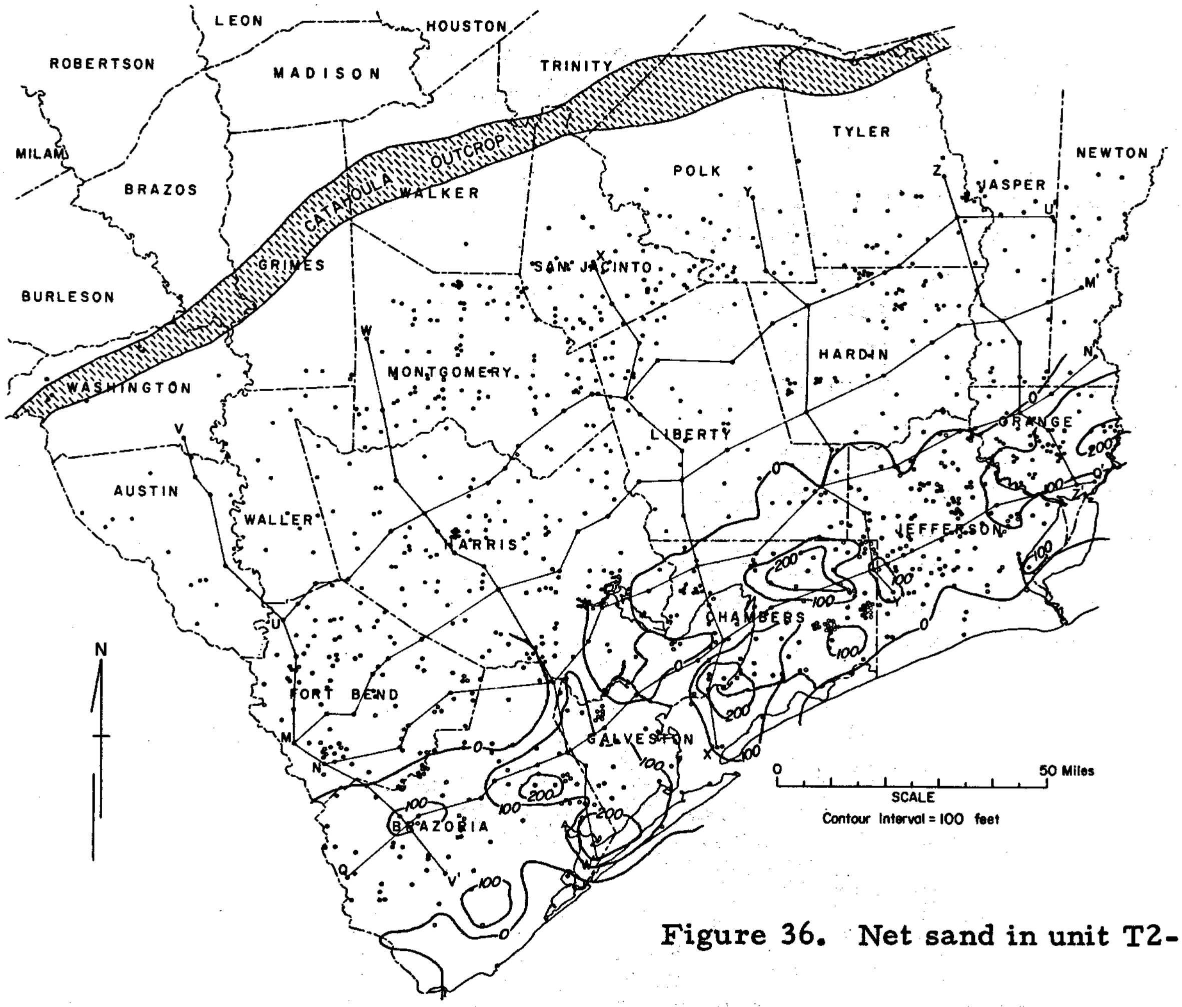


Figure 36. Net sand in unit T2-T3.

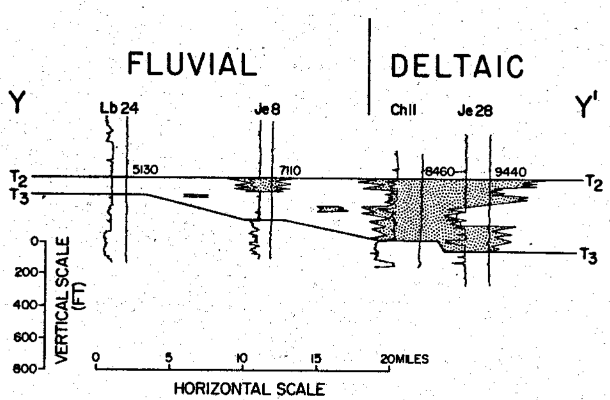


Figure 37. Sand distribution and interpreted depositional environments in unit T2-T3 along section Y-Y'.

SAND DISTRIBUTION--T1-T2

Sparse sand of T1-T2 forms a very ill-defined trend that may represent shelf sands of an updip high-sand system which has subsequently been truncated.

Sand is sparse in unit T1-T2; the entire unit contains 0 to 20 percent sand along the ill-defined trend (fig. 38). Net sand totals less than 50 feet over most of the trend (fig. 39). Individual sand bodies seldom exceed 10 feet in thickness (fig. 40).

The lack of significant sand development in T1-T2 probably results either from lack of feeder systems to supply the sand or from truncation of most of the interval leaving only the downdip shelf system intact.

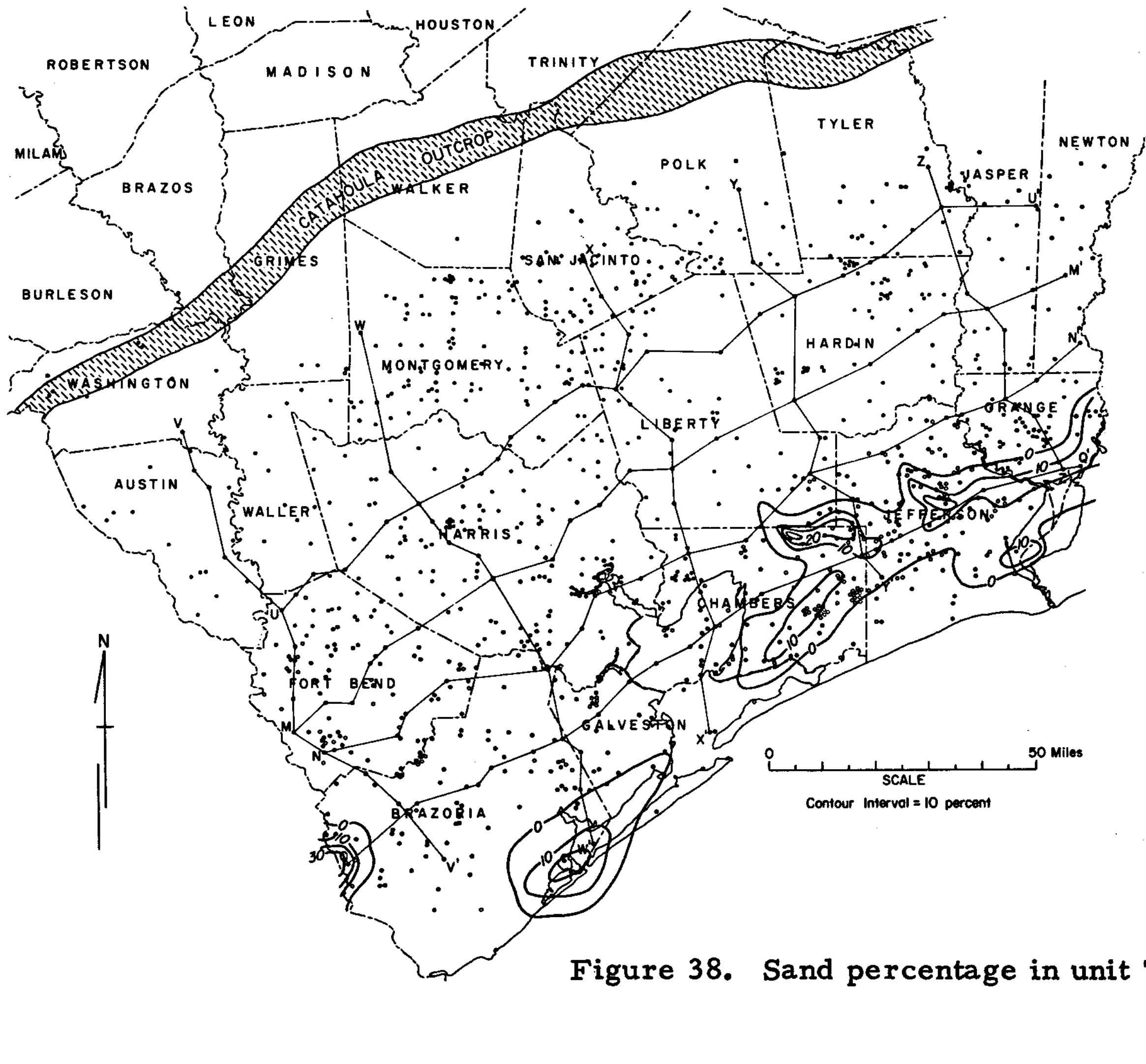


Figure 38. Sand percentage in unit T1-T2.

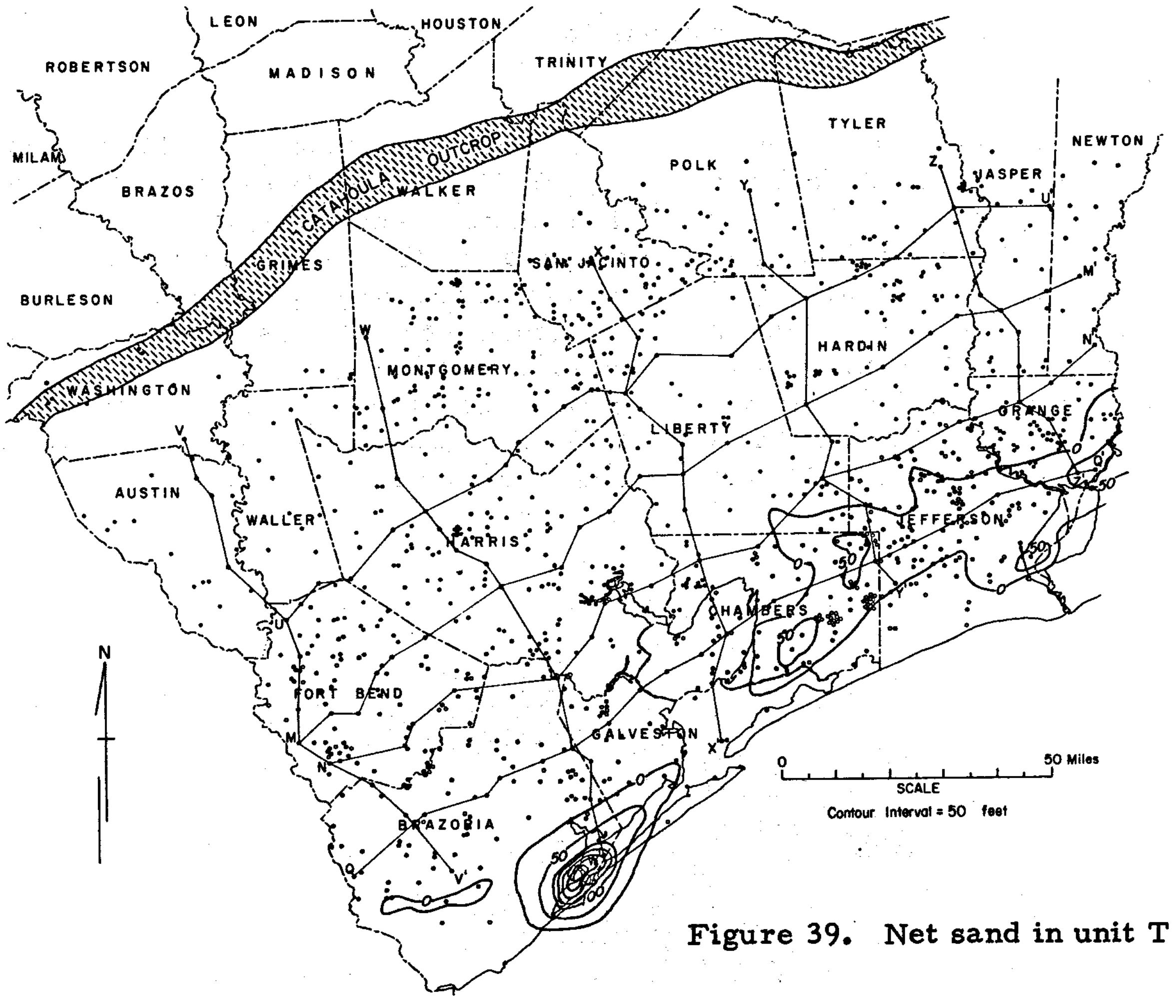


Figure 39. Net sand in unit T1-T2.

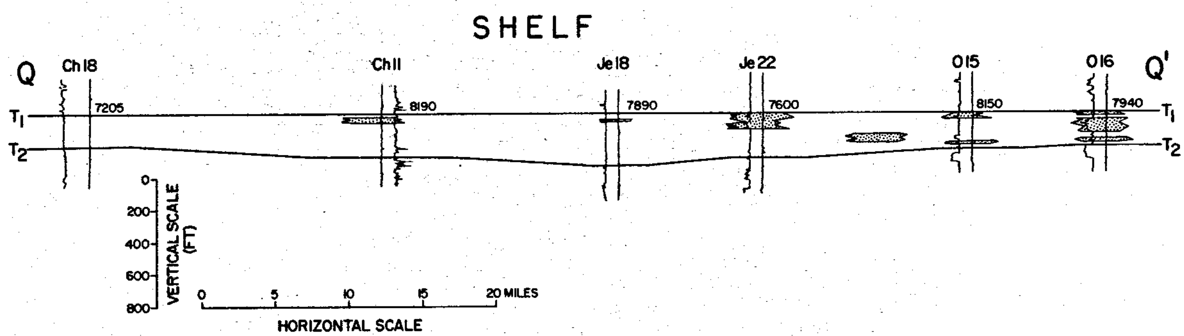


Figure 40. Sand distribution and interpreted depositional environments in unit T1-T2 along section Q-Q'.

SAND DISTRIBUTION--T0-T1

Sand is sparse in unit T0-T1 and distribution is similar to that of the previous unit, T1-T2.

Like the underlying T1-T2 unit, T0-T1 contains sparse sand. Sand is lacking throughout most of the trend and only reaches 20 percent locally in two areas (fig. 41). Total net sand reaches 150 feet in one well in Brazoria County (fig. 42); throughout the remaining area, there is commonly less than 20 feet of net sand. Individual sand bodies are less than 10 feet thick.

The sand mapped in T0-T1 and also in T1-T2 appears very similar in distribution and abundance to that downdip of the main sand depocenters of the underlying mapped units. It therefore seems possible that these units are lacking main sand trends because of later truncation. However, lack of a sand source during this time could also be responsible for this facies pattern.

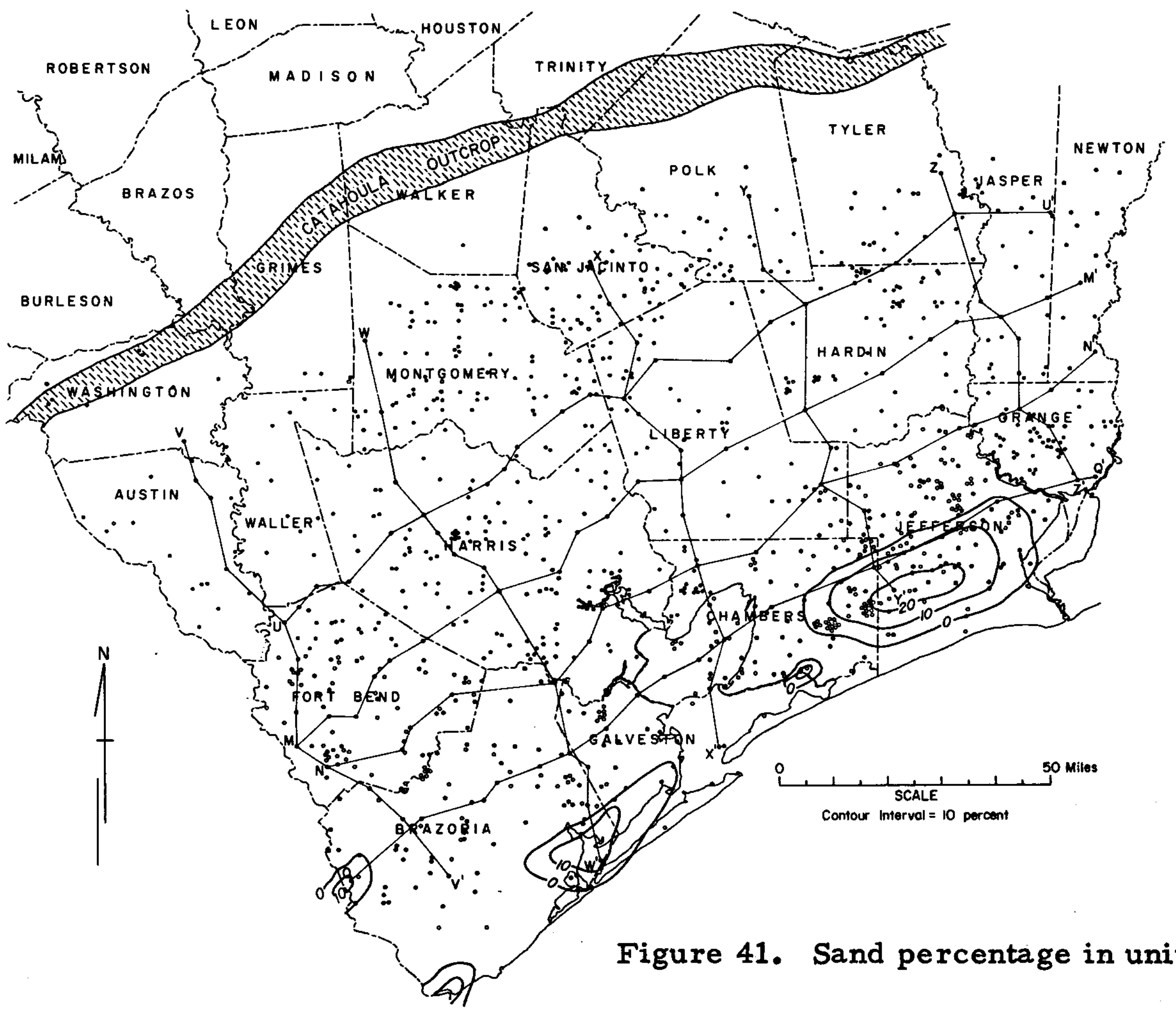


Figure 41. Sand percentage in unit T0-T1.

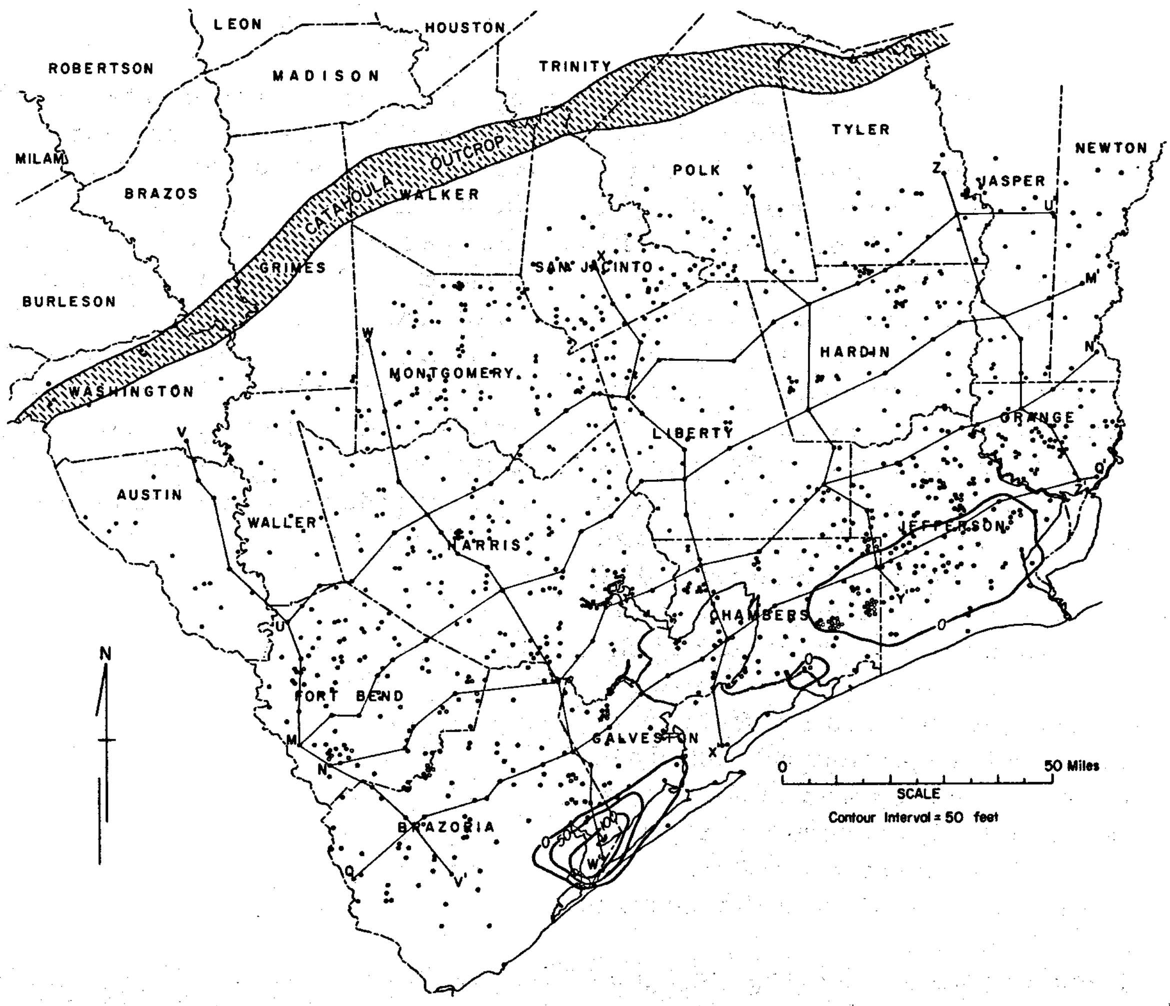


Figure 42. Net sand in unit T0-T1.

GEOPRESSURED FRIO RELATED TO SAND DISTRIBUTION

Along the Upper Texas Gulf Coast, the sands that occur beneath the top of geopressure are seaward of the main sand depocenter and were deposited in the shelf environment.

Wells drilled into the thick Tertiary section along the Upper Texas Gulf Coast encounter normal hydrostatic subsurface fluid pressure of .464 pounds per square inch per foot (psi/ft) for the upper 8,000 to 10,000 feet. Below this approximated depth, subsurface pressure increases significantly due largely to movement along growth faults which traps the interstitial water by separating it from the updip porous aquifers. When the subsurface fluid pressure exceeds .7 psi/ft, the fluid is considered to be geopressured. The top of geopressure can be picked from physical changes in the character of the electrical logs, such as reduction in the negative self-potential deflection of the sands and reduction of the shale resistivity. It can also be picked from changes in drilling procedure, such as increase in drilling-mud weight above 13.5 pounds per gallon and the setting of intermediate casing.

Recognition of the top of geopressure in the exploration for geothermal reservoirs is important because all prospects lie below this horizon. However, subsurface fluid temperatures generally range between only 160 and 200°F at the top of geopressure; temperatures high enough to be prospective are in reservoirs which lie more than 4,000 feet below the top of geopressure.

The top of geopressure (fig. 43) occurs within the Frio Formation only within a 30-mile-wide band along the coast where it lies between 9,000 and almost 12,000 feet below sea level. All of the Frio sediments in the geopressured zone were deposited seaward of the main sand depocenter, probably in a shelf environment. Within the geopressured zone, the Frio has less than 20 percent sand (fig. 44) and total sand thickness of less than 800 feet (fig. 45). However, several sand bodies cumulate to hundreds of feet within the geopressured zone in Brazoria and Galveston Counties and are considered to be prospective.

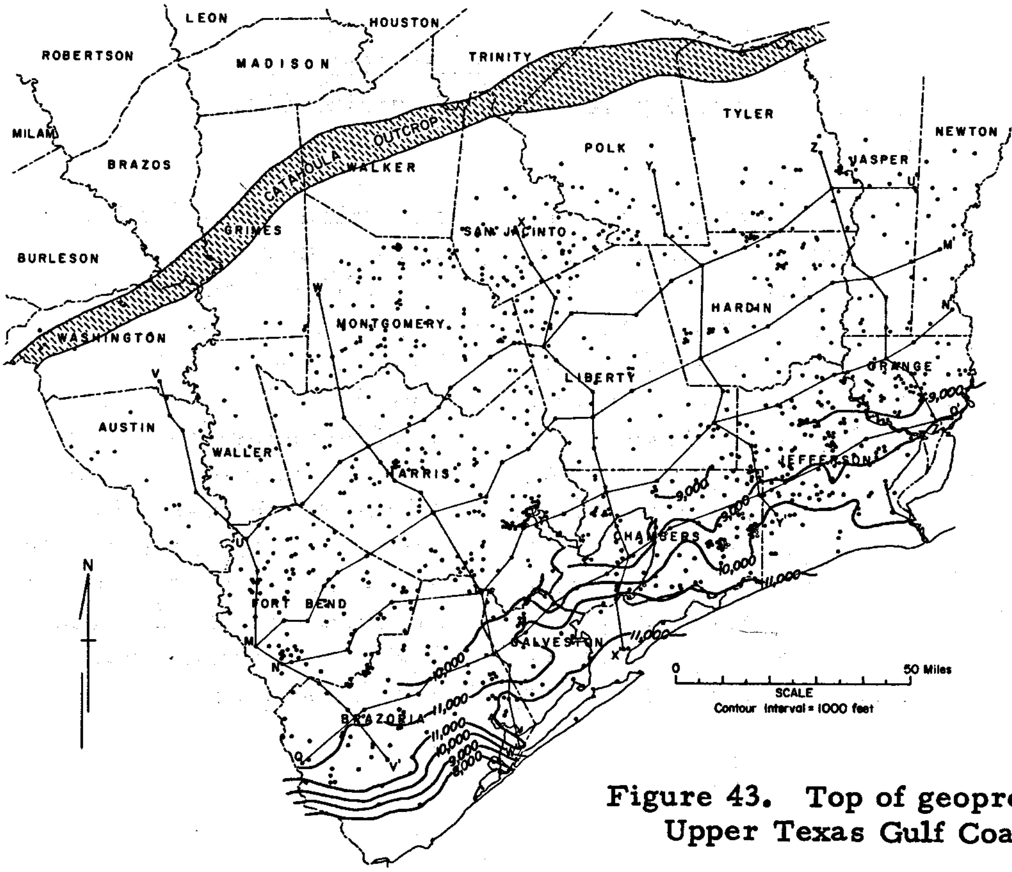


Figure 43. Top of geopressure, Upper Texas Gulf Coast.

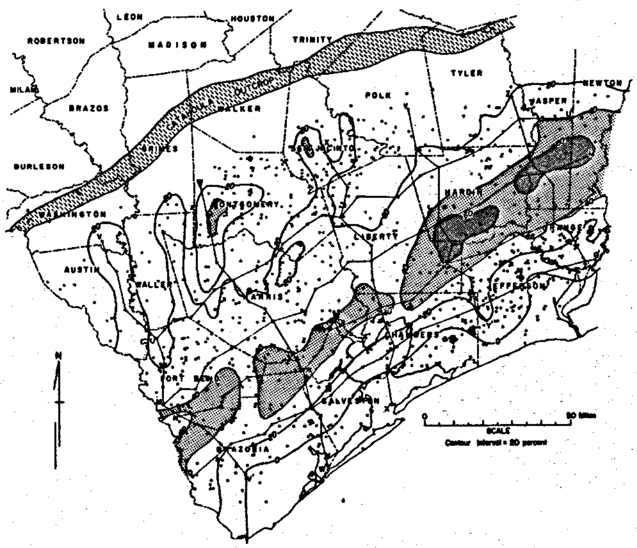


Figure 44. Total sand percentage of the Frio Formation.

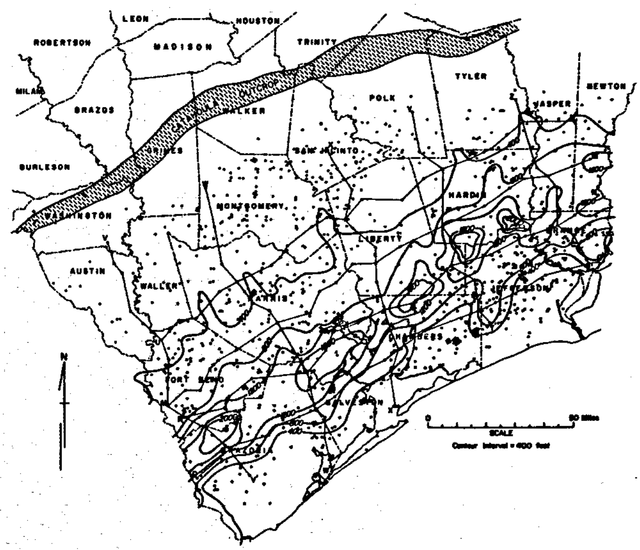


Figure 45. Total net sand of the Frio Formation.

ISOTHERMAL MAPS

Subsurface fluid temperatures of greater than 250°F occur in the Frio sand bodies up to 100 feet thick downdip of the high-sand trends.

Subsurface fluid temperature is obtained from well-log headings where bottom-hole temperature of each log run is recorded. These temperatures, however, were not measured under stable-hole conditions and are expected to be at least 10 percent lower than actual subsurface temperature. Isothermal maps constructed from these bottom-hole temperatures are based on sparse data because there is commonly only one temperature recorded in the Frio per well. Therefore, data density is approximately one-third that used in the preparation of the other maps.

The isothermal maps of the lower three correlation units, T5-T6, T4-T5, and T3-T4 (figs. 46-48), show that fluid temperatures within the main sand depocenter are lower than 200°F; the temperature gradient steepens above 200°F just below the top of geopressure. Subsurface fluid temperatures of greater than 250°F occur in prospective sands deposited in the shelf environment downdip of the main sand depocenter.

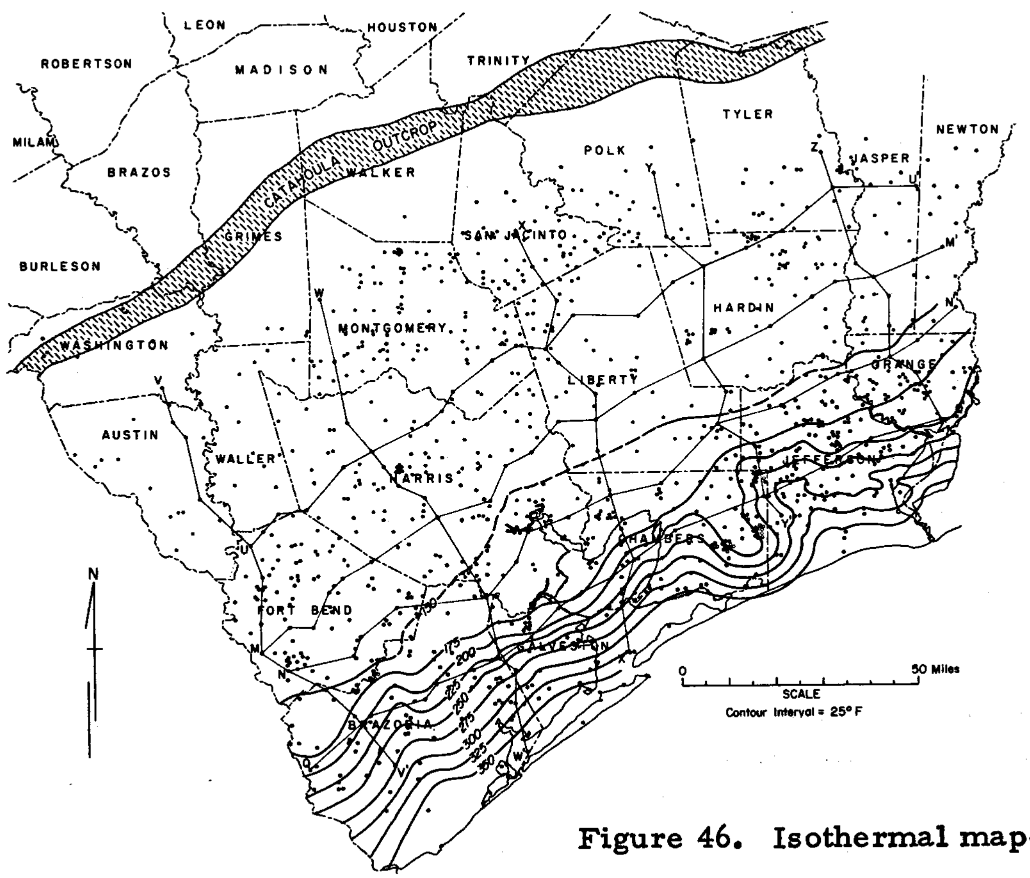


Figure 46. Isothermal map--unit T5-T6.

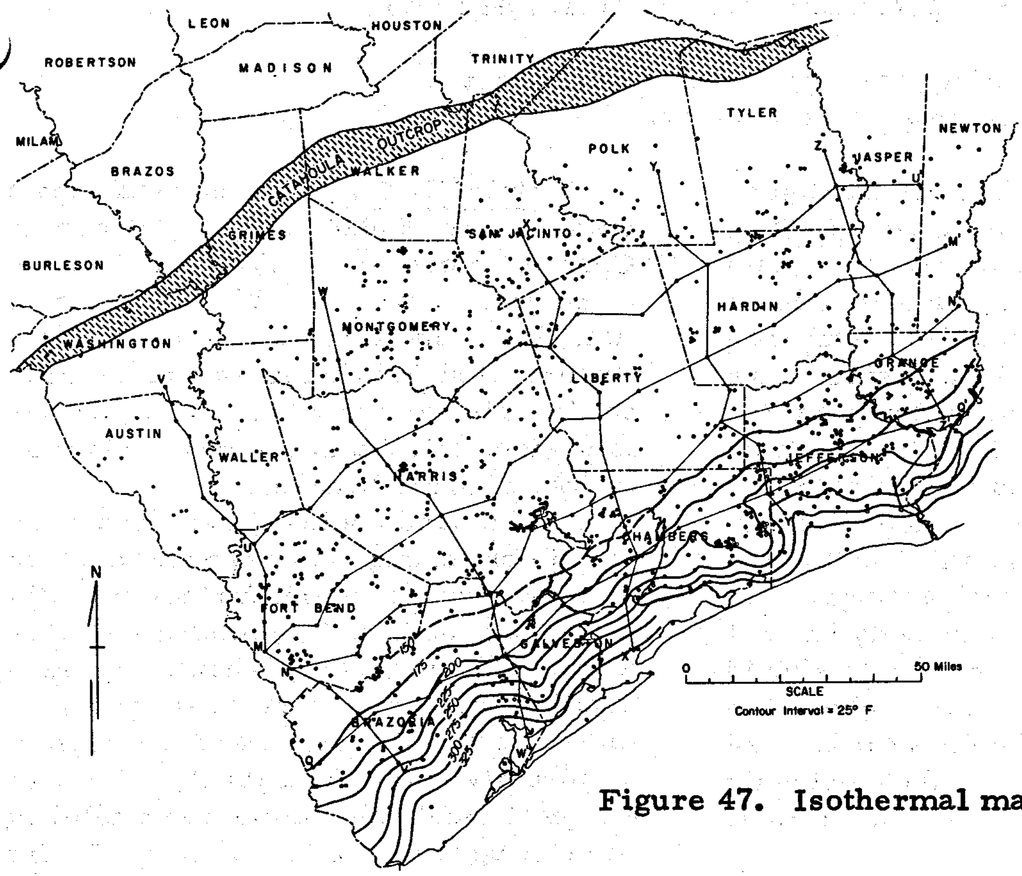


Figure 47. Isothermal map--unit T4-T5.

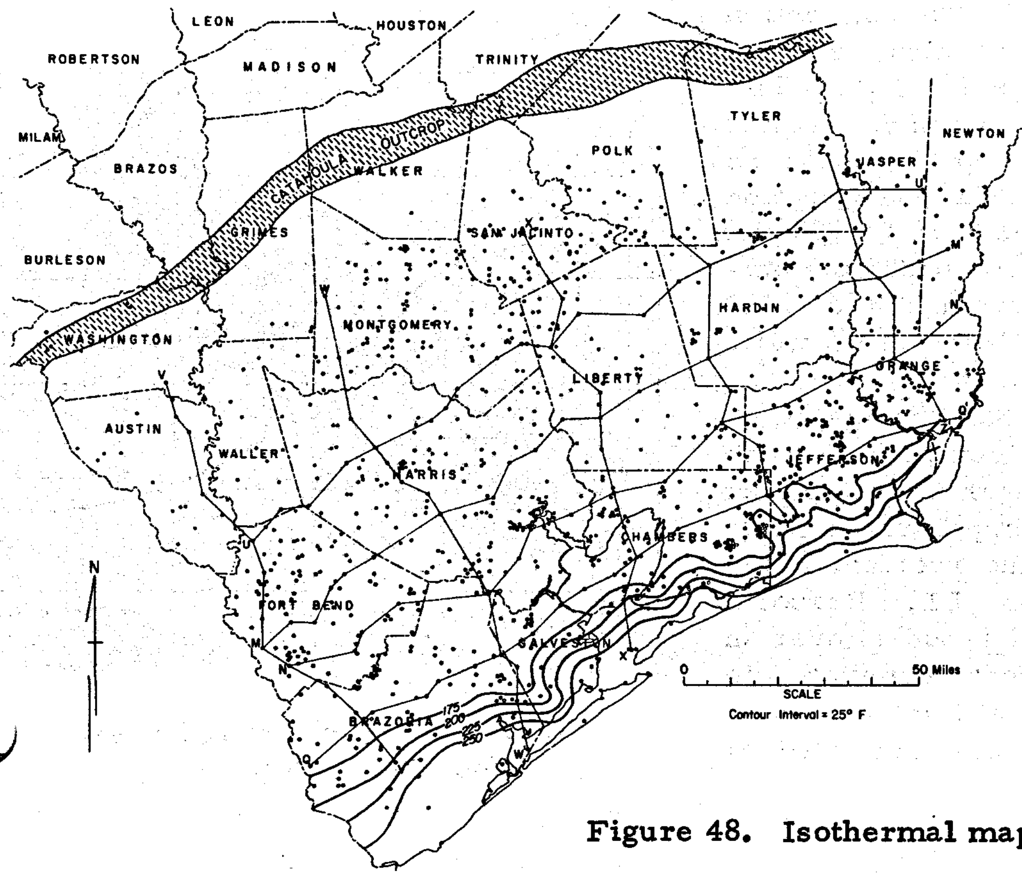


Figure 48. Isothermal map--unit T3-T4.

CONCLUSIONS AND POTENTIAL GEOTHERMAL FAIRWAYS

Geothermal fairways along the Upper Texas Gulf Coast occur downdip of the main sand depocenter.

In searching for potential geothermal fairways, two criteria have been considered: sand bodies should have a volume of greater than 3 cubic miles and uncorrected fluid temperature in excess of 250°F. Using these criteria, a broad band in Brazoria and Galveston Counties has been delineated (fig. 49). The sands identified occur in most of the Frio subunits, but in general, the sands are thin and broken by a number of shale partings. The areal extent of each sand body has not been determined at present; it should not be assumed, however, that each extends throughout the delineated fairway area because of the extreme structural complexity of this coastal zone.

Unit T5-T6. -- A cumulative thickness of more than 1,200 feet of sand occurs over a 3,100-foot section along a narrow belt which extends from northeast Brazoria County into southwest Galveston County. Individual sand bodies range in thickness from 10 to 35 feet. This sand section occurs between depths of 14,700 and 17,800 feet and has recorded bottom-hole temperatures from 278 to 314°F in the Humble No. 1 Skrabanek well, Brazoria County (fig. 50).

Unit T4-T5. -- Sand bodies ranging from 10 to 100 feet thick occur in several wells at depths greater than 14,000 feet. Fluid temperatures range from 260° to 330°F uncorrected. In the Phillips #1 Houston LL, Brazoria County, several sand bodies over an interval of 500 feet cumulate to greater than 200 feet thick (fig. 51). Fluid temperatures are recorded at 306°F uncorrected.

Unit T1-T2. -- In the Gulf Texas State Lease 53034 Well #2, Brazoria County, more than 200 feet of sand cumulates over an 800-foot section (fig. 52), starting at -12,680 feet. Uncorrected fluid temperature recorded in this sand is 270°F. Several 20- to 60-foot-thick sands appear relatively free of shale breaks.

The sand bodies identified here are thick enough and are an adequate temperature to merit further investigation as potential geothermal fairways. Further study should include detailed mapping of the areal extent of these reservoir sands and prediction of porosity and permeability. Without adequate sand volume and permeability, fluid production will not be sufficient for economical electric power generation.

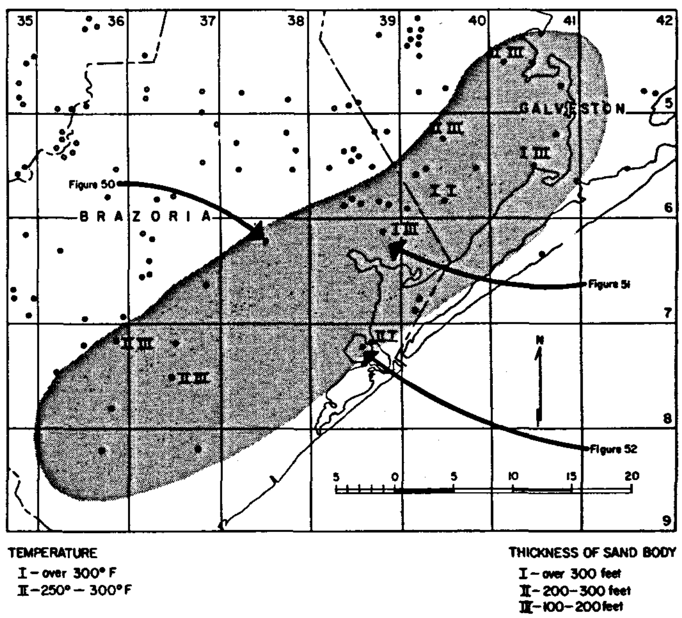


Figure 49. Geothermal fairway, Upper Texas Gulf Coast.

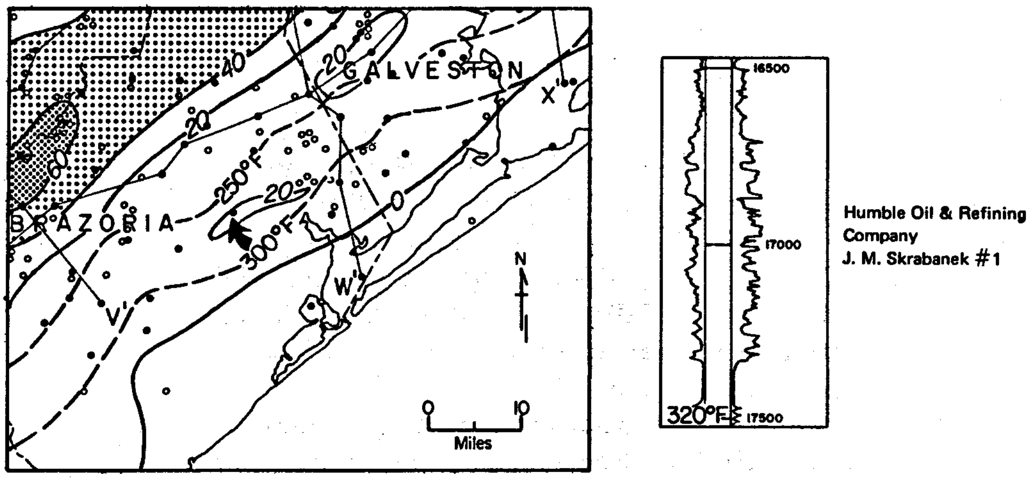


Figure 50. Sand-percent map of unit T5-T6 with 250° and 300°F isotherms. Electrical log shows thick sand development and fluid temperature greater than 300°F from this unit.

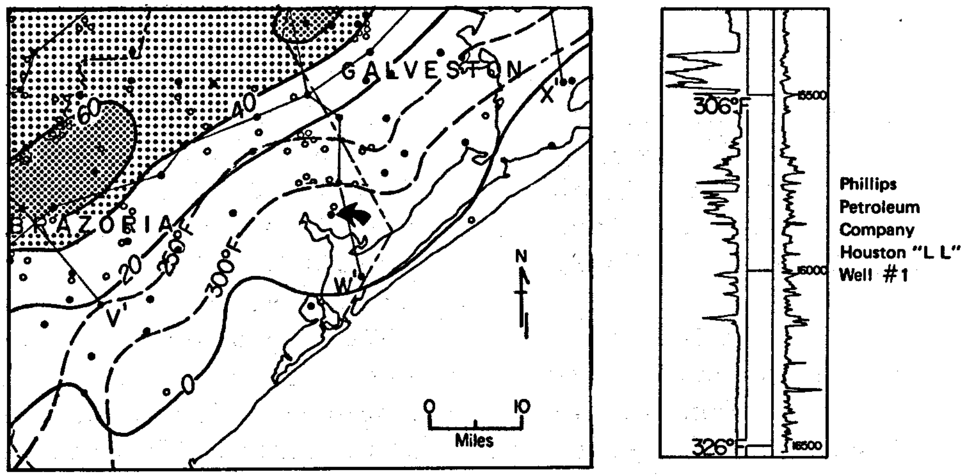


Figure 51. Sand-percent map of unit T4-T5 with 250° and 300°F isotherms. Electrical log shows a number of thin sands with fluid temperature greater than 300°F from this unit.

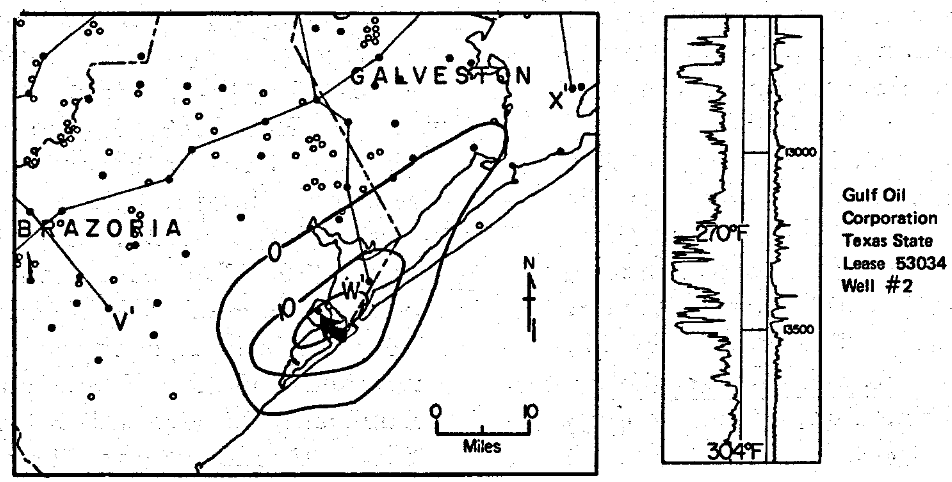


Figure 52. Sand-percent map of unit T1-T2 and electrical log of a well from this unit showing thick sand with fluid temperature greater than 270°F.

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Other studies related to geopressured geothermal energy along the Texas Gulf Coast are being coordinated by The University of Texas Center for Energy Studies.

SELECTED REFERENCES

Bebout, D. G., Dorfman, M. H., and Agagu, O. K., 1975, Geothermal resources--Frio Formation, South Texas: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 75-1, 36 p.

_______, Agagu, O. K., and Dorfman, M. H., 1975, Geothermal resources--Frio Formation, Middle Texas Gulf Coast: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 75-8, 43 p.

Bruce, C. H., 1973, Pressured shale and related sediment deformation: Mechanism for development of regional contemporaneous faults: Am. Assoc. Petroleum Geologists Bull., v. 57, p. 878-886.

Fisher, W. L., and McGowen, J. H., 1967, Depositional systems in the Wilcox Group of Texas and their relationship to the occurrence of oil and gas: Gulf Coast Assoc. Geol. Socs., Trans., v. 17, p. 105-125. Reprinted as Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 67-4.

_______, Brown, L. F., Jr., Scott, A. J., and McGowen, J. H., 1969, Delta systems in the exploration for oil and gas: Univ. Texas, Austin, Bur. Econ. Geology, Syllabus for Research Colloquium held in Austin, Texas, August 27-29, 1969, 212 p.

Guevara, E. H., and Garcia, R., 1972, Depositional systems and oil-gas reservoirs in the Queen City Formation (Eocene), Texas: Gulf Coast Assoc. Geol. Socs., Trans., v. 22, p. 1-22. Reprinted as Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 72-4.

Halbouty, M. T., 1967, Salt domes, Gulf region, United States and Mexico: Houston, Texas, Gulf Publishing Co., 425 p.

Jones, P. H., 1969, Hydrodynamics of geopressure in the northern Gulf of Mexico basin: Jour. Petroleum Technology, v. 21, p. 803-810.

_______ 1975, The origin and detailed occurrence of the resource--Geothermal and hydrocarbon regimes, northern Gulf of Mexico basin: in Dorfman, M. H., and Deller, R. W., eds., Proceedings, First Geopressured Geothermal Energy Conference: Univ. Texas, Austin, Center for Energy Studies, p. 15-89.