GEOTHERMAL RESOURCES, VICKSBURG FORMATION, TEXAS GULF COAST

By

R. G. Loucks

Assisted by

S. C. Claypool	P. E. Luttrell
V. J. Gavenda	K. L. Milliken
J. H. Han	M. G. Moseley

Prepared for

The Division of Geothermal Energy, U. S. Department of Energy

in partial fulfillment of

CONTRACT NO. AT-E(40-1)-4891 (EY-76-S-05-4891)

January 1978

Bureau of Economic Geology

The University of Texas at Austin

W. L. Fisher, Director

CONTENTS

SUMMARY

The potential for discovering geopressured geothermal reservoirs in the Vicksburg Formation is limited to Hidalgo County along the Lower Texas Gulf Coast. In Hidalgo County, an area of approximately 385 square miles (designated the Vicksburg Fairway) contains up to 1,300 feet of geopressured sandstones with fluid temperatures greater than 300^{o}F. In-place effective permeability, however, averages less than 1 millidarcy in the Vicksburg sandstones because of fine grain size and extensive late carbonate cementation. Also, areal extent of individual reservoirs is limited in a dip direction by growth faults and in a strike direction by the lenticular morphology of the sandstone bodies. In conclusion, under the present specifications set for a geothermal fairway, the Vicksburg has minimal potential because of low reservoir deliverability, which is constrained by low permeability and somewhat limited reservoir continuity. If future tests indicate that lower permeabilities are acceptable, the Vicksburg Fairway should be reconsidered because of the presence of extremely thick sandstone bodies.

INTRODUCTION

General Statement

Geopressured geothermal prospects of the Oligocene Vicksburg Formation (fig. 1) along the Texas Gulf Coast are minimal because of low permeability and restricted areal extent of reservoirs. This evaluation of the Vicksburg Formation results from a program being conducted by the

CENOZOIC – TEXAS GULF COAST

SYSTEM	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. Modified from Gregory (1966) and Bebout and others (1975).

Bureau of Economic Geology to evaluate the potential of producing geopressured geothermal energy from onshore Tertiary formations along the Texas Gulf Coast. Two other Tertiary units have been investigated: the Frio Formation (Bebout, Dorfman, and Agagu, 1975; Bebout, Agagu, and Dorfman, 1975; Bebout, Loucks, Bosch, and Dorfman, 1976; and Bebout, Loucks, and Gregory, 1977) and the Wilcox Group (Bebout, Gavenda, and Gregory, 1978).

An area of approximately 385 square miles (11 by 35 miles) was identified as the Vicksburg Fairway in Hidalgo County along the Lower Texas Gulf Coast (fig. 2). A geopressured geothermal fairway is an area that meets a set of easily recognizable minimum requirements necessary for the production of geothermal energy and therefore warrants further investigation. These requirements demand a sandstone volume of 3 cubic miles (for example, 300 feet by 50 square miles) and subsurface fluid temperatures greater than 300°F. Further investigation of a fairway area would concentrate on reservoir permeability and continuity, parameters which are more difficult to analyze.

An area with deep, massive sandstones in the Vicksburg Fairway was recognized by Bebout (1975) in a preliminary study of geopressured geothermal corridors in Texas (fig. 3). Bebout also indicated that the Vicksburg Formation in an area of the Upper Texas Gulf Coast (fig. 3) may have potential, but no prospective sandstones were identified during subsequent studies reported herein.

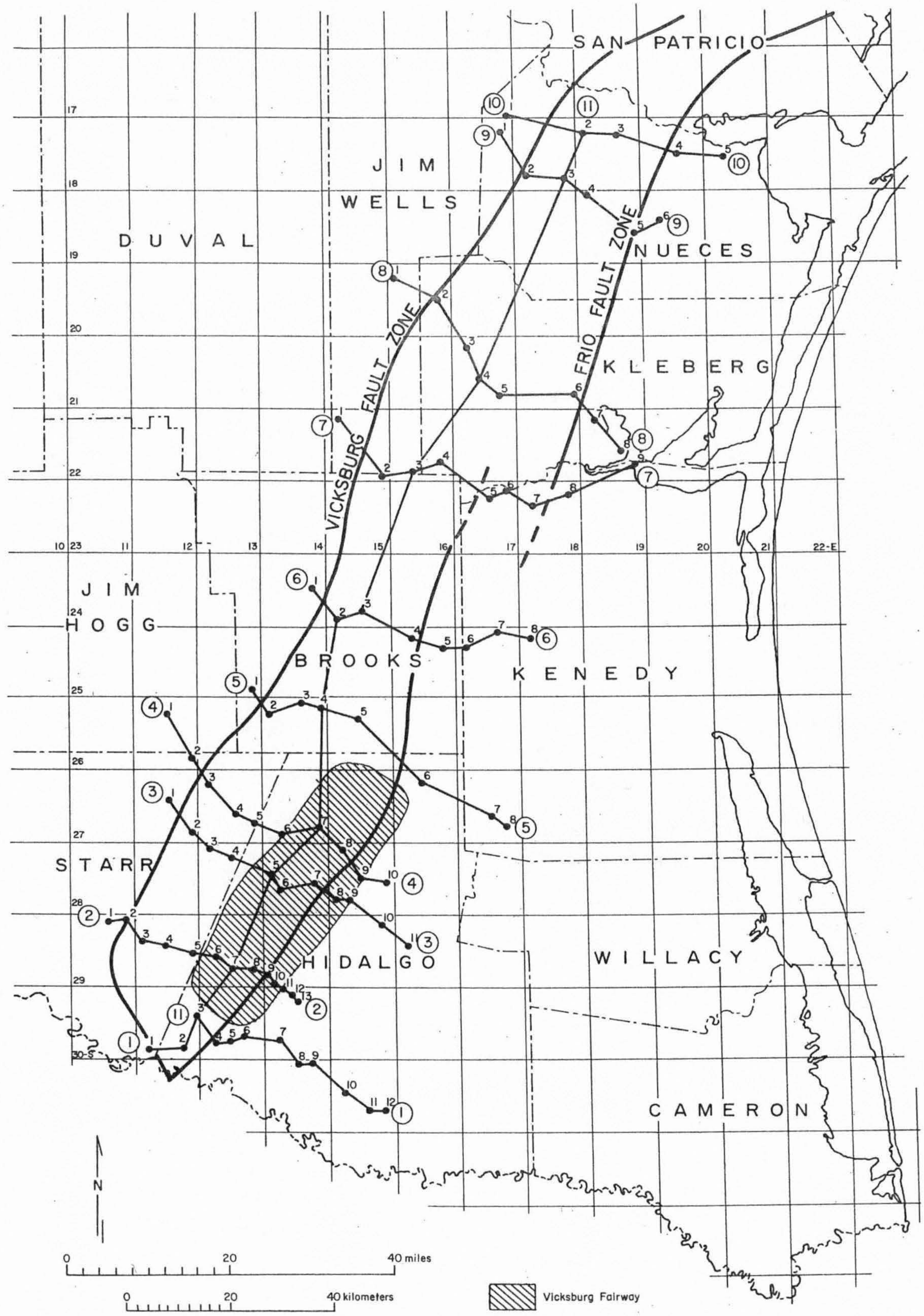

Figure 2. Location of Vicksburg Fairway and lines of sections shown in Figures 9 to 29.

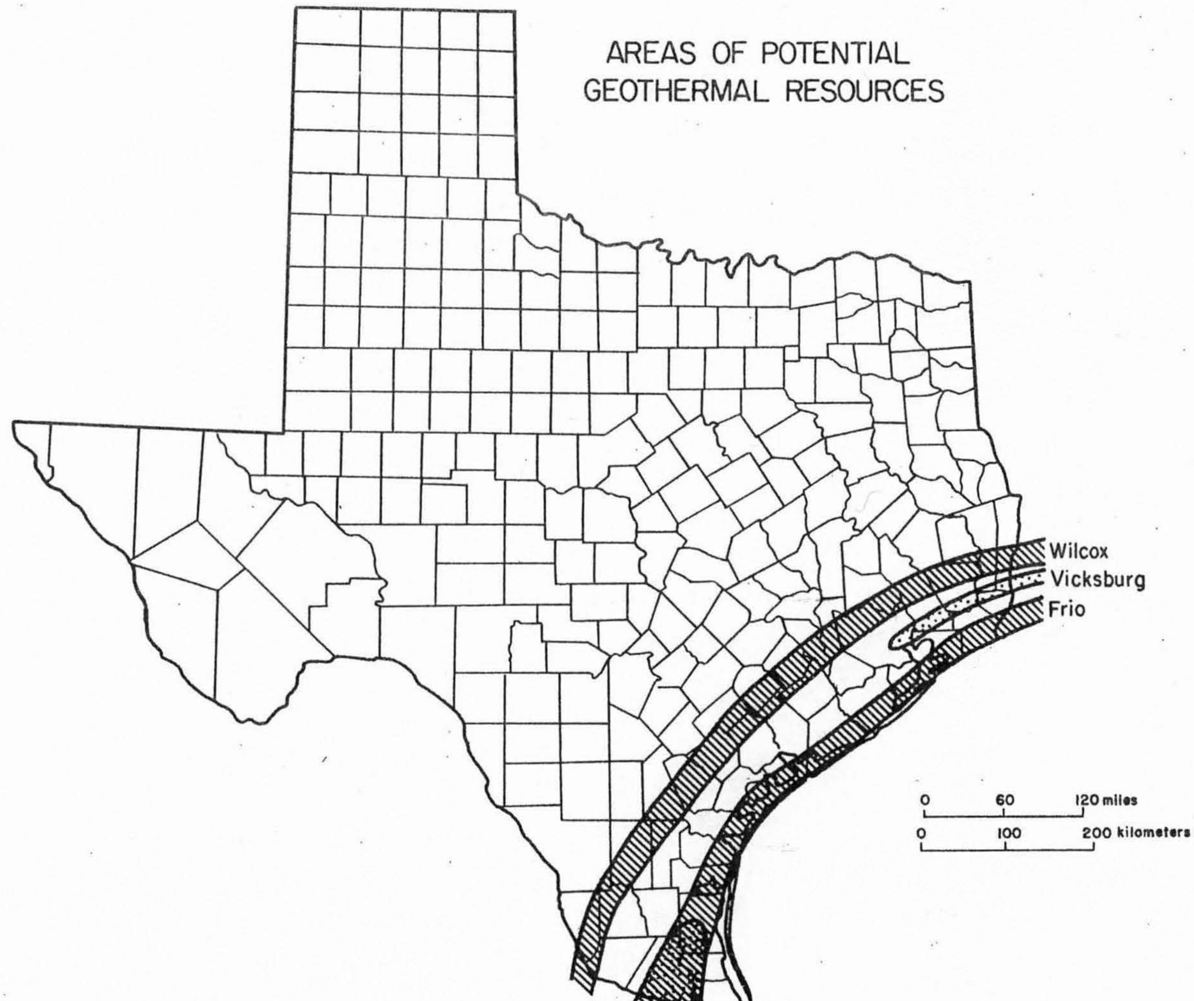

Figure 3. Geothermal corridors of potential fairways. From Bebout (1976).

Method of Study

Stratigraphic and structural cross sections were constructed on a grid along the Lower Texas Gulf Coast, downdip of the Vicksburg fault zone, where deep electrical-log data were available (fig. 2). These cross sections are regional in scope and are interpretive in part where data are sparse or absent. No cross sections were prepared for the Middle and Upper Texas Gulf Coast because few deep wells were available downdip of the Vicksburg fault zone (fig. 4), and what deep data were available indicated no sandstones occur in the zone of interest.

Published reservoir quality data by Ritch and Kozik (1971) and Swanson, Oetking, Osoba, and Hagens (1976) were integrated with data from this study to complete the preliminary analysis of the Vicksburg Fairway. Final detailed analysis of the fairway will come from a site selection study now in progress at the Bureau of Economic Geology.

REGIONAL GEOLOGY

Growth Faults

Growth faults, a common structural feature in the Gulf Coast area (Bruce, 1973), formed by contemporaneous subsidence during sediment loading (fig. 5). Two major zones of growth faults affected the Vicksburg Formation: the Vicksburg and the Frio fault zones (fig. 4).

More than 7,000 feet of Vicksburg sediment accumulated on the downthrown side of growth faults along the Vicksburg fault zone. Gulfward on the downthrown side of the Frio fault zone, massive Frio sandstones

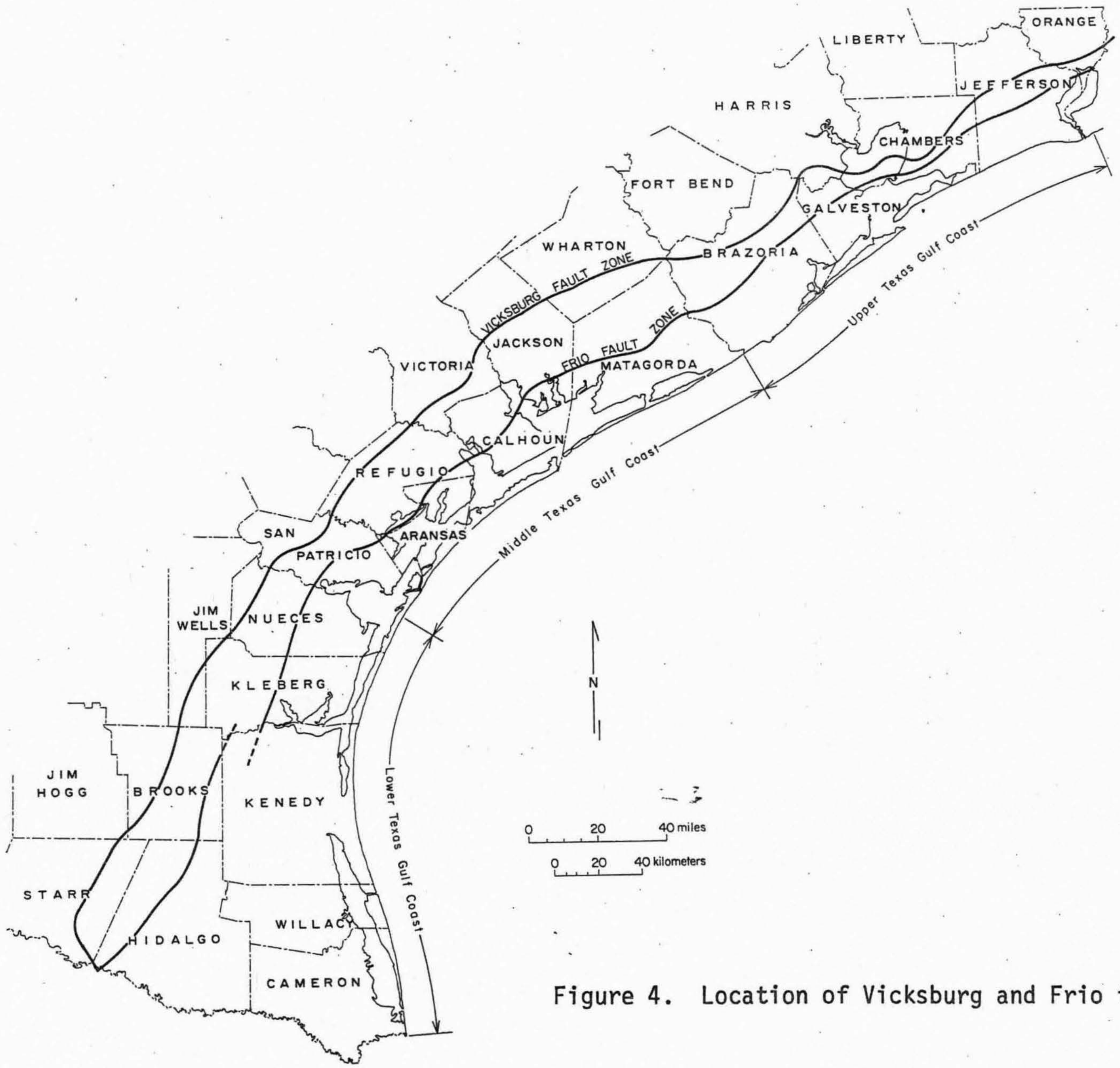

Figure 4. Location of Vicksburg and Frio fault zones.

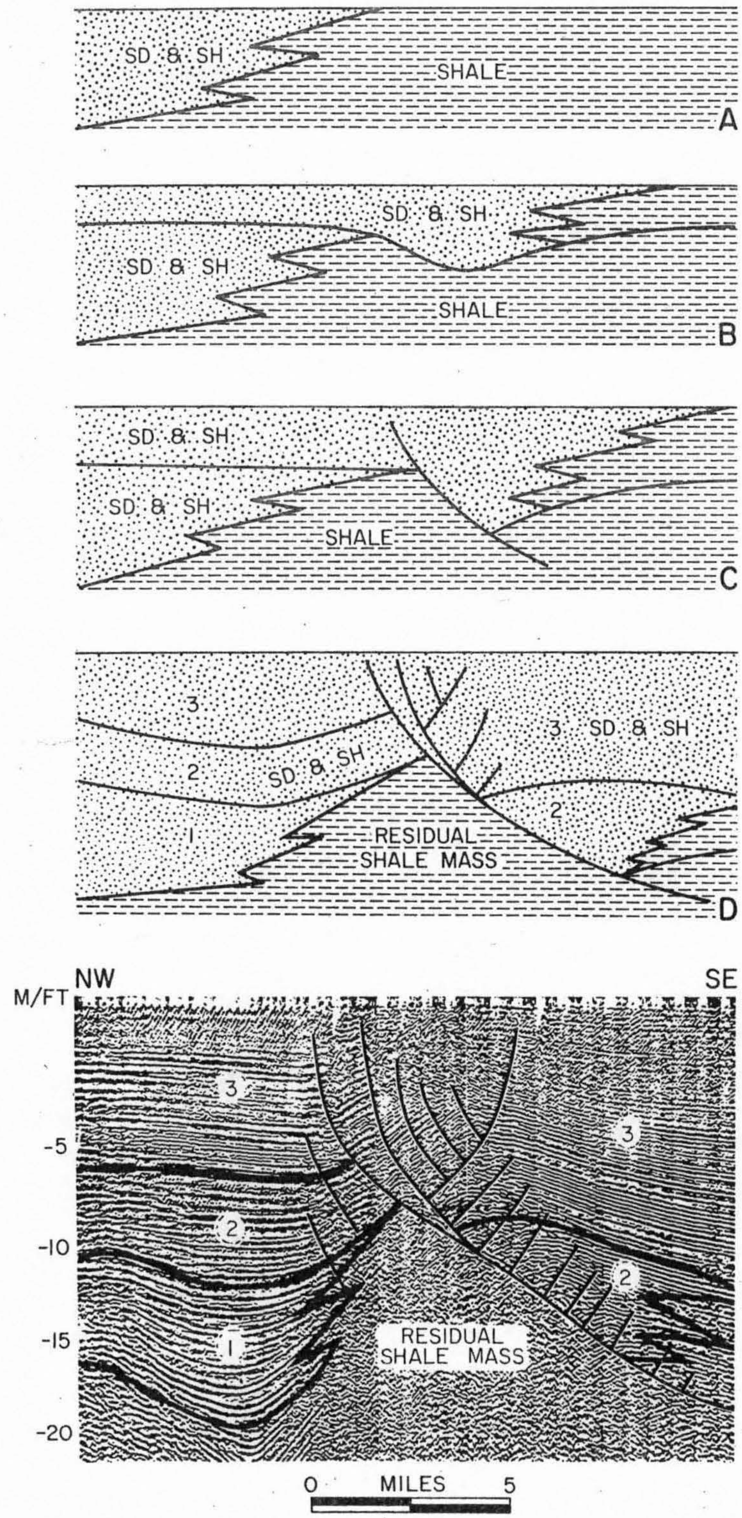

Figure 5. Growth-fault development interpreted from a seismic section and shown sequentially by diagrams (Bruce, 1973).

were juxtaposed with older Vicksburg shales by movement along growth faults. Therefore, a basic understanding of the depositional and structural history of basal Frio sandstones is necessary in order to delineate the distribution of the Vicksburg sandstones, which are similar in appearance on electrical logs to the Frio sandstones.

Index Foraminifera

Index Foraminifera are the basis for distinguishing formations in the otherwise similar sandstone-shale sequences of the Tertiary Gulf Coast basin. Contact between the Vicksburg Formation and the Frio Formation is traditionally picked at the first occurrence of *Textularia warreni* (fig. 6). This study, however, indicates that in the Lower Texas Gulf Coast area the contact between the Vicksburg Formation and the basal Frio is at the base of a thick progradational sequence of shale and sandstone that contains *T. warreni* (fig. 7). *Textularia warreni*, therefore, must be a basal Frio index foraminifer and does not occur in the Vicksburg Formation.

Updip of the Frio fault zone, the basal Frio is predominantly fluvial in origin and contains only *T. warreni* in marine sandstones and shales which occur only in the lower part of the section (fig. 7). On the other hand, gulfward of the Frio fault zone, the entire, predominantly marine, basal Frio strata contain a full suite of Frio index Foraminifera.

GREGORY (1966)				INDEX FORAMINIFERA	THIS REPORT		
TERTIARY	OLIGOCENE	ANAHUAC		*Discorbis nomada* *Discorbis gravelli* *Heterostegina* sp.	ANAHUAC	Mio-cene ?	TERTIARY
		ANAHUAC		*Marginulina idiomorpha* *Marginulina vaginata* *Marginulina howei*	FRIO	OLIGOCENE	
		FRIO	Upper	*Cibicides hazzardi* *Marginulina texana* *Hackberry assemblage*	FRIO		
		FRIO	Middle	*Nonion struma* *Nodosaria blanpiedi* *Discorbis (D)*	FRIO		
		FRIO	Lower	*Textularia seligi* *Anomalina bilateralis* *Cibicides (IO)*	FRIO		
		VICKS-BURG	Upper	*Textularia warreni*	FRIO		
		VICKS-BURG	Upper	*Loxostoma (B) delicata*	VICKSBURG		
		VICKS-BURG	Middle	*Clavulina byramensis* *Cibicides pippeni* *Cibicides mississippiensis*	VICKSBURG		
		VICKS-BURG	Lower	*Uvigerina mexicana*	VICKSBURG		

Figure 6. Index Foraminifera. Data accumulated from Gregory (1966), Bebout and others (1975), and this investigation.

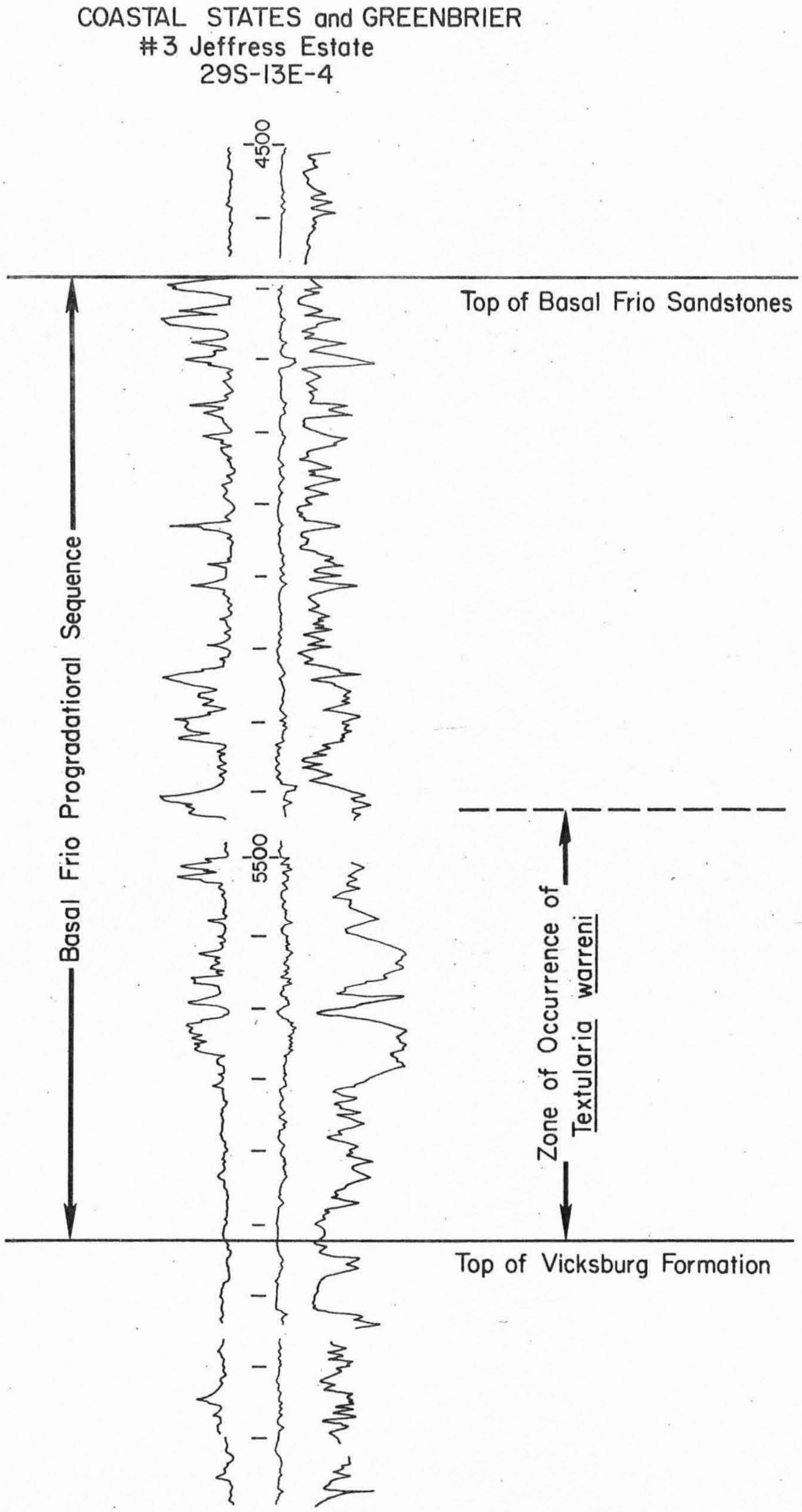

Figure 7. Electrical log showing contact between Vicksburg and basal Frio sandstones. Zone of occurrence of *Textularia warreni* is the lower part of the basal Frio progradational sequence.

Vicksburg and Basal Frio Sandstone Distribution

General Statement

The Vicksburg Formation, downdip of the Vicksburg fault zone, changes from a very prominent sandstone section along the Lower Texas Gulf Coast to a sandstone-poor section along the Middle and Upper Texas Gulf Coast (figs. 8 to 29). The major source of sand in the Vicksburg was the ancient Rio Grande as indicated by the dominance of sandstone only in the Hidalgo County area. In contrast, basal Frio sandstones are relatively continuous along the entire Texas Gulf Coast (figs. 8 to 29).

Vicksburg Sandstone Distribution

Vicksburg Fairway Area. In the Vicksburg Fairway area along the Lower Texas Gulf Coast, the Vicksburg section expands from a few hundred feet thick updip of the Vicksburg fault zone to more than 4,000 feet on the downthrown side of the fault (figs. 8, 11 to 16). The lower part of the Vicksburg Formation contains more sandstone than the upper part of the Vicksburg. Massive sandstones in the lower part of the Vicksburg section occur as far downdip as the Frio fault zone. These sandstones probably extend beyond the Frio fault zone but have not yet been penetrated. Also, the lower part of the Vicksburg Formation expands in thickness on the downthrown side of several growth faults downdip from the Vicksburg fault zone, isolating sandstone bodies into separate fault blocks.

The upper part of the Vicksburg Formation contains massive sandstones immediately downdip of the Vicksburg fault zone, but toward the

Frio fault zone these sandstones grade gulfward to shale. The sandstones in the upper part of the Vicksburg Formation are too shallow to have fluid temperatures greater than 300°F and are not prospective geothermal reservoirs. Only the sandstones in the lower part of the formation are sufficiently hot to qualify the area as a geothermal fairway.

A generalized facies tract exhibited by the Vicksburg Formation progresses gulfward (1) from thin sandstones within a shale sequence (fluvial), (2) into a massive sandstone sequence composed of numerous sandstone units separated by thick shales (high constructive lobate to elongate deltas), (3) into thin sandstones within a shale sequence (distal delta), and (4) ultimately into a shale sequence (prodelta to slope). In a vertical sequence immediately updip of the Frio fault zone, the Vicksburg Formation grades upward from massive deltaic sandstones in the lower part to slope shales in the upper part, indicating a major marine transgression.

<u>South of the Vicksburg Fairway Area</u>. The entire Vicksburg Formation south of the fairway and downdip of the Vicksburg fault zone is predominantly shale containing a few thin siltstone lenses up to four feet thick (fig. 9). These strata were deposited in distal delta to prodelta environments which are unfavorable for the development of geothermal reservoirs.

<u>North of the Vicksburg Fairway Area</u>. North of the fairway area along the Lower Texas Gulf Coast, the lower part of the Vicksburg Formation grades from sandstone to shale followed by a similar change in the upper part of the Vicksburg Formation (figs. 17, 19, 21, 23, 25, 27, and 29).

Along the Middle and Upper Texas Gulf Coast, most of the Vicksburg sequence is shale as indicated by published cross sections (Gregory, 1966; fig. 30) and scattered deep wells. Some sandstones occur in the upper part of the Vicksburg section, but these sandstones are too shallow to have high fluid temperatures required for production of geothermal energy.

Basal Frio Sandstone Distribution

Along the Lower Texas Gulf Coast, basal Frio section expands across several large growth faults associated with the Frio fault zone located near the underlying Vicksburg shelf edge (figs. 8 to 29). Updip of the Frio fault zone, basal Frio strata grade gulfward from a fluvial system containing scattered sandstones within a shale sequence to a deltaic system composed of massive sandstones.

The basal Frio deltaic system thickened across the Frio fault zone, juxtaposing downthrown massive Frio deltaic sandstones and upthrown prodelta slope shale deposits of the Vicksburg Formation (figs. 8 to 28). Swanson and others (1976) have interpreted some massive Frio sandstones downdip of the Frio fault zone in Kenedy County as Vicksburg sandstones. However, according to Stratigraphic Dip Sections 6 and 7 (figs. 19 and 21) these deep massive sandstones must be Frio sandstones because the facies tract updip of these sandstones is predominantly prodelta to slope shales of Vicksburg age. The sediment dispersal system for the deep sandstones in Kenedy County occurs in the massive basal Frio sandstone section updip of the Frio fault zone.

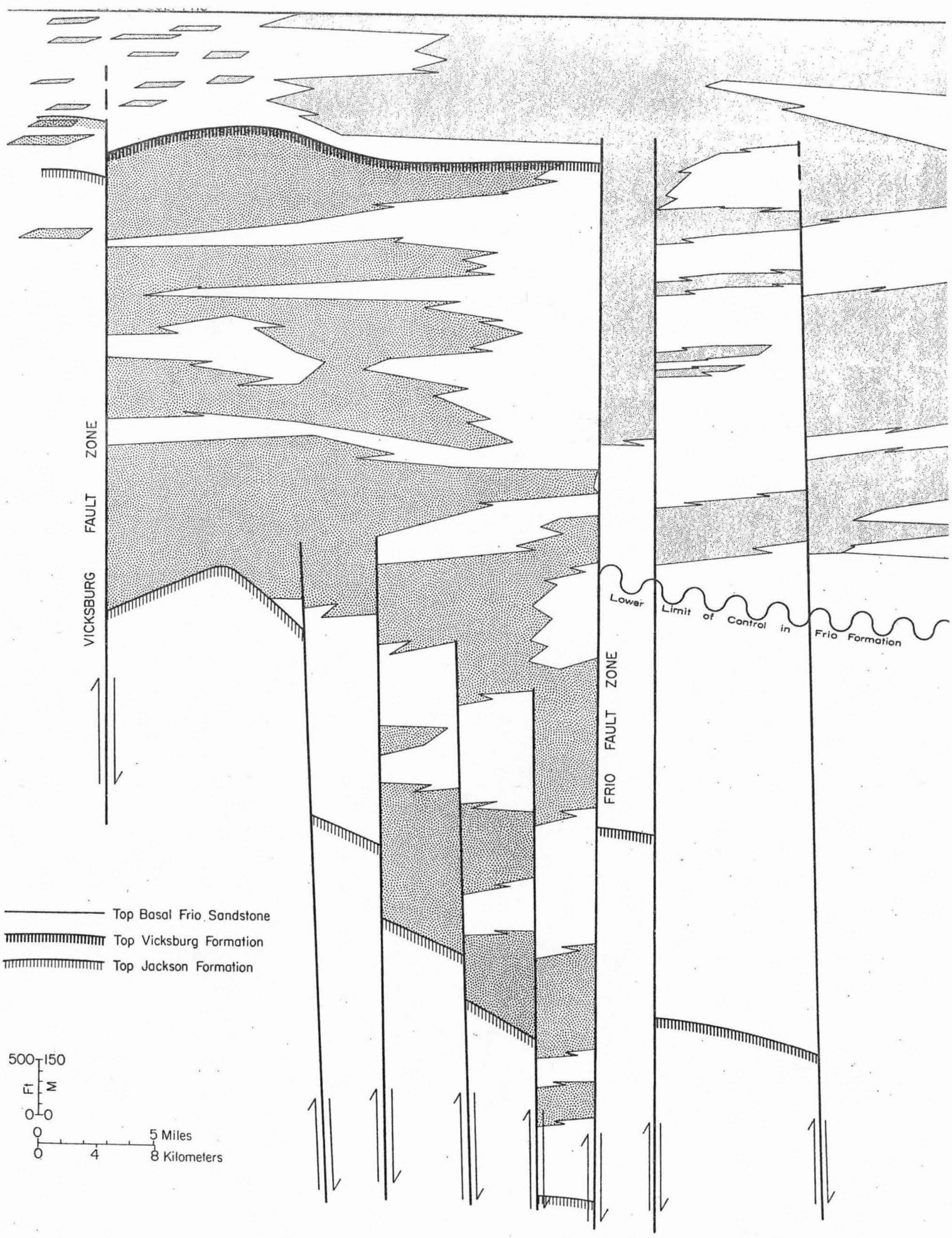

Figure 8. Stratigraphic dip section showing Vicksburg and basal Frio sandstone distribution in the Vicksburg Fairway. Line of section is the same as in Figure 10.

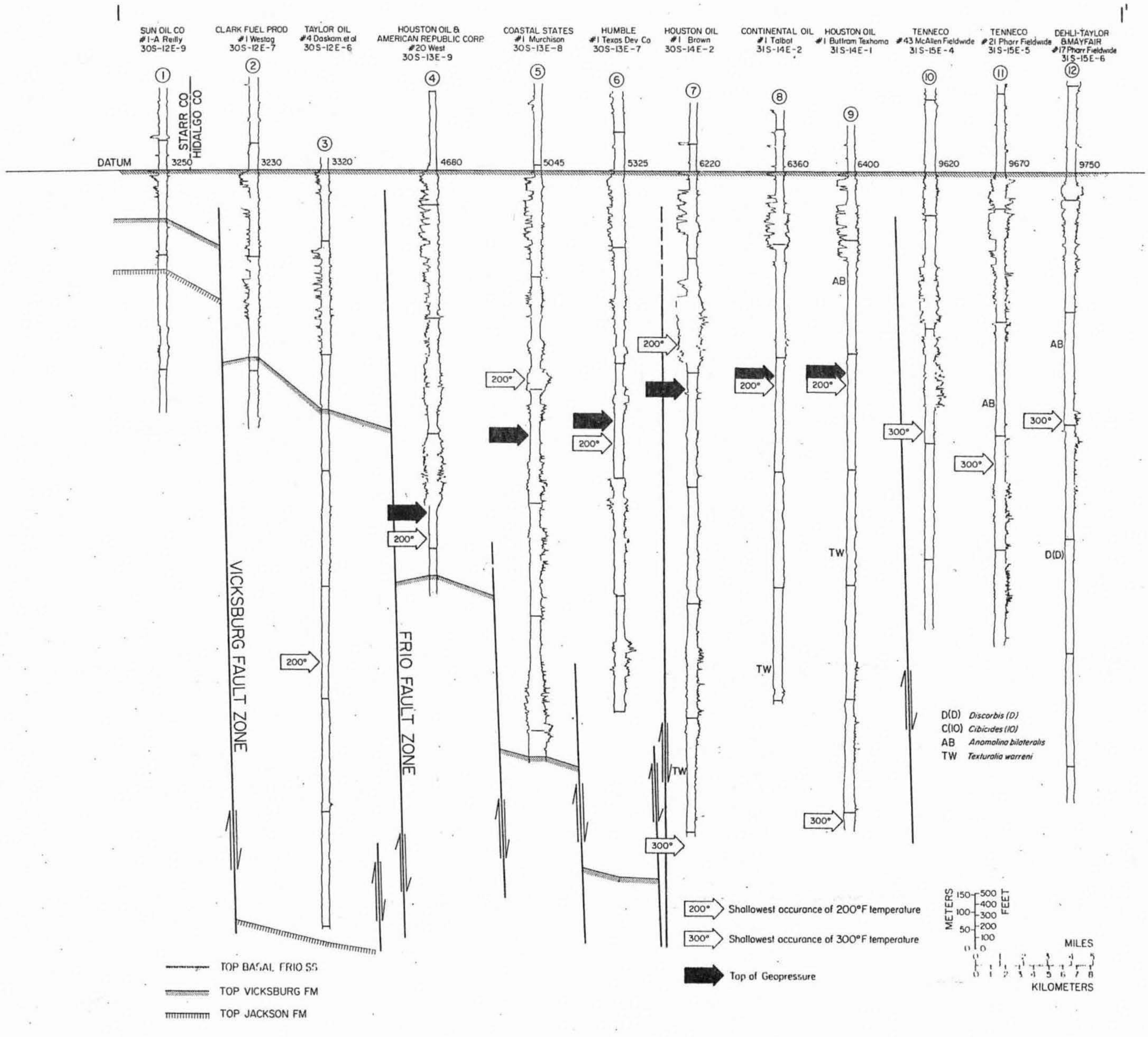

Figure 9. Stratigraphic dip section 1. The locations of this section and those which follow (figs. 10 to 29) are shown in Figure 2. The datum for each stratigraphic section is the top of the basal Frio, and the datum for each structural section is sea level. The top of geopressure is shown by the black arrows, and the approximate points at which 200°F and 300°F are reached are shown by the arrows labeled 200°F and 300°F.

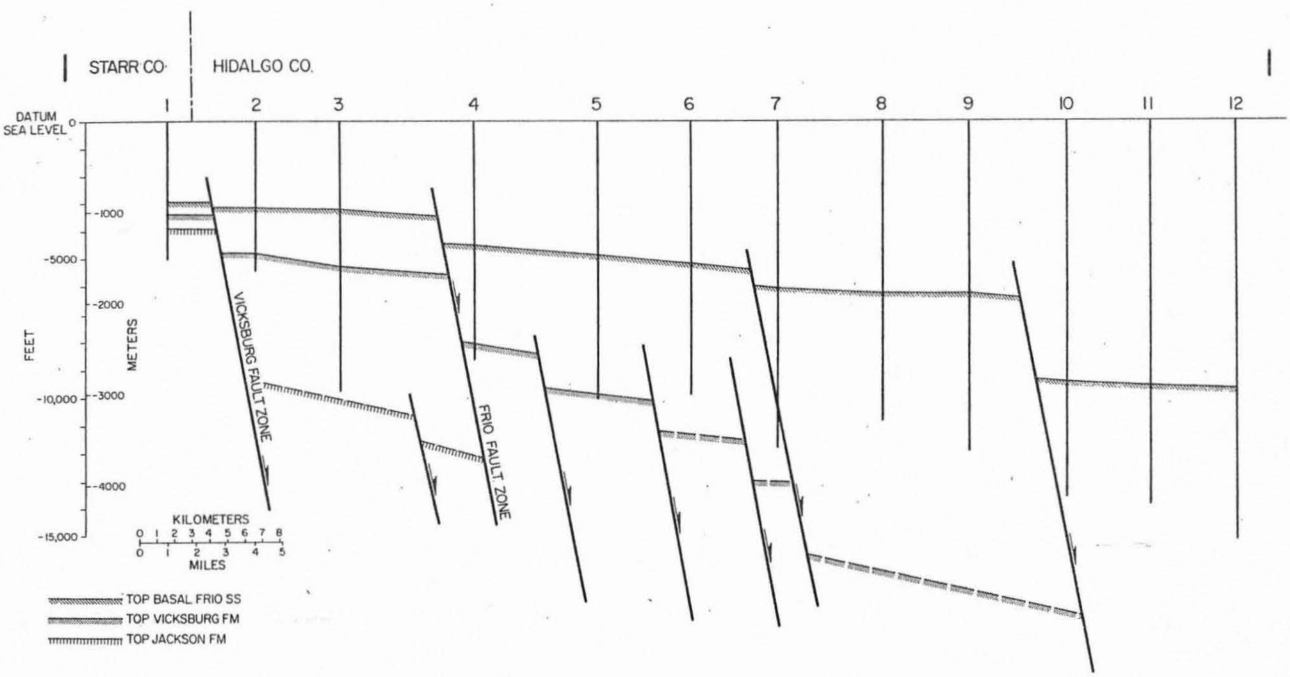

Figure 10. Structural section 1.

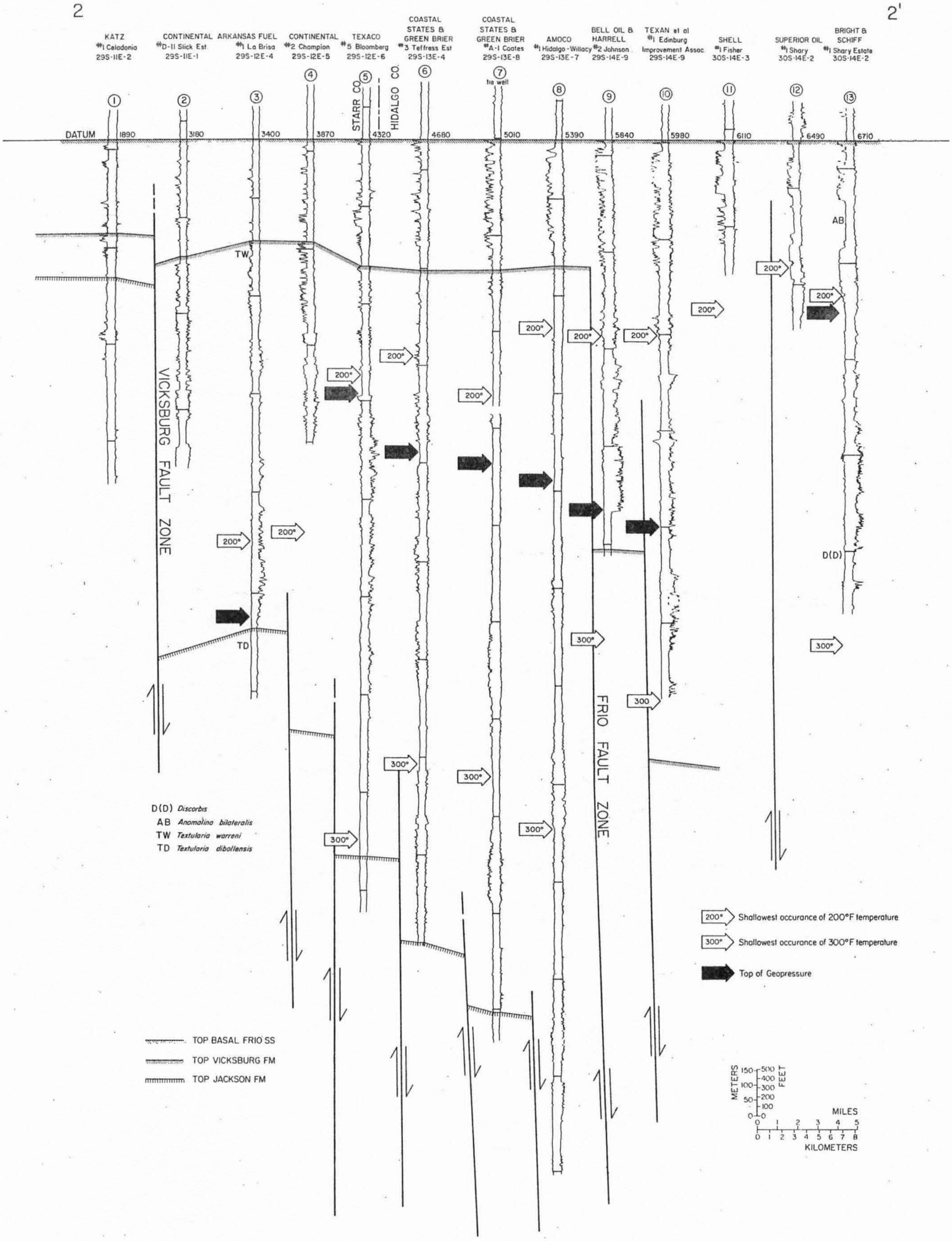

Figure 11. Stratigraphic dip section 2.

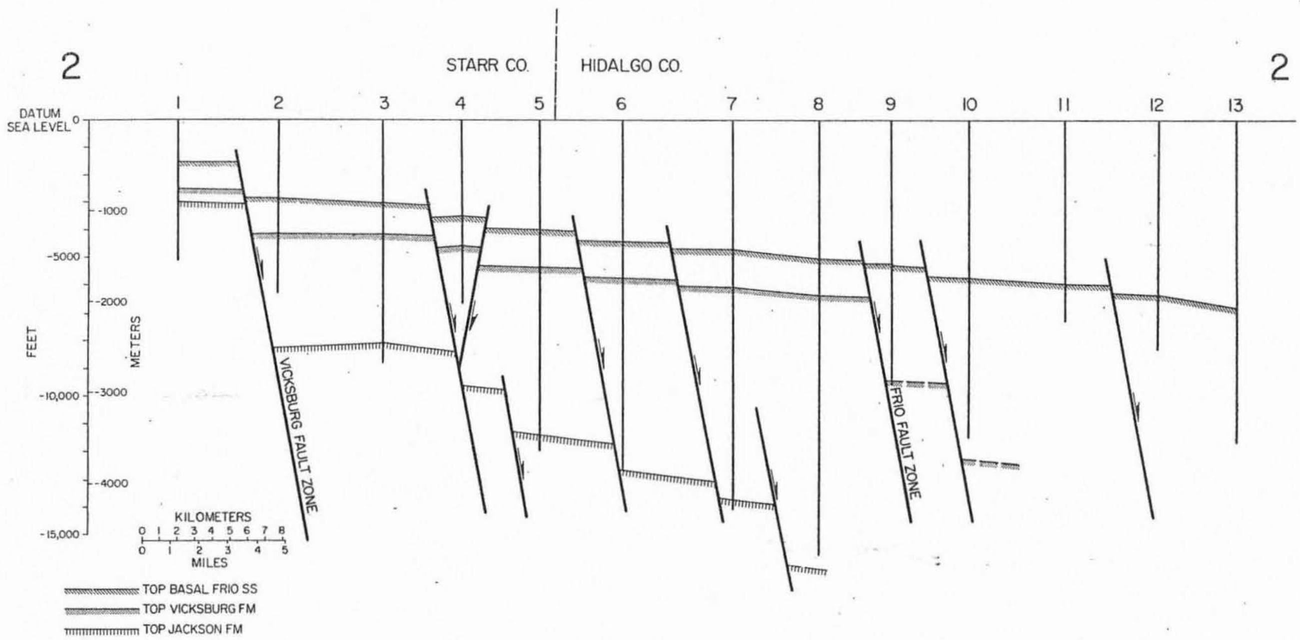

Figure 12. Structural section 2.

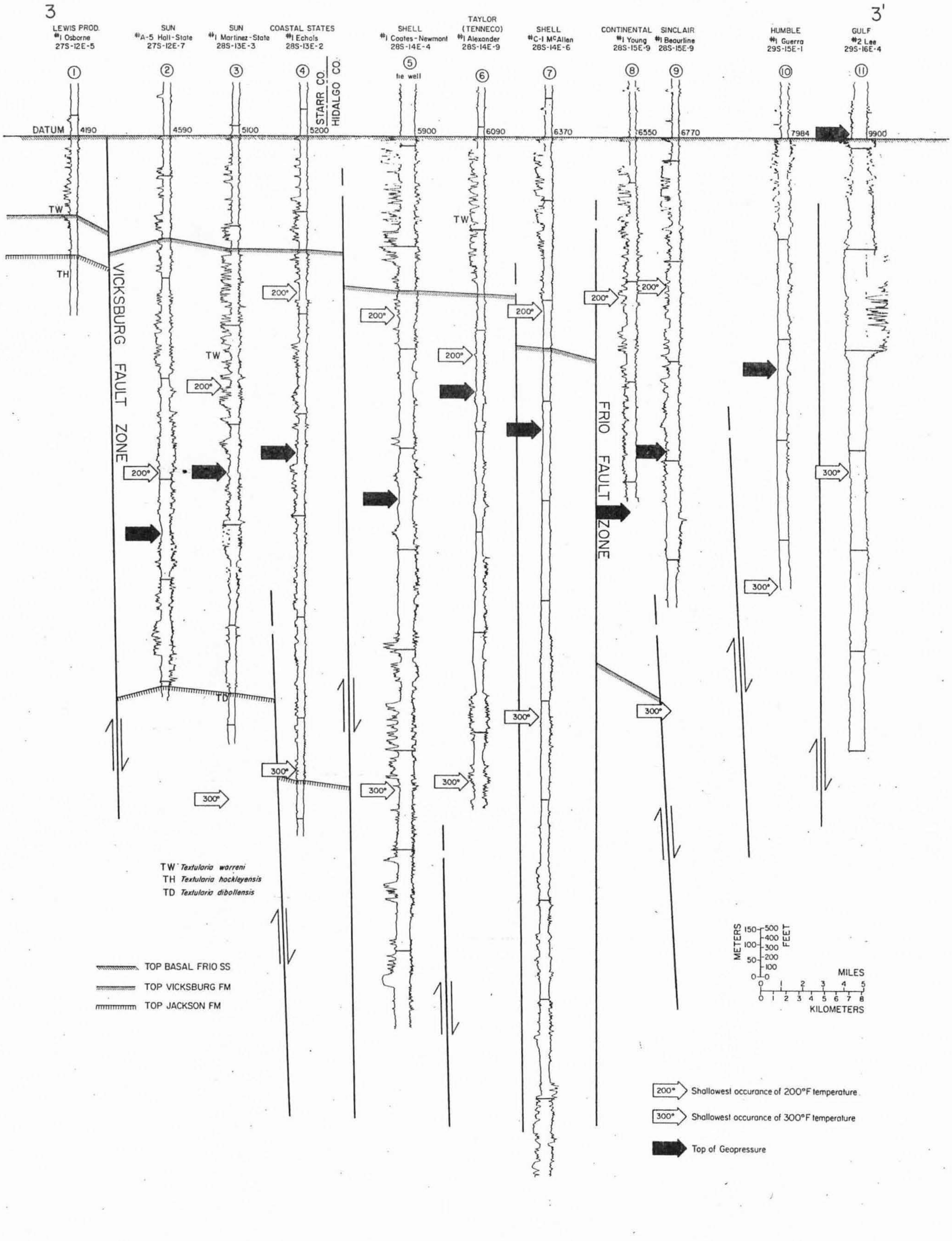

Figure 13. Stratigraphic dip section 3.

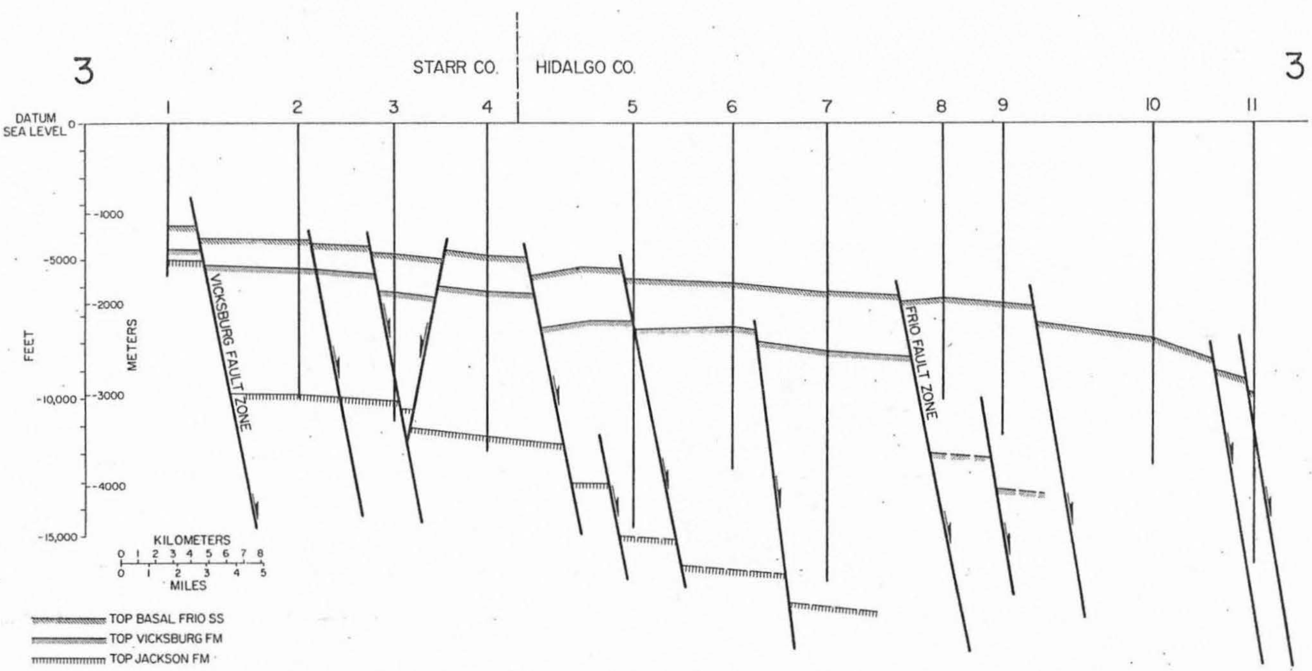

Figure 14. Structural section 3.

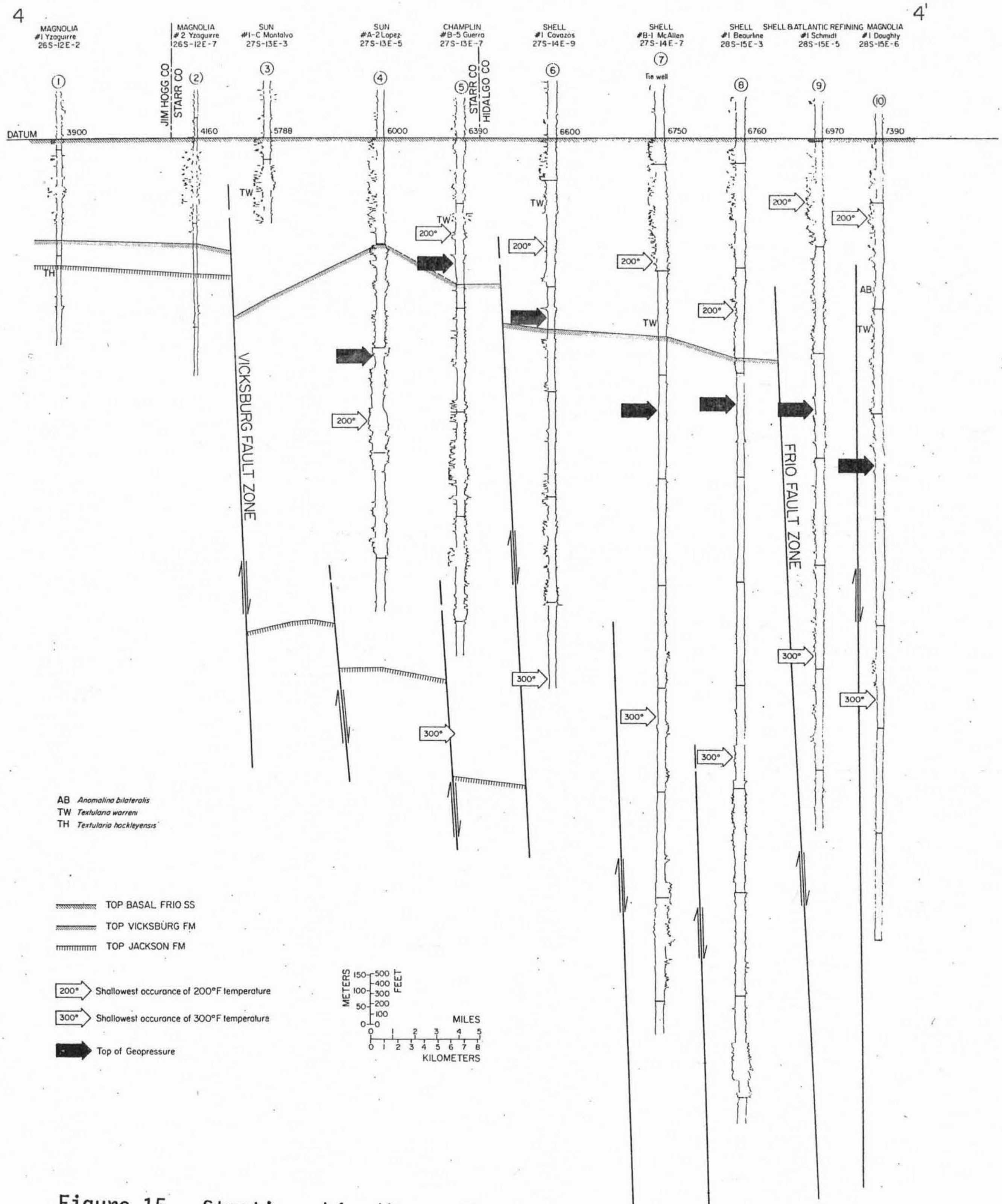

Figure 15. Stratigraphic dip section 4.

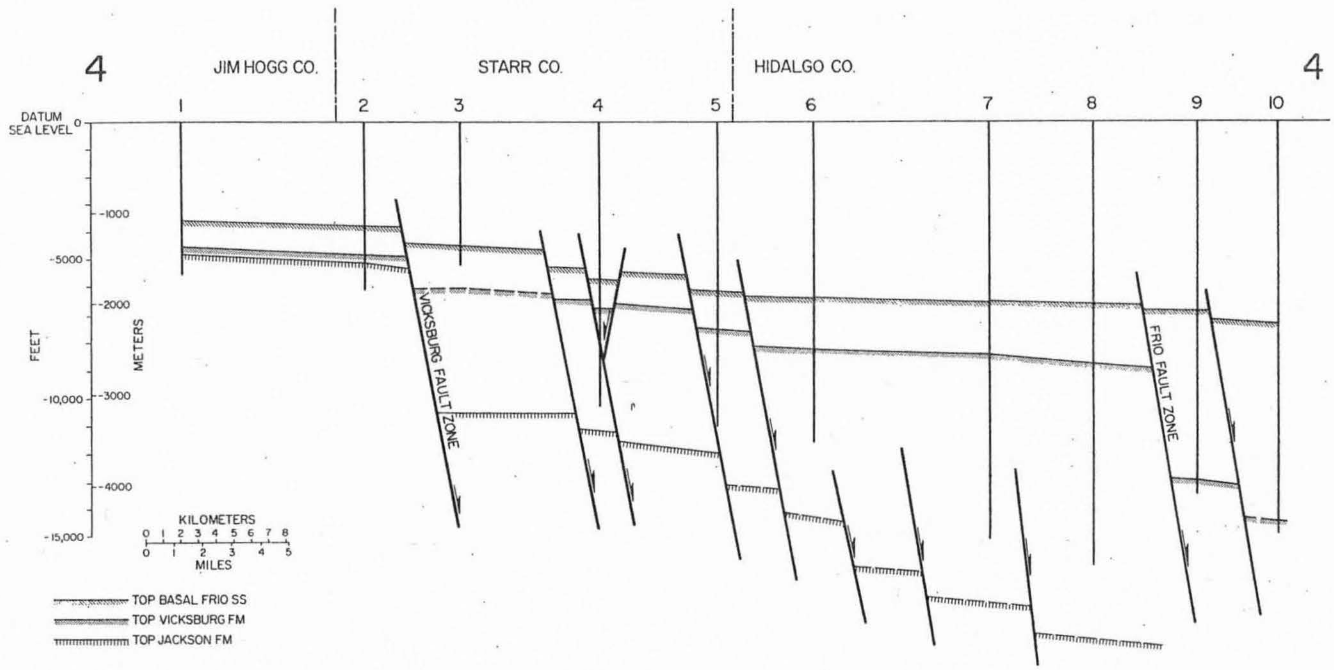

Figure 16. Structural dip section 4.

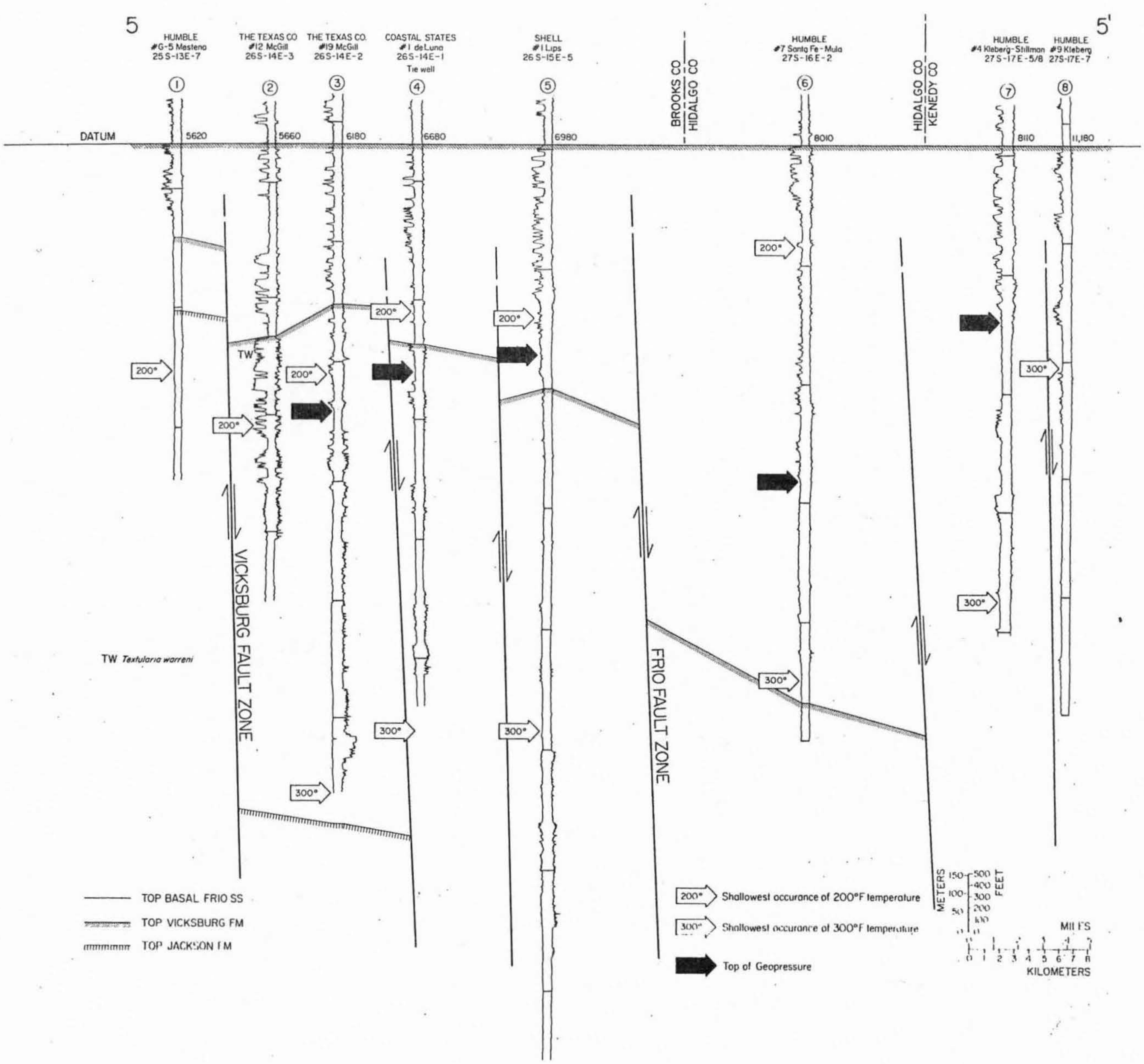

Figure 17. Stratigraphic dip section 5.

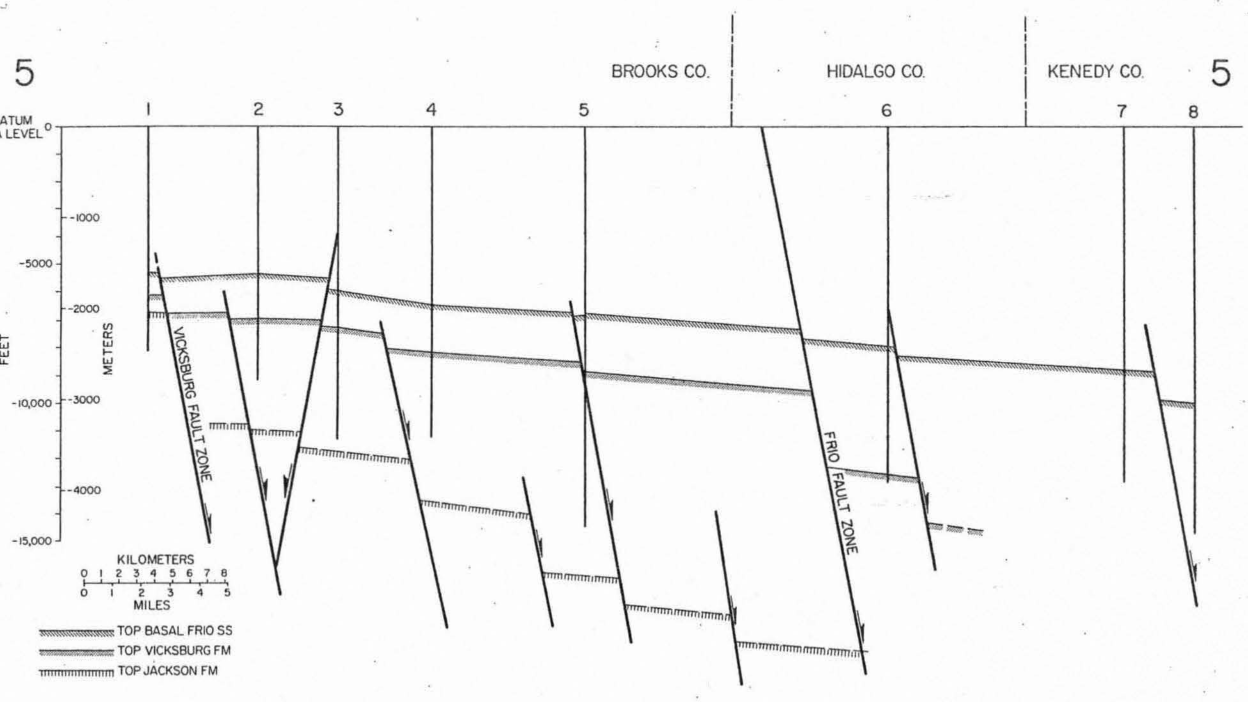

Figure 18. Structural section 5.

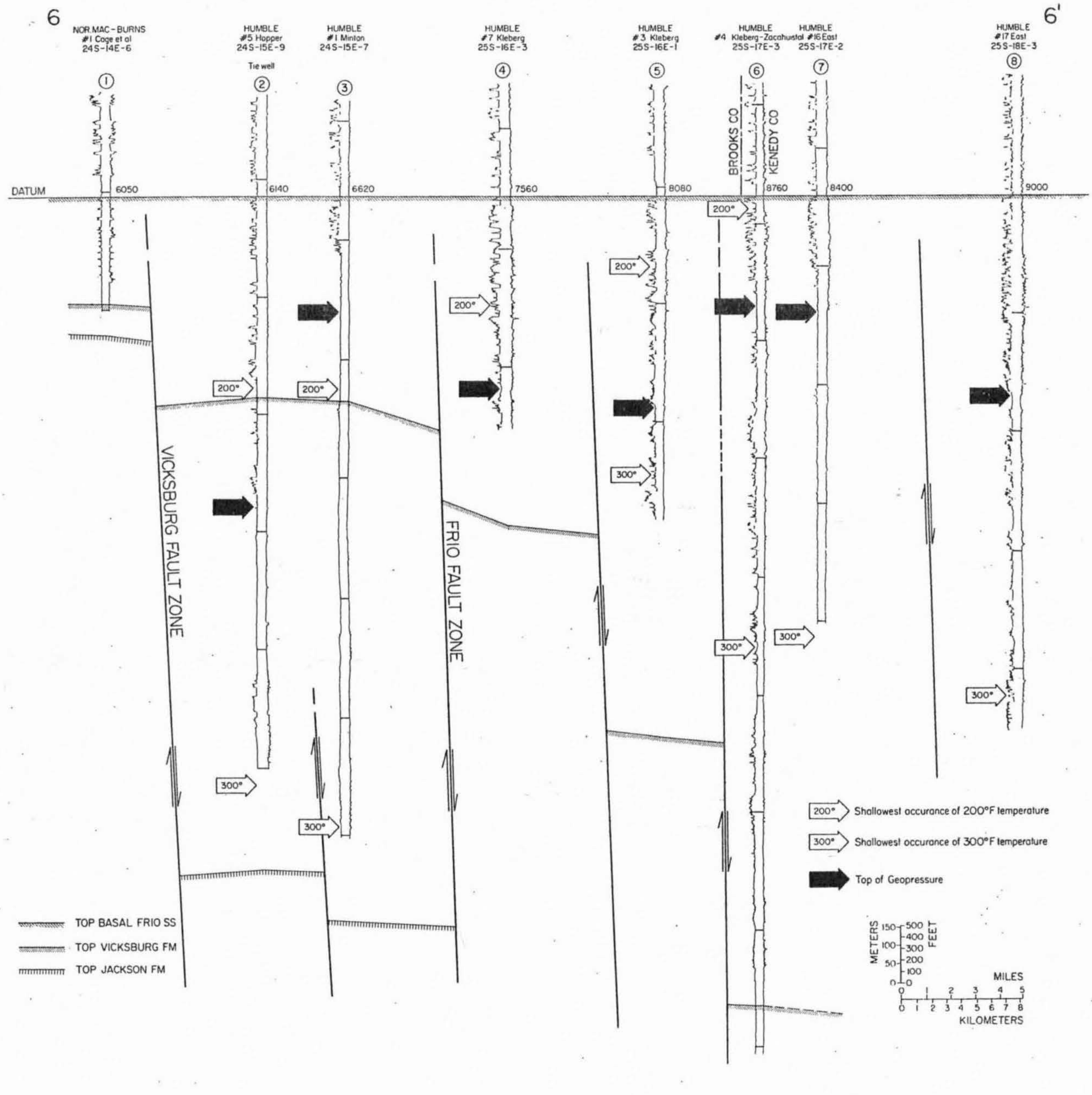

Figure 19. Stratigraphic dip section 6.

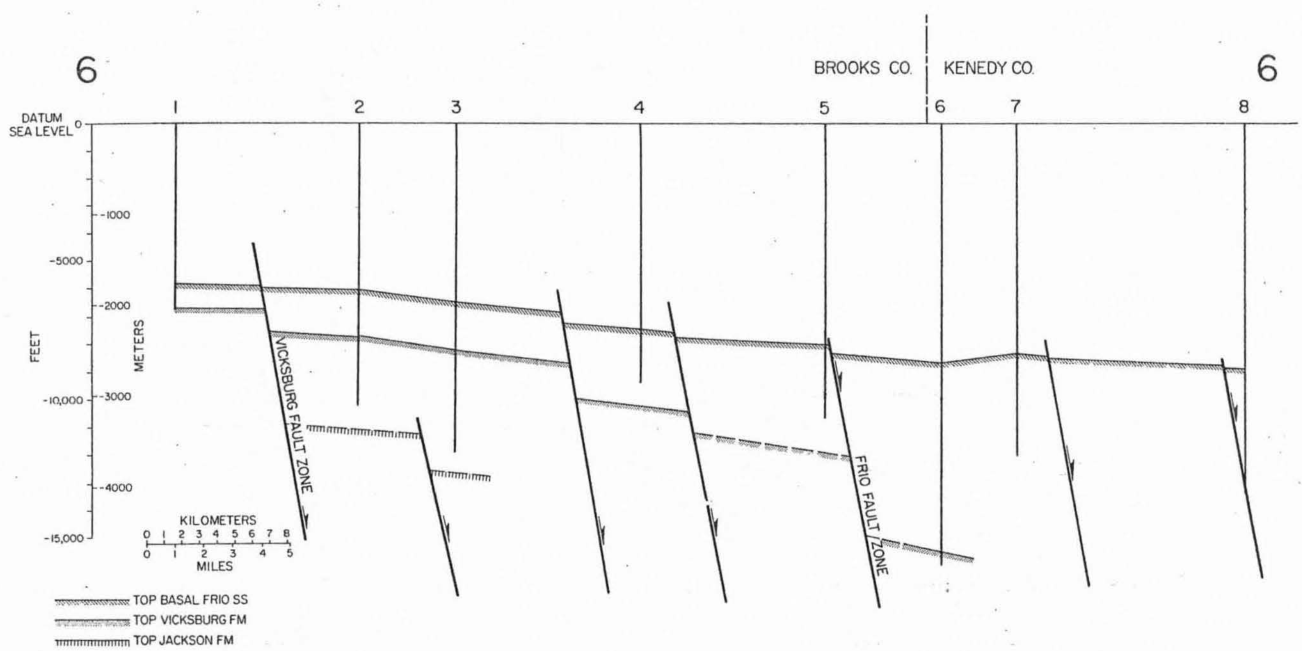

Figure 20. Structural section 6.

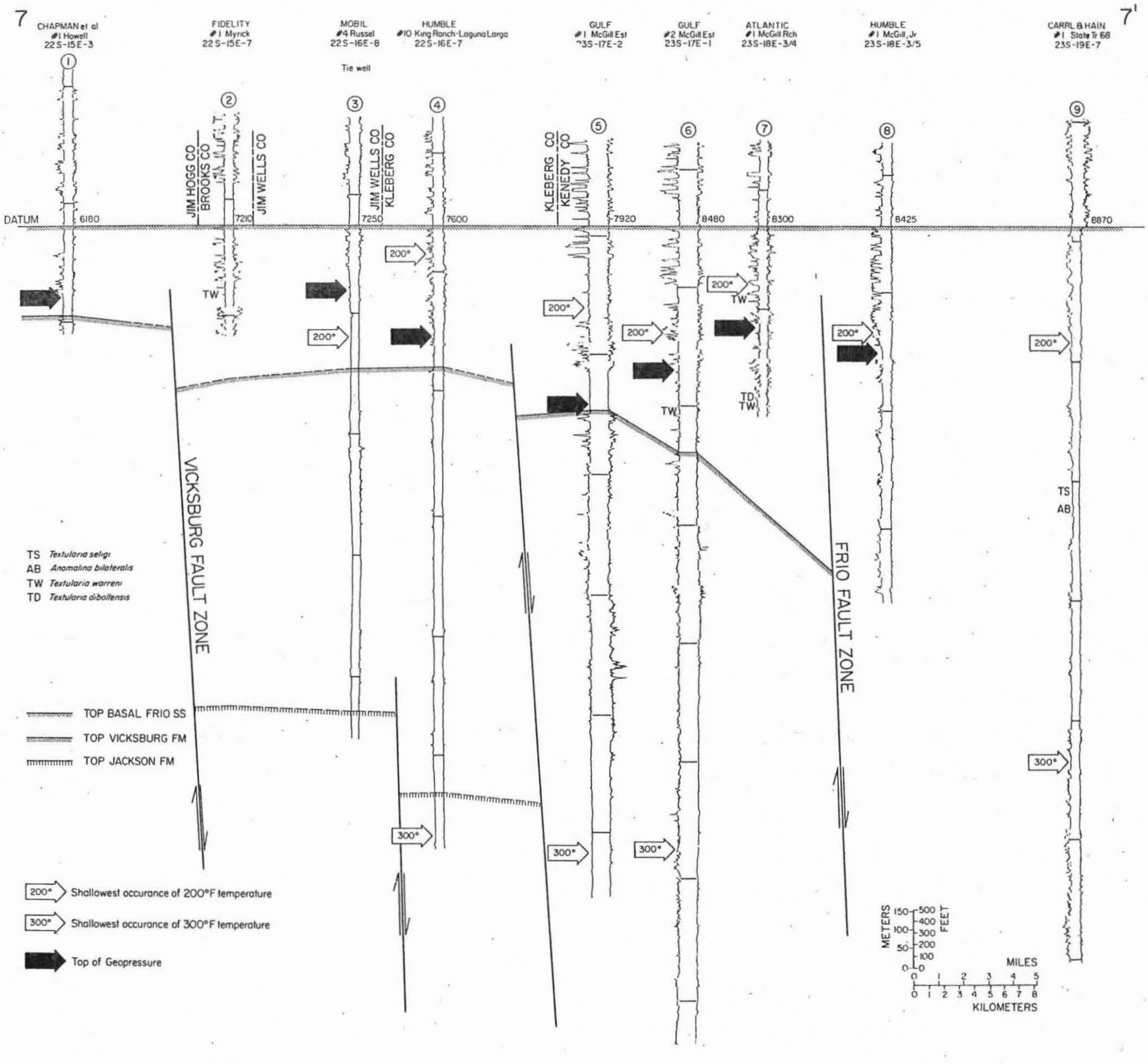

Figure 21. Stratigraphic dip section 7.

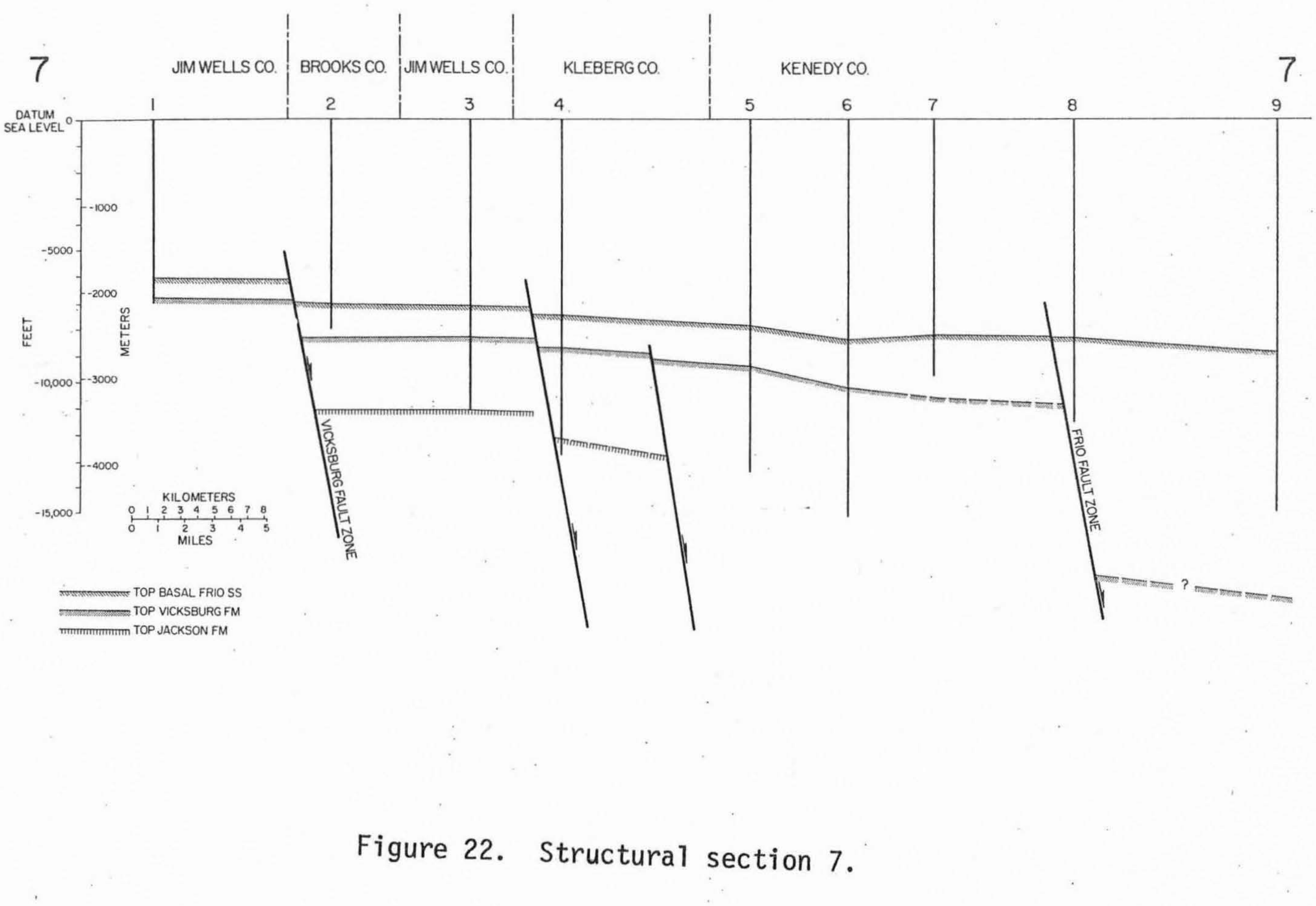

Figure 22. Structural section 7.

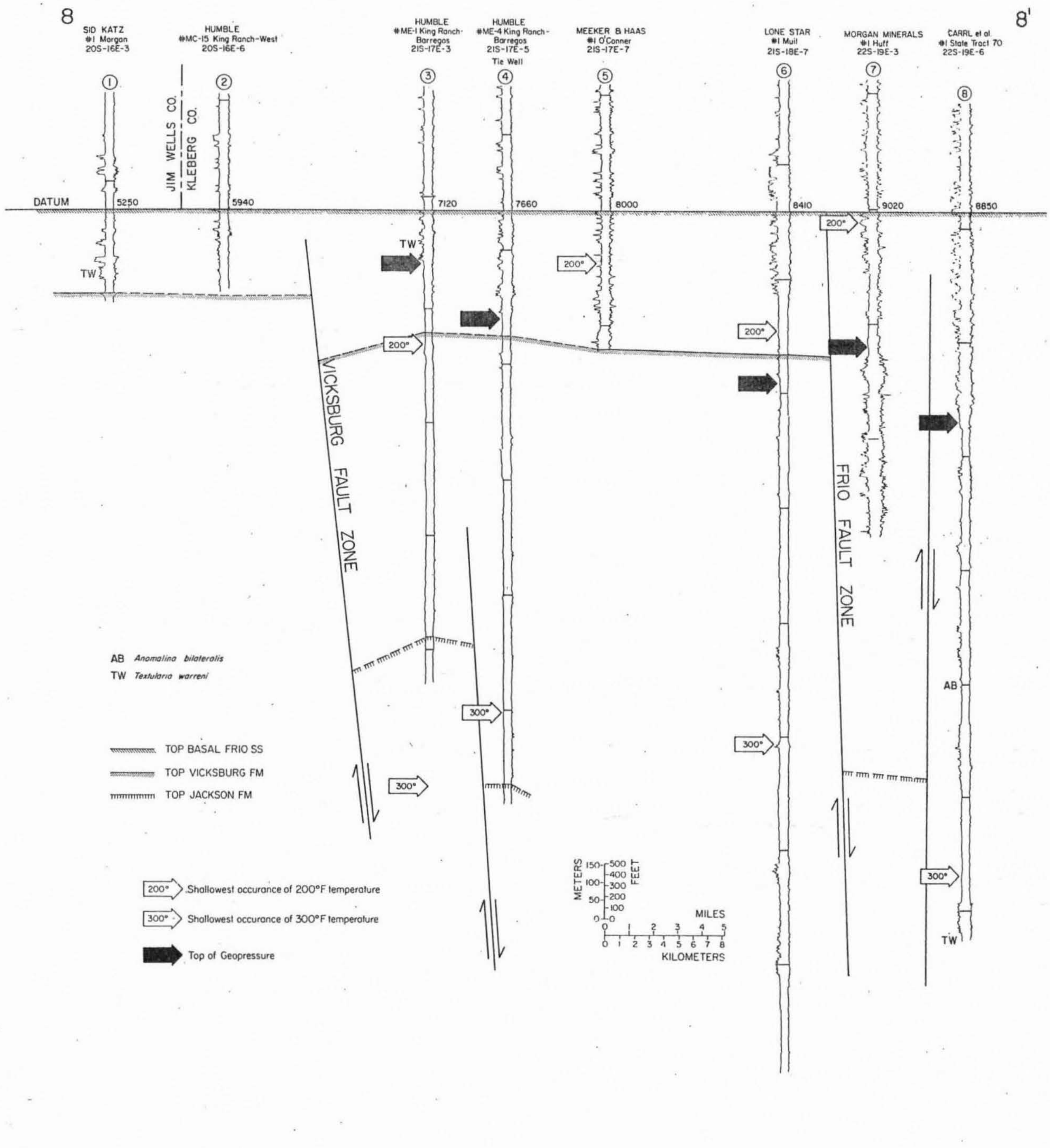

Figure 23. Stratigraphic dip section 8.

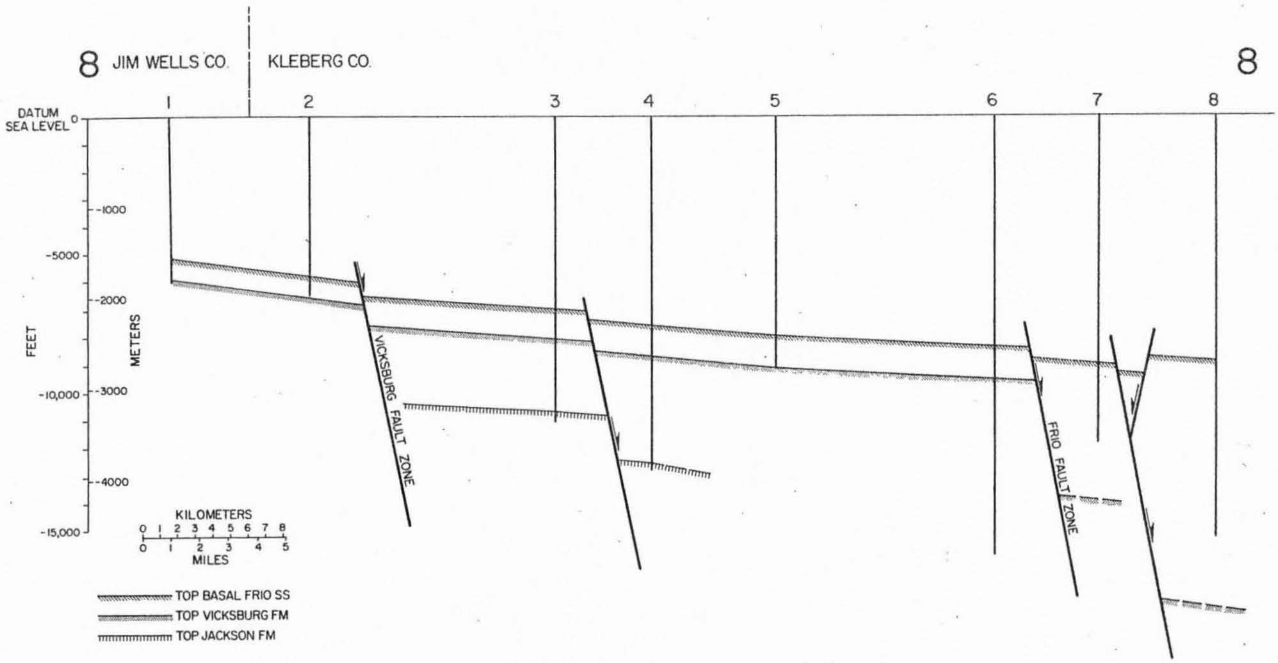

Figure 24. Structural section 8.

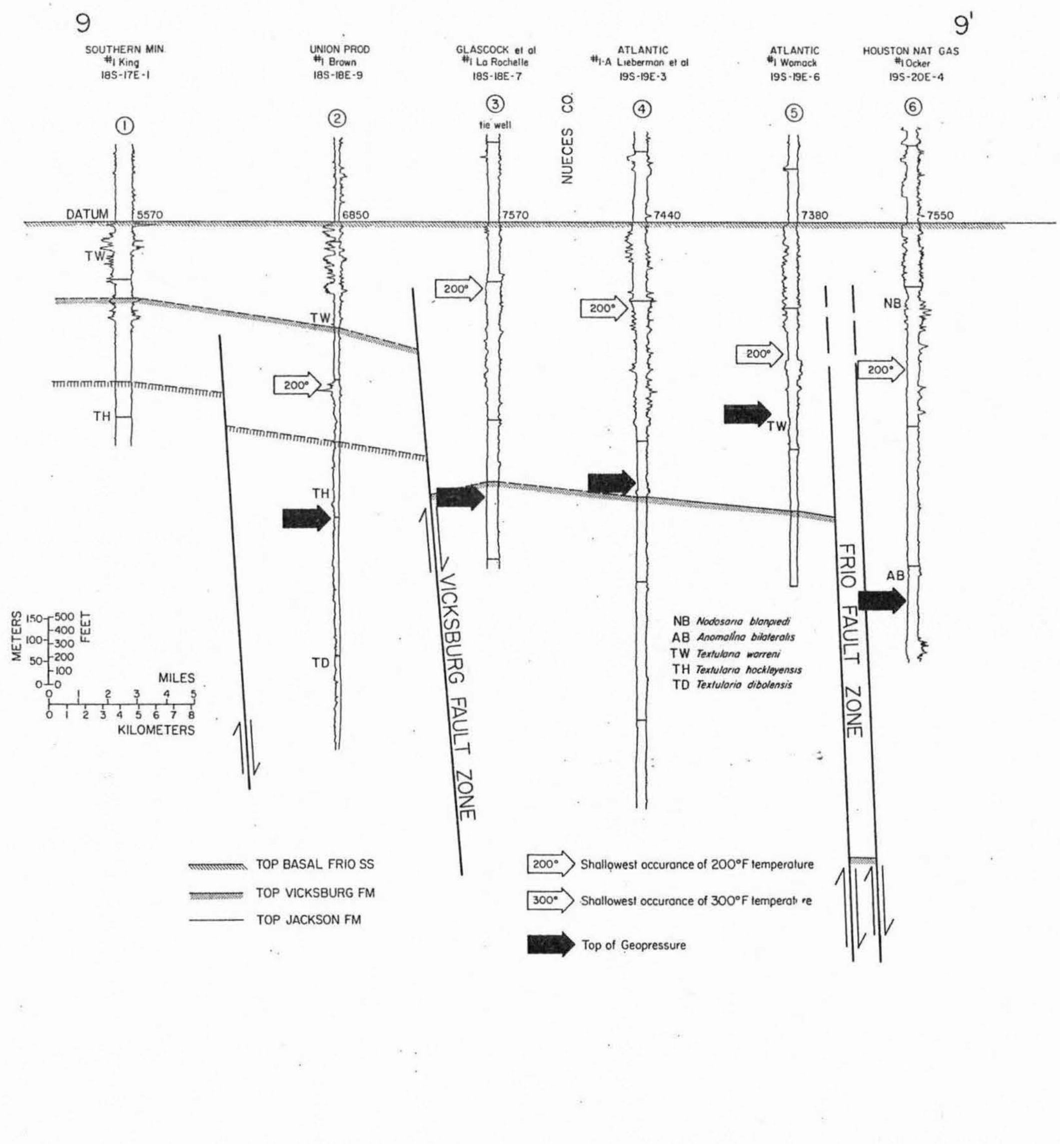

Figure 25. Stratigraphic dip section 9.

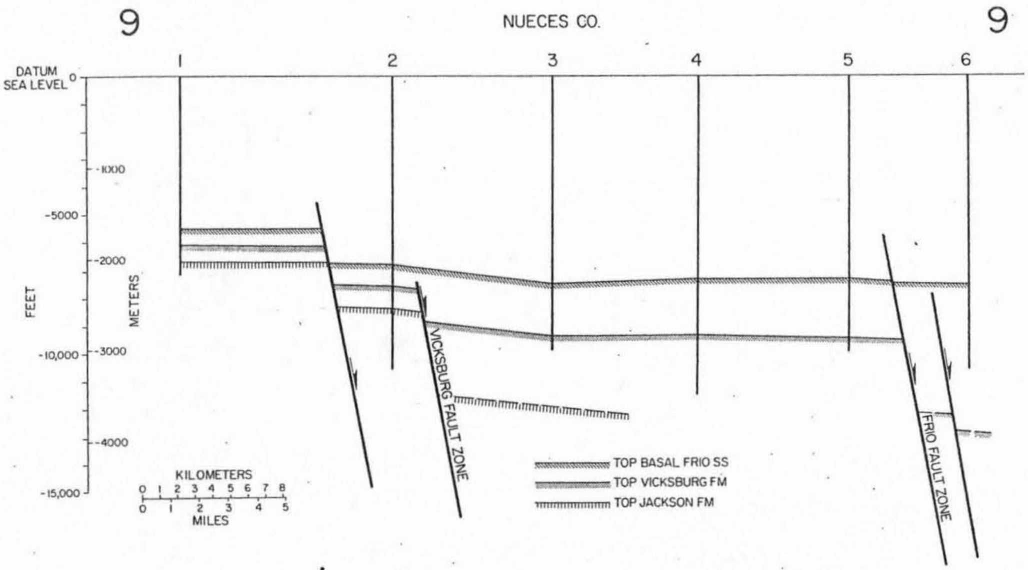

Figure 26. Structural section 9.

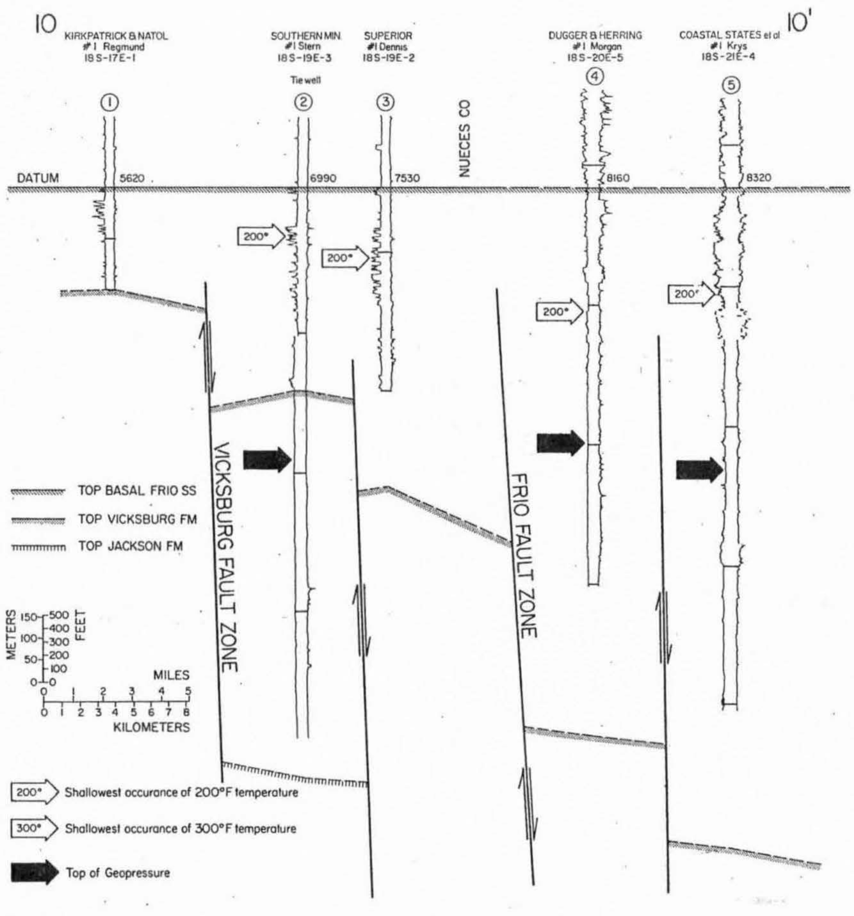

Figure 27. Stratigraphic dip section 10.

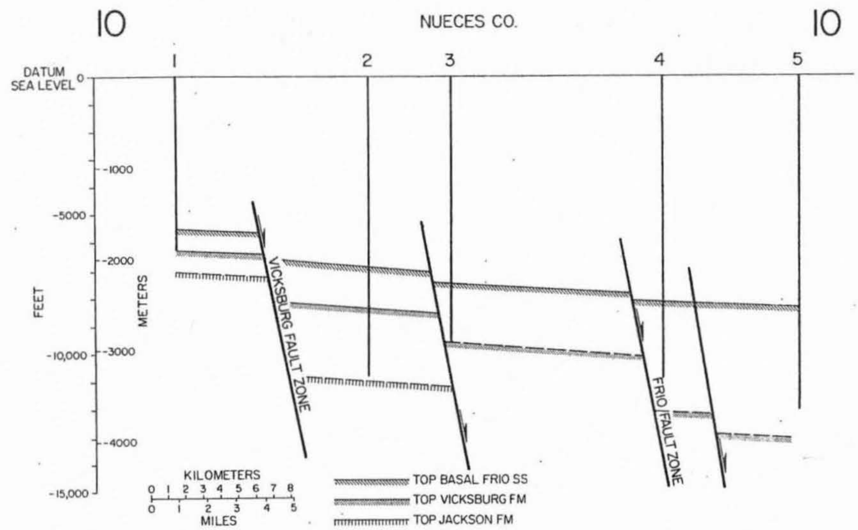

Figure 28. Structural section 10.

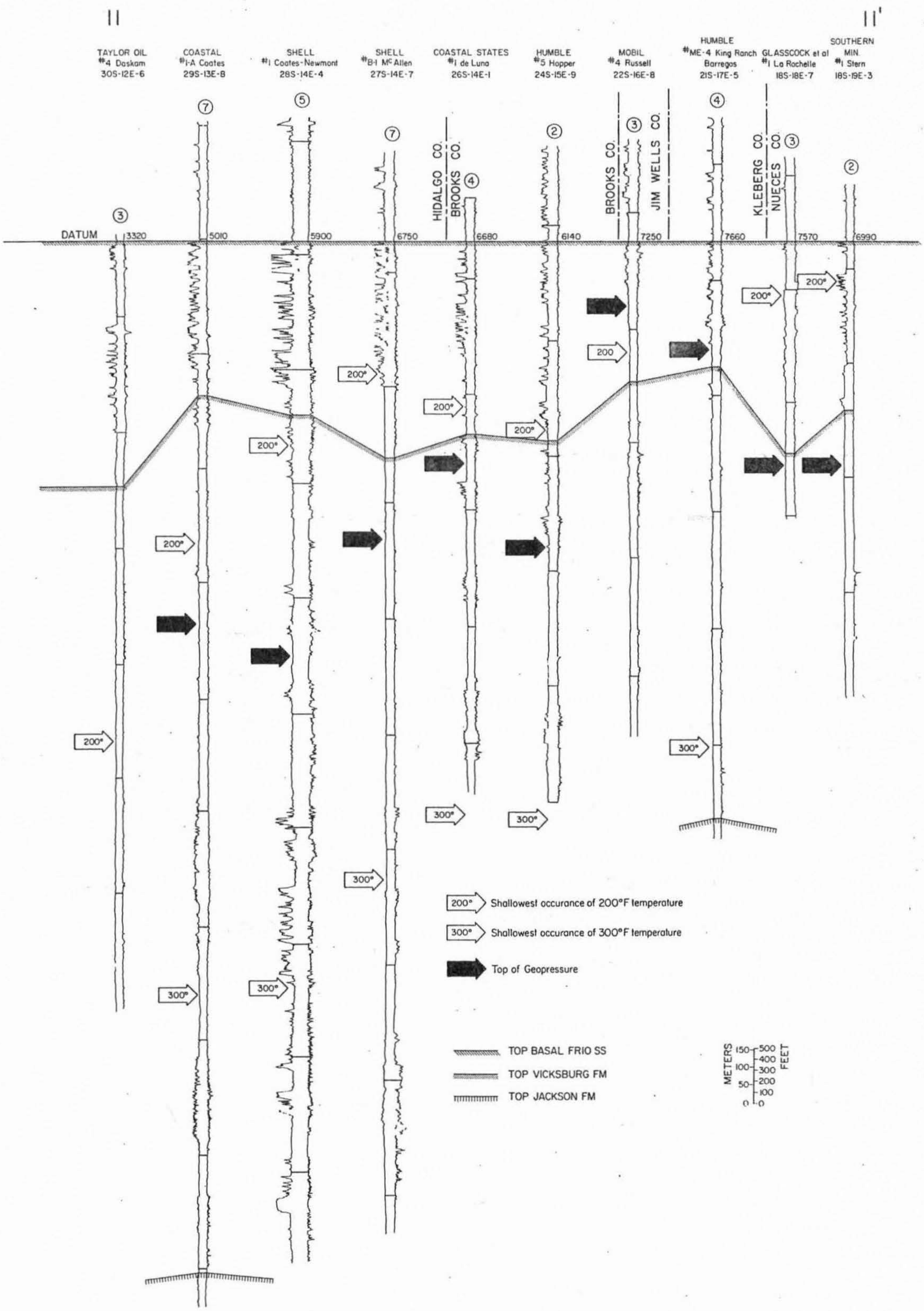

Figure 29. Stratigraphic strike section 11.

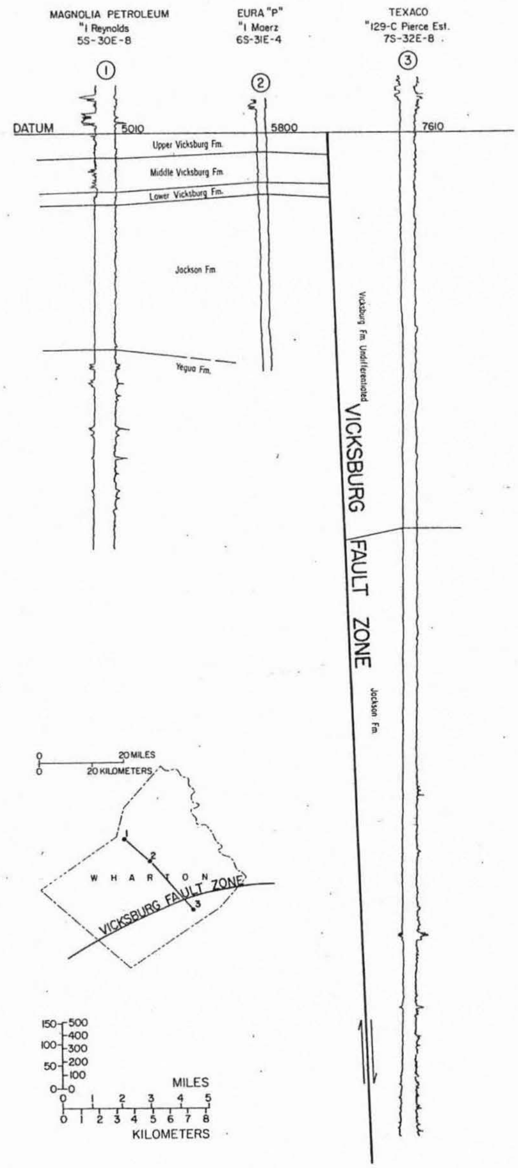

Figure 30. Stratigraphic dip section in Wharton County, Upper Texas Gulf Coast. Section is modified from cross section C-C' of Gregory (1966).

Vicksburg Sandstone Composition, Diagenesis, and Porosity

The Vicksburg fine-grained sandstones in the zone of geothermal reservoirs were chemically unstable and, thus, have undergone intense diagenesis. The sandstone grains are composed of quartz, feldspar, and carbonate and volcanic rock fragments and are classified (classification of Folk, 1974) as arkoses and volcanic lithic arkoses (fig. 31).

Intense diagenesis in the sandstones has destroyed most of the primary porosity through cementation by quartz, calcite, and Fe-rich dolomite or ankerite. Most porosity remaining in the deep Vicksburg Formation is secondary in origin and results from the leaching of feldspar grains and carbonate cements. Similar leaching and late stage cementation occurred in the Frio Formation at depths of 8,000 to 11,000 feet in South Texas (Lindquist, 1977; Loucks, Bebout, and Galloway, 1977).

The prospect of finding highly permeable reservoirs in the deep Vicksburg sandstones is negligible because Vicksburg sandstones are fine grained, chemically immature, and highly altered. The Frio in the South Texas Hidalgo Fairway (Bebout, 1976) has similar properties and was judged to have no potential for the production of geothermal energy because of the lack of permeability.

VICKSBURG FAIRWAY

Pressure, Temperature, and Salinity

In the Vicksburg Fairway the top of the geopressured zone (pressure gradient greater than 0.7 psi per foot) ranges from 7,000 to 11,000 feet

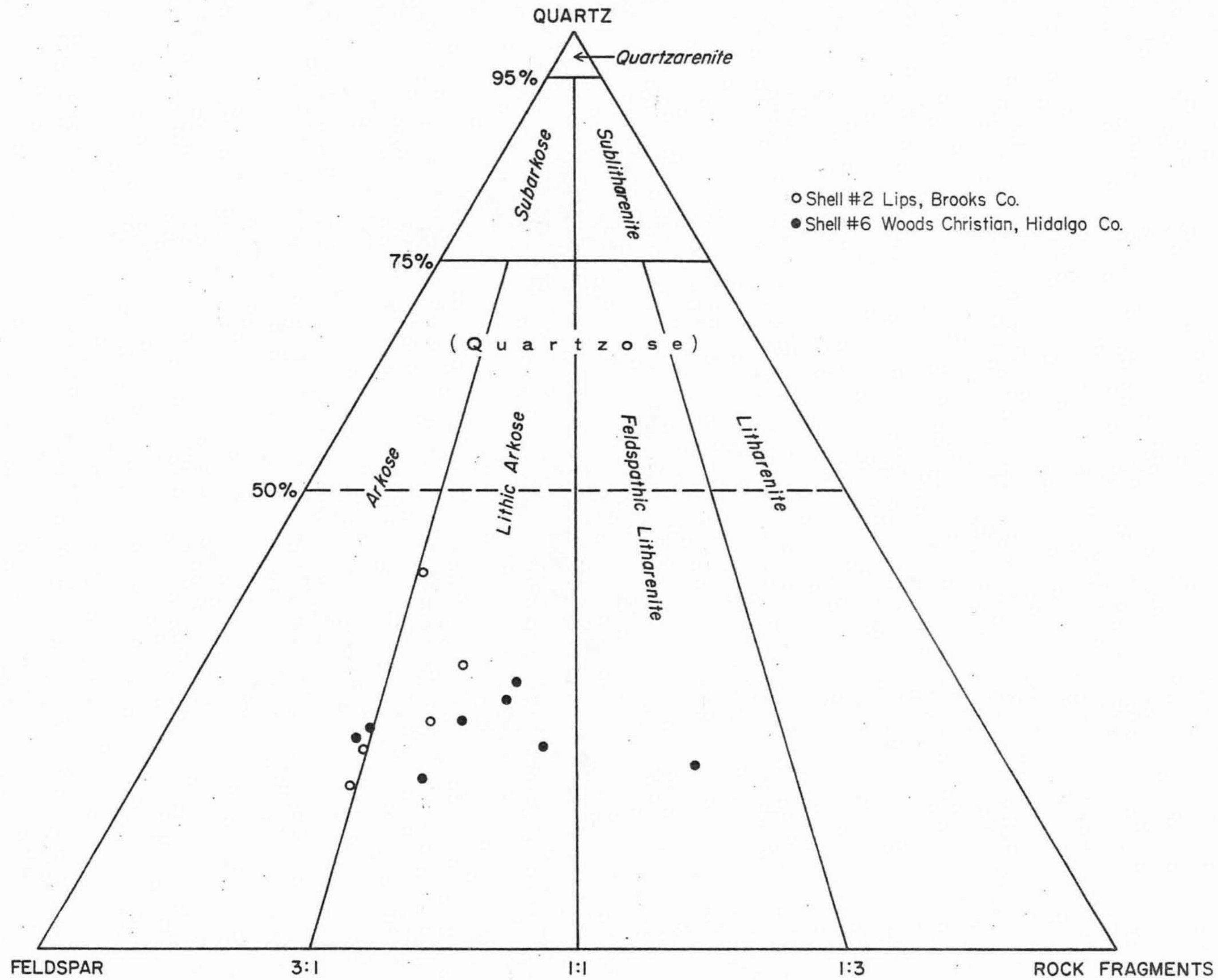

Figure 31. Vicksburg sandstone composition. Sandstone classification after Folk (1968).

(fig. 32) and averages 8,700 feet in depth (Swanson and others, 1976). The top of the geopressured zone is indicated on the stratigraphic dip sections (figs. 9, 11, 13, 15, 17, 19, 21, 23, 25, and 27). In the McAllen Ranch Field (fig. 32) the top of geopressure ranges from 7,000 to 8,400 feet in depth (Ritch and Kozik, 1971) and the transition zone from hydropressure into geopressure is 500 to 700 feet thick. In this field the pore pressure gradient in the geopressured zone is from 0.86 to 0.92 psi per foot.

The 300°F isotherm is located approximately 2,700 feet below the top of geopressure, at an average depth of 11,400 feet as on stratigraphic dip sections 1 through 10 (figs. 9, 11, 13, 15, 17, 19, 21, 23, 25, and 27) and as indicated by data from Swanson and others (1971; fig. 32). Fluid temperatures in the McAllen Ranch Field range from 240°F at 9,000 feet to 340°F at 14,000 feet (Ritch and Kozik, 1971); therefore the thermal gradient in this field is 2.0°F per 100 feet. This thermal gradient agrees with the 2.1°F per 100 feet plotted for the geopressured zone in the Vicksburg Fairway (fig. 33). In addition, Swanson and others (1976) report a geothermal gradient in the hydropressured zone of 1.8°F per 100 feet in the McAllen Ranch Field, very close to the 1.9°F per 100 feet for the Vicksburg Fairway (fig. 33).

Available salinity data from two Vicksburg fields, Jefferies and McAllen Ranch (fig. 32), indicate the average salinity range in the geopressured Vicksburg Fairway is from 14,000 to 40,000 ppm (Ritch and Kozik, 1971; Swanson and others, 1976).

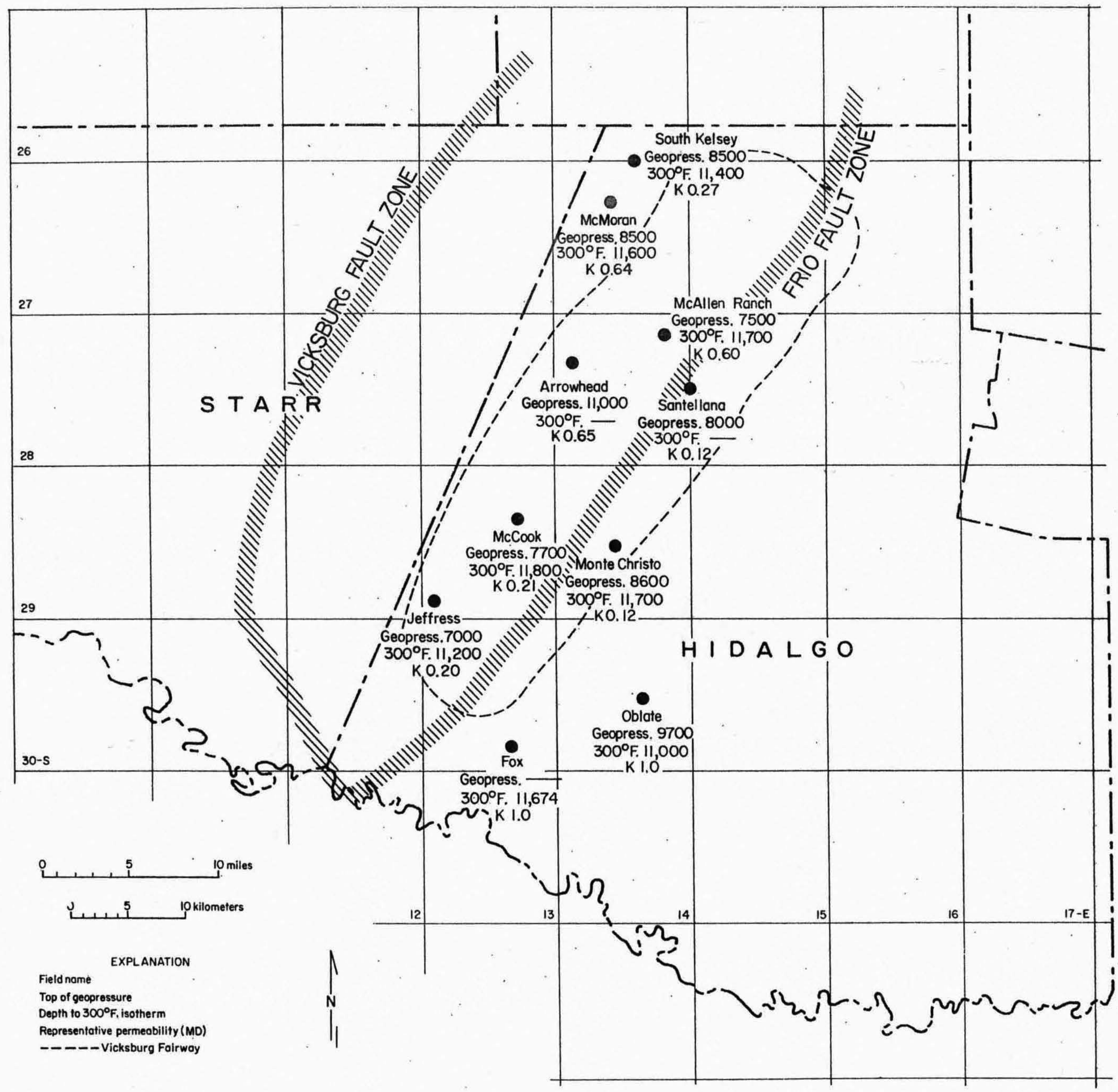

Figure 32. Reservoir data in the Vicksburg and Frio Formations in Hidalgo County. Data from Swanson and others (1976).

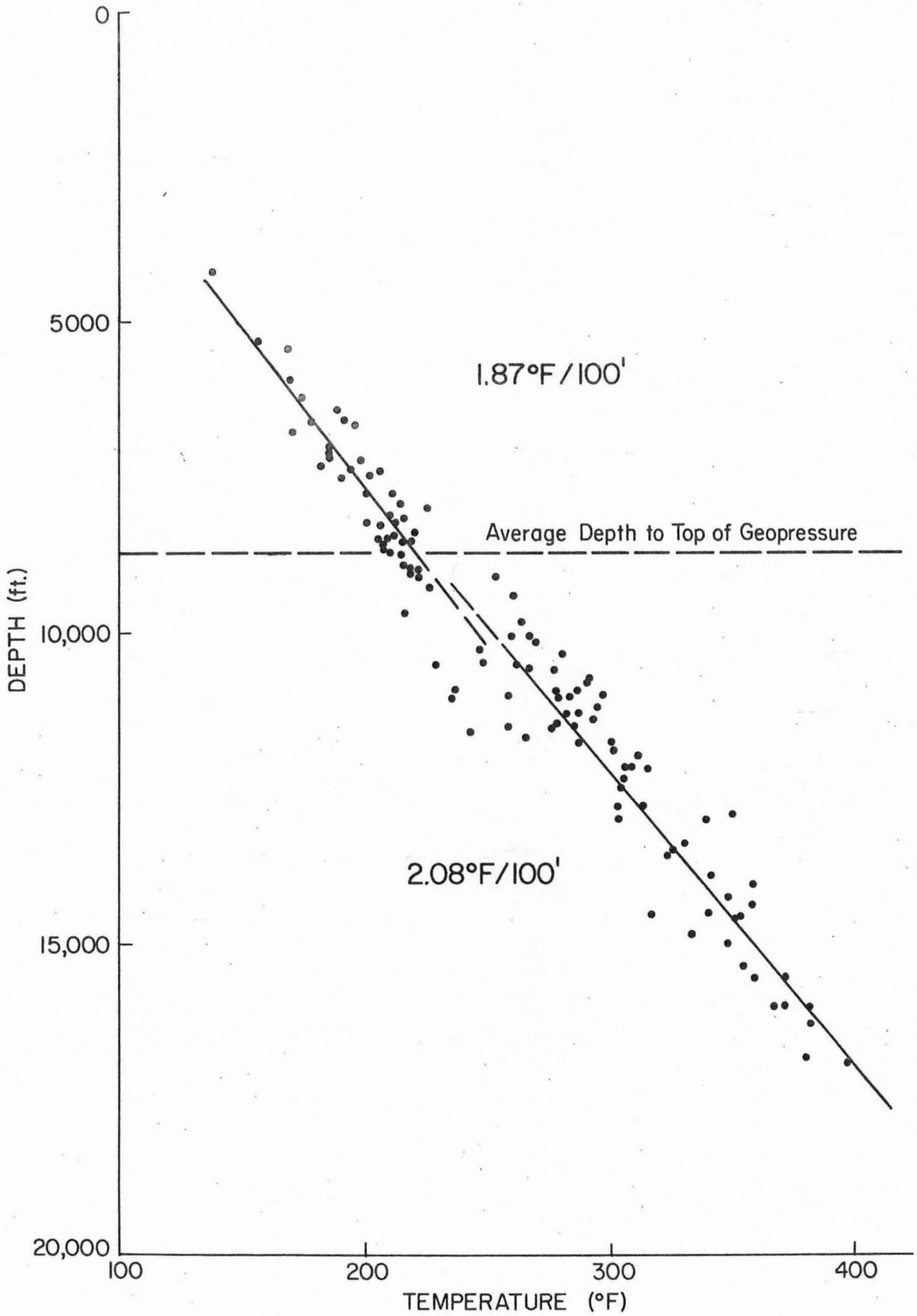

Figure 33. Depth vs. temperature plot for wells from the Vicksburg Fairway.

Porosity and Permeability

Low permeability is the limiting factor for the production of geopressured geothermal energy from the Vicksburg Fairway. Detailed investigations by both Ritch and Kozik (1971) and by Swanson and others (1976) conclude that porosity and permeability in the geopressured Vicksburg Formation are low.

Investigation of effective permeability from flow tests from six geopressured Vicksburg gas fields (table 1) by Swanson and others (1976) shows that the average in-place effective permeability is less than 1 millidarcy. Swanson and others also note that permeability is a function of depth, decreasing by approximately one order of magnitude between the depths from 6,000 to 14,000 feet for every 2,000 feet of depth (fig. 34). Also by superimposing the depth range for the 300^{o}F isotherm onto a depth-versus-effective permeability plot developed by Swanson and others (1976), it can be readily seen that essentially no effective permeabilities greater than 1.0 millidarcy exist (fig. 34).

Detailed porosity and permeability data for the geopressured Vicksburg Formation of the McAllen Ranch Field were summarized by Ritch and Kozik (1971) as follows:

> Based on the available data of 535 quality core samples, the majority (60.7%) had air permeabilities less than 1 md. with 78.3% and 87.8% having air permeabilities less than 2 and 5 md. respectively. Only 6.2% had air permeabilities greater than 10 md. Porosities for these 535 samples ranged from about 16 to 25%. The average porosity for all 535 samples was about 19%.

These porosity and permeability values from the McAllen Ranch Field are surface readings to air at one atmosphere. Ritch and Kozik point out

Table 1. Representative In-Place Effective Permeability
In Geopressured Gas Fields
Along the Vicksburg Fault Zone in Hidalgo County
Data from Swanson and others (1976)

Field Name	Permeability (md)
South Kelsey	0.27
McMoran	0.69
McAllen Ranch	0.60
Arrowhead	0.65
McCook	0.21
Jeffress	0.20

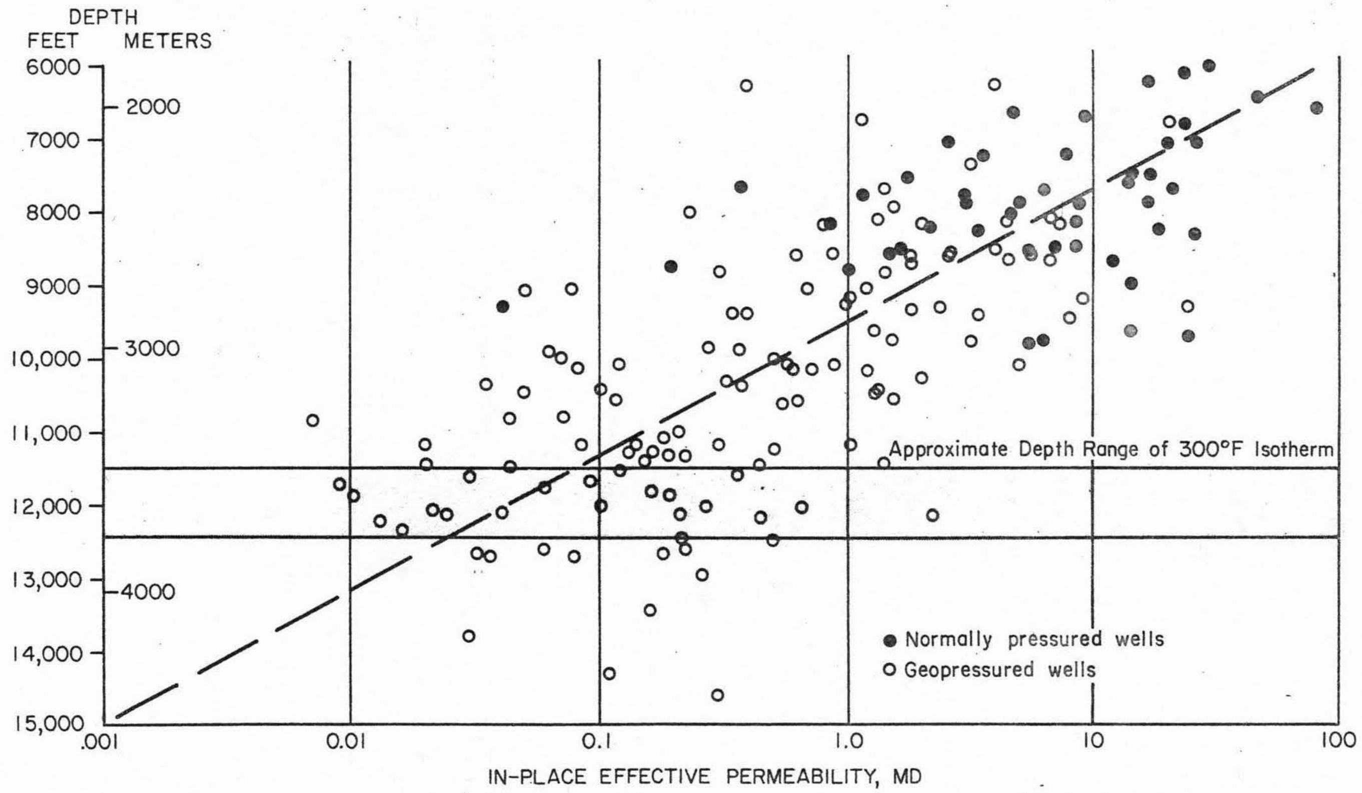

Figure 34. Depth to top of 300°F isotherm overlain on effective permeability vs. depth plot for a large number of gas wells in Hidalgo, Brooks, Cameron, and Kenedy Counties in South Texas. Modified from Swanson and others (1976).

from isostatic compaction studies, using brine filled core samples, that porosity readings taken at the surface should be reduced by 1.5 porosity percent. Also, air permeability readings should be reduced by an order of magnitude for the effects of brines and differential pressure; for example, 1.35 millidarcys air permeability reduces to 0.24 millidarcys in-place effective permeability.

Sandstone Thickness and Lateral Continuity

Sandstone reservoirs in the Vicksburg Fairway occur in units up to 1,100 feet thick separated by shale sequences up to 1,600 feet thick. Within the sandstone units the individual sandstone beds range in thickness from a few feet to 120 feet, averaging between 10 and 30 feet thick, and are separated from each other by shale beds ranging from a few feet to 30 feet thick (figs. 11, 13, and 15).

Lateral continuity of the potential reservoirs is controlled by distribution of the sandstones which in turn depends on depositional environment. Ritch and Kozik (1971) show that the Vicksburg sandstones of the Vicksburg Fairway were deposited in a large deltaic system (fig. 35). This deltaic depositional episode as indicated in stratigraphic dip sections 2, 3, 4, and 5 (figs. 11, 13, 15, and 17) is composed of several depositional events indicated by the numerous sandstone facies sequences (fig. 36). Preliminary sandstone isopachous maps from the Jefferies Field area suggest that these deltas in the lower part of the Vicksburg Formation may be high-constructive deltas with a strong dip orientation. Lateral continuity of individual sandstones in these

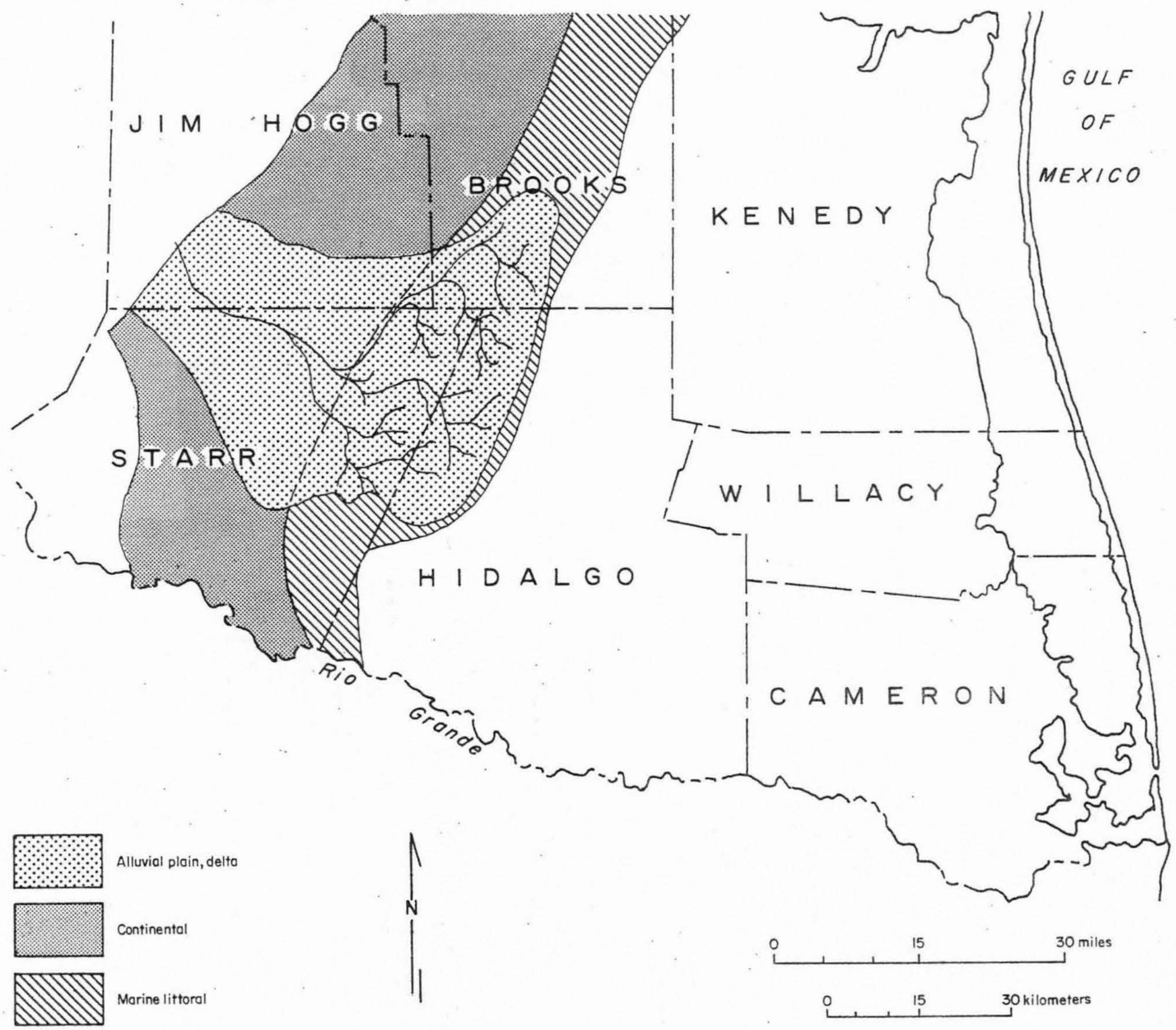

Figure 35. Lower Vicksburg depositional environments. Modified from Ritch and Kozik (1966).

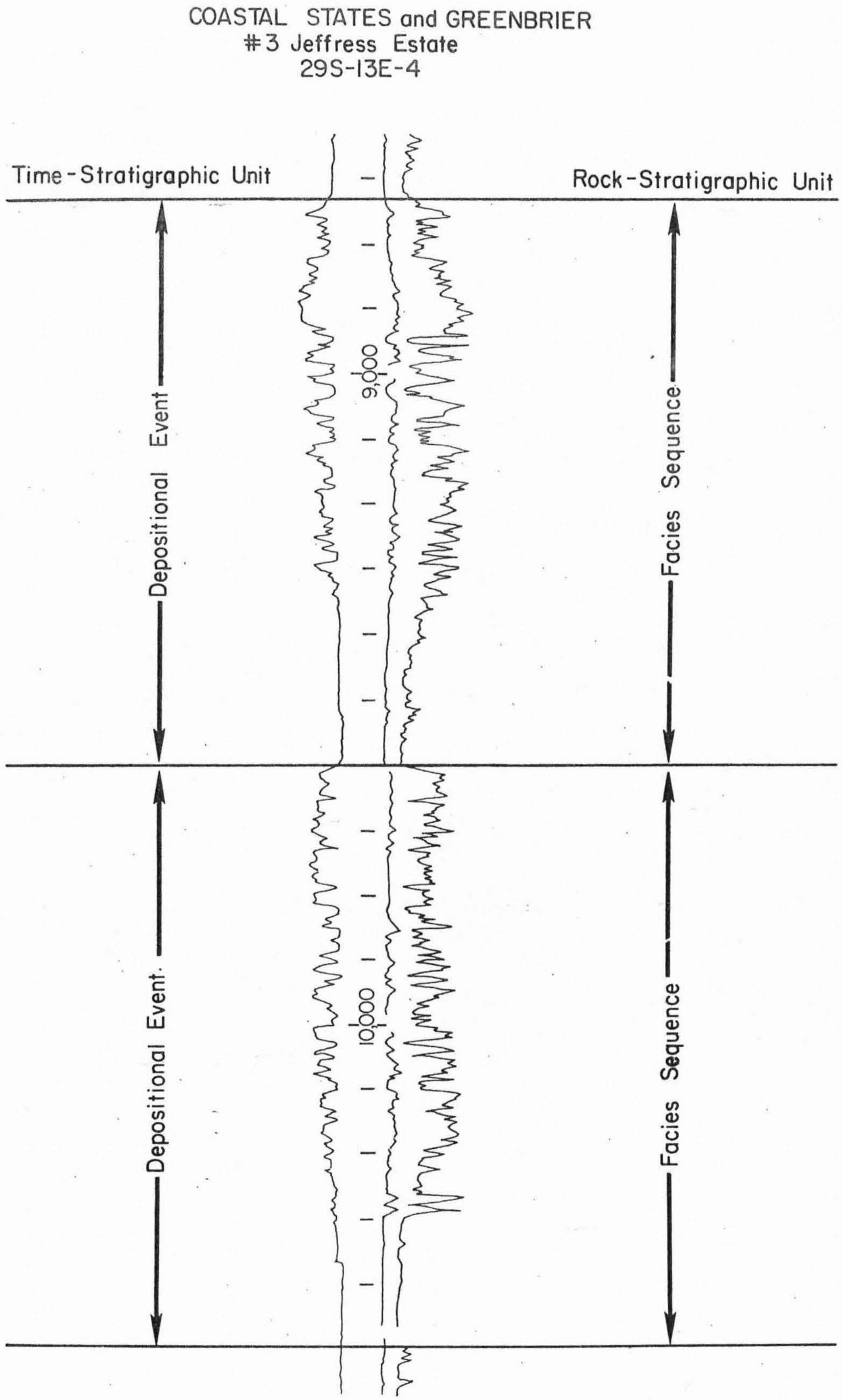

Figure 36. Example of Vicksburg facies sequences deposited during depositional events.

deltas is expected to be poor and probably will not extend more than a few miles in a strike direction. Lateral continuity of sandstones in a dip direction is interrupted by numerous growth faults in the lower part of the Vicksburg Formation. Poor lateral continuity of sandstone reservoirs is also described by Swanson and others (1976) who report that many geopressured fields in South Texas consist of only one well. They also state that the complexity of faulting within the Vicksburg increases with depth. The faults are primarily growth faults spaced approximately 4 miles apart, as shown in cross sections 2, 3, and 4, (figs. 11, 12, and 15).

RECOMMENDATIONS

According to present criteria established for identifying geopressure geothermal fairways, the Vicksburg is not a promising source of geothermal energy. However, because of the presence of high fluid temperatures and thick sandstone bodies in the Vicksburg Fairway, takeover of a previously drilled well or a currently drilling well ("well-of-opportunity") that is considered to be uneconomical for hydrocarbons should be evaluated. An experimental test should provide data needed about deliverability of fluids from low permeability reservoirs and of dissolved methane contained in deep geothermal fluids. Therefore it is recommended that a geologic investigation at the site-selection level be prepared for the Vicksburg Fairway to delineate the most promising areas. Also, a site-selection study will be needed if new data from the Frio Austin Bayou Prospect in Brazoria County, Texas (Bebout and others, 1977), reveal that there can be production from low permeabilities over a thick sandstone section.

ACKNOWLEDGEMENTS

Numerous persons aided in the completion of this report and their time and interest are gratefully acknowledged. D. G. Bebout and W. E. Galloway offered useful ideas and criticism. George Forming (Tenneco Oil Company) contributed information early in the project that pointed it in the right direction.

Funding for the entire geopressured geothermal assessment program has been provided by the Division of Geothermal Energy, U. S. Department of Energy.

REFERENCES

Bebout, D. G., 1976, Subsurface techniques for locating and evaluating geopressured geothermal reservoirs along the Texas Gulf Coast: Proceedings Second Geopressured Geothermal Energy Conference; Vol. II, Resource Assessment; Center for Energy Studies, Univ. Texas, Austin, 44 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.

________, 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.

________, Gavenda, V. J., and Gregory, A. R., 1978, Geothermal resources, Wilcox Group, Texas Gulf Coast: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ.

________, Loucks, R. G., Bosch, S. C., and Dorfman, M. H., 1976, Geothermal resources--Frio Formation, Upper Texas Gulf Coast: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 76-3, 47 p.

________, Loucks, R. G., and Gregory, A. R., 1977, Frio sandstone reservoirs in the deep subsurface along the Texas Gulf Coast--their potential for the production of geopressured geothermal energy: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 91.

Bruce, D. H., 1973, Pressured shale and sediment deformation: mechanism for development of regional contemporaneous faults: Am. Assoc. Petr. Geologists Bull., v. 57, p. 878-886.

Folk, R. L., 1974, Petrology of sedimentary rocks: Austin, Hemphill Publishing Co., 182 p.

Gregory, J. E., 1966, A lower Oligocene delta in the subsurface of southeastern Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 16, p. 227-241.

Lindquist, S. J., 1977, Secondary porosity development and subsequent reduction, overpressured Frio Formation sandstone (Oligocene), South Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 27, p. 99-107.

Loucks, R. G., Bebout, D. G., and Galloway, W. E., 1977, Relationship of porosity to sandstone consolidation history--Gulf Coast lower Tertiary Frio Formation: Gulf Coast Assoc. Geol. Socs. Trans., v. 27, p. 109-120.

Ritch, H. J., and Kozik, H. G., 1971, Petrophysical study of overpressured sandstone reservoirs, Vicksburg Formation, McAllen Ranch Field, Hidalgo County, Texas: Society Production Well Log Analysis Twelfth Annual Logging Symposium, 14 p.

Swanson, R. K., Oetking, P., Osoba, J. S., and Hagens, R. C., 1976, Development of an assessment methodology for geopressured zones of the Upper Gulf Coast based on a study of abnormally pressured gas fields in South Texas: Southwest Research Institute, San Antonio, Texas, ERDA Contract No. E (11-1)-2687, 75 p.