DOE/ET/27161--T1

NOTICE

SUBSURFACE GEOLOGY AND GEOPRESSURED/GEOTHERMAL RESOURCE EVALUATION OF THE LIRETTE-CHAUVIN-LAKE BOUDREAUX AREA TERREBONNE PARISH, LOUISIANA

DOE/ET/27161--T1

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MASTER

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ACKNOWLEDGMENTS

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ABSTRACT

The geology of a 125 square mile area located about 85 miles southeast of Baton Rouge and about 12 miles southeast of Houma, Louisiana, has been studied to evaluate its potential for geopressured/geothermal energy resources. Structure, stratigraphy, and sedimentation were studied in conjunction with pressure and temperature distributions over a broad area to locate and identify reservoirs that may be prospective. Recommendations concerning future site specific studies within the current area are proposed based on these findings.

Sediments of the stratigraphic interval studied are late-middle to early-late Miocene in age and are characterized by the occurrence of the *Bigenerina humblei* through *Textularia* "L" *articulata* biostratigraphic zones. The depositional pattern during most of this interval was one of overall regression and shallowing of paleoecologic zones. Additionally, the section is observed to expand greatly from the north boundary of the study area to the south. The expansion is due to several large shelf-break hinge-line faults which were active during the time of deposition of much of the stratigraphic section studied.

Structurally, the area developed during the same interval of geologic time with most activity occurring before the

end of *Bigenerina* "2" deposition. Uplifts in the area are probably shale-cored and are the result of heavy deposition on the downthrown sides of simultaneously active hinge-line growth faults. To assist structural and stratigraphic interpretations, a single north-south seismic line was purchased and incorporated into the study. The well control and the seismic line were found to agree in detail; therefore, structural interpretations are probably fairly accurate.

After complete evaluation of the area, only one sand appears to be even marginally prospective. The *Cyclammina* sand, as it is here termed, is found over much of the northern part of the study area. The reservoir probably has a large continuous volume, especially in the northeastern quarter of the study area. Unfortunately, where the reservoir volumes are largest, the sand body is relatively deep. In addition, estimated temperatures of fluids in the reservoir are borderline under presently established geopressured/geothermal guidelines.

INTRODUCTION

Location and Boundaries of the Study Area

The region studied includes some 125 square miles of surface area located along the east-central border of Terrebonne Parish, and centered approximately 12 miles southeast of the town of Houma, Louisiana (figure 1). Most of the area lies within the boundaries of townships 18 and 19 south and ranges 18 and 19 east.

Petroleum fields within the study area provided necessary well control for subsurface investigations. These fields along with their discovery dates are as follows: A) Lirette, 1937; B) Bay Baptiste, 1938; C) North Lapeyrouse, 1967; D) Lake Boudreaux, 1971; E) South Chauvin, 1960; F) South Houma, 1938; G) Bayou Chauvin, 1959; H) Chauvin, 1957; and I) Montegut, 1957. See figure 1 for field locations.

The northern boundary to the study area is defined by the downthrown trace of a large subregional down-to-the-south fault. The southern and western boundaries are bounded by similar faults whereas the eastern boundary is an arbitrarily placed one, governed mostly by a decrease in well control.

It is worthwhile to note that this report complements other studies conducted in the surrounding area by the

LOCATION OF STUDY AREA-- TERREBONNE PARISH, LOUISIANA

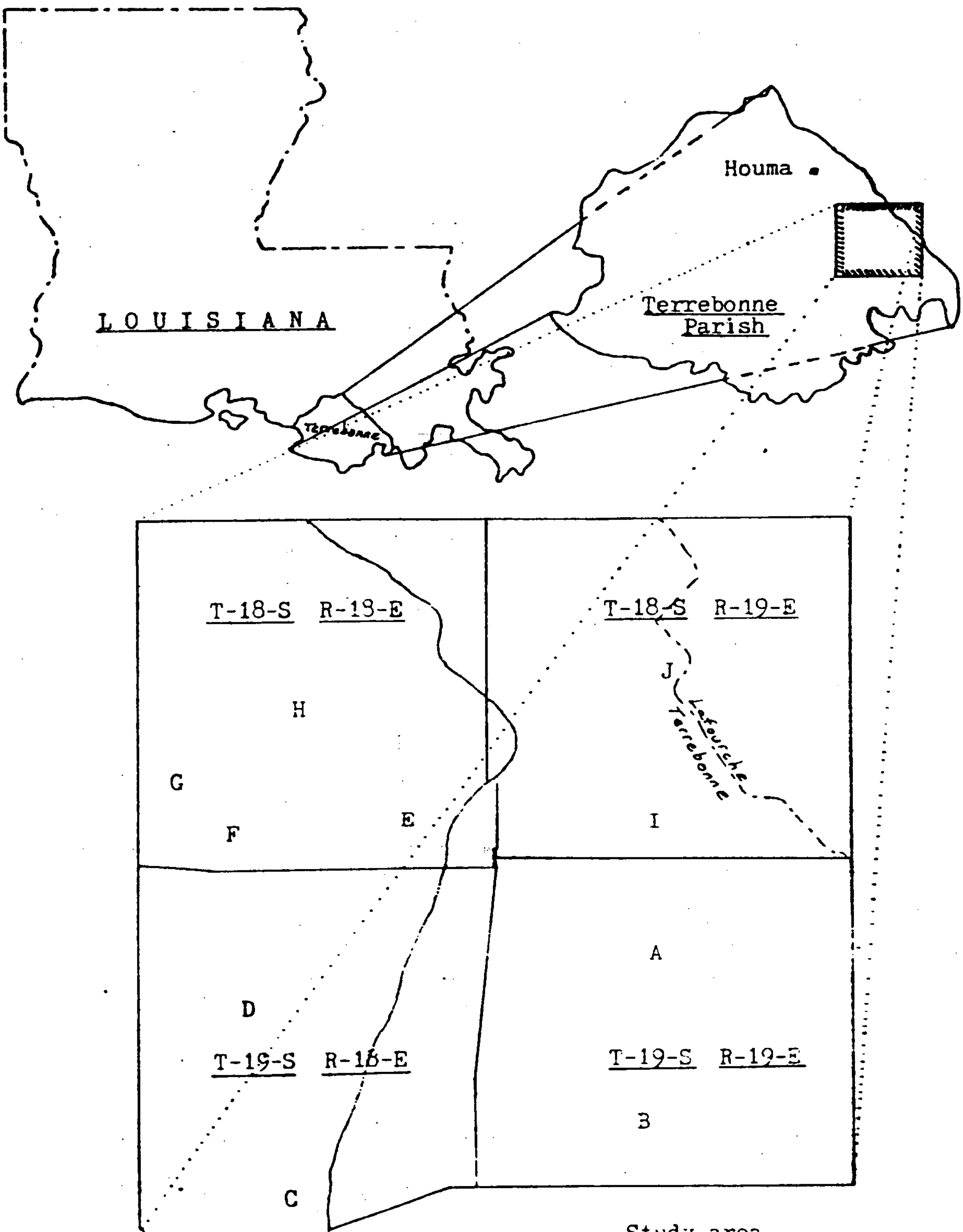


Figure 1. Study area location map

geology students of the University of Southwestern Louisiana and Louisiana State University, whose efforts are combining to create a comprehensive study of sedimentation and geopressure in the subsurface of Terrebonne Parish (Pradidtan, 1982; Moore, 1982; Mumme, 1979; Flournoy, 1980; Paine, 1977; Snyder, 1981).

Purpose of the Study

This research was conducted under United States Department of Energy contract DE-A505-78ET27161 with the primary intent of locating and identifying prospective geopressured/geothermal reservoirs in this portion of southeast Louisiana. In so doing, maps of pressure, temperature, structure, and net sand were constructed over the area to make a preliminary assessment of the potential of the region as a geopressured/geothermal resource area.

General Methods of Study

All information used in this report was derived from electric logs, paleontological studies and seismic data. Subsurface structure was determined by correlation and mapping using conventional subsurface methods and a seismic record section. Net sand isopach maps were also prepared using standard methods. Thermal information for temperature maps was also derived from well logs and adjusted to reveal required data. Pressure data were obtained from well logs using a combination of methods. Both thermal and pressure methods will be discussed in greater detail in a later section.

Based on the information obtained from the above, a series of structure maps, structural cross sections, stratigraphic cross sections, net sand isopach maps and temperature and pressure maps were constructed in order to assess the geology and geopressured/geothermal potential of the area.

REGIONAL STRATIGRAPHY AND SEDIMENTATION

Sediments in the area under consideration are primarily Miocene in age. Rainwater (1964) has described the Miocene of southern Louisiana as one of the thickest known accumulations of terrigenous clastic sediments in the world. Additionally, Crouch (1959) has estimated that the composite thickness of these Miocene sediments is in excess of 48,000 feet. The maximum thickness at any one locality, however, occurs in southeast Louisiana just to the south of the study area, in what has been termed the "Terrebonne Trough" by Limes and Stipe (1959). Deep wells have been drilled in the vicinity of Coon Point, a Terrebonne Trough field southwest of the study area, that by 17,000 feet had not yet penetrated even the upper Miocene (Limes and Stipe, 1959). It is estimated by Rainwater (1964) and others that the Miocene section here is more than 20,000 feet thick.

The Miocene in south Louisiana is, in general, not easily correlated on a regional basis. Correlations along strike are made with greater ease than are those in a dip direction. The difficulty also increases from north to south as one explores the section.

Since this is so, geologists working with the Miocene have relied heavily upon foraminifera for their regional correlations. Due to the deltaic nature of Miocene sediments, however, the establishment of a working network of marker fossils was difficult and required many years of effort. Dominantly deltaic environments such as those of the Miocene in south Louisiana are not conducive to the existence of good regional foraminiferal markers. The resulting terminology is somewhat confused and many versions of the Miocene stratigraphic chart have been produced for southeast Louisiana (Mclean, 1957).

The reasons for this are many. First, subdivision of the Miocene into biostratigraphic zones required that extinction tops be present. Since environmental conditions did not change much during the Miocene, extinctions of planktonic foraminifers were few, preempting their use in subdividing the section (Rainwater, 1964). Extinction tops of benthonic forams though were frequently found to exist, and were thus employed by paleontologists. Benthonic forams, however, are facies-controlled organisms and an extinction in one area does not automatically require extinction in another. Extinction tops from shallow neritic environments and along depositional strike may be quite reliable as time equivalent markers. On the other hand, in a dip direction, these tops may be useless as time-equivalents, since in deeper water the environment did not change, and simultaneous updip and downdip extinctions did not occur. Thus, as exploration continued south, many "marker" forams were found to extend much further up into the section than at first thought. Some are found to exist even today, though they are named differently (Rainwater, 1964). Slowly the time relationships of the various forams became clarified. Bigenerina humblei has, for instance, become recognized as one of the best time-stratigraphic horizons in the Miocene of the Gulf Coast (Crouch, 1955).

Regionally useful Miocene stratigraphic charts based on index forams have to be very general. An example of such is given in figure 2, after Murray (1961). The many other, more detailed stratigraphic charts are most useful on a local scale, especially where they were developed, and one of these is presented subsequently for the study area (figure 6).

From figure 2, it seems evident that the top of the Miocene occurs at the top of the depositional interval containing Bigenerina "A" or Amphistegina species, and that the base of the Miocene is defined by the top of the depositional interval containing Discorbis gravelli (restricted). Both boundaries are, in fact, questionable and in dispute. The transitional sediments of the uppermost Miocene are overlain by those of the Pliocene which may be either very similar or even nonexistent in some areas. The Pliocene was a time of regional exposure and the parts of the shelf inundated during the Miocene may have been sites of sedimentary bypassing

GENERAL STRATIGRAPHIC CORRELATION CHART
SOUTHEAST LOUISIANA MIOCENE

ERA	SYSTEM	SERIES	STAGE	DIVISION	INDEX FORAMINIFERA
CENOZOIC	TERTIARY	PLIOCENE			top Bulminella sp. to top Miocene fauna otherwise undifferentiated
		MIOCENE	CLOVELLY	A	top Bigenerina "A" floridana or Amphistegina sp. to top Bucella mansfieldi
				B	top Bucella mansfieldi to top Bigenerina "2" nodosaria var. directa
			DUCK LAKE	C	top Bigenerina "2" nodosaria var. directa to top Textularia "W" stapperi
				D	top Textularia "W" stapperi to top Bigenerina humblei
				E	top Bigenerina humblei to top Amphistegina "B" sp.
				F	top Amphistegina "B" sp. to top Operculinoides sp. (Camerina "I")
				G	top Operculinoides sp. (Camerina "I") to top Robulus chambersi (= Cristellaria "A")
			NAPOLEONVILLE	H	top Robulus chambersi (= Cristellaria "A") to top Marginulina ascensionensis
				I	top Marginulina ascensionensis to top Siphonina davisi
				J	top Siphonina davisi to top of Oligocene Discorbis zone
		OLIGO-CENE			top Discorbis zone to top Camerina "A" sp.

Figure 2. Modified after Murray (1961) and Rainwater (1964).

during this time (Rainwater, 1964). The lower boundary of the Miocene is one of continuous marine sedimentations and is therefore difficult to place. The controversy here centers around the stratigraphic position of sediments containing Planulina palmerae and Abbeville fauna. Goheen (1959) has placed these sediments in the upper Oligocene Anahuac formation. Others, such as Sloane (1970), place sediments bearing Planulina palmerae and in part Abbeville fauna as lowermost Miocene in age.

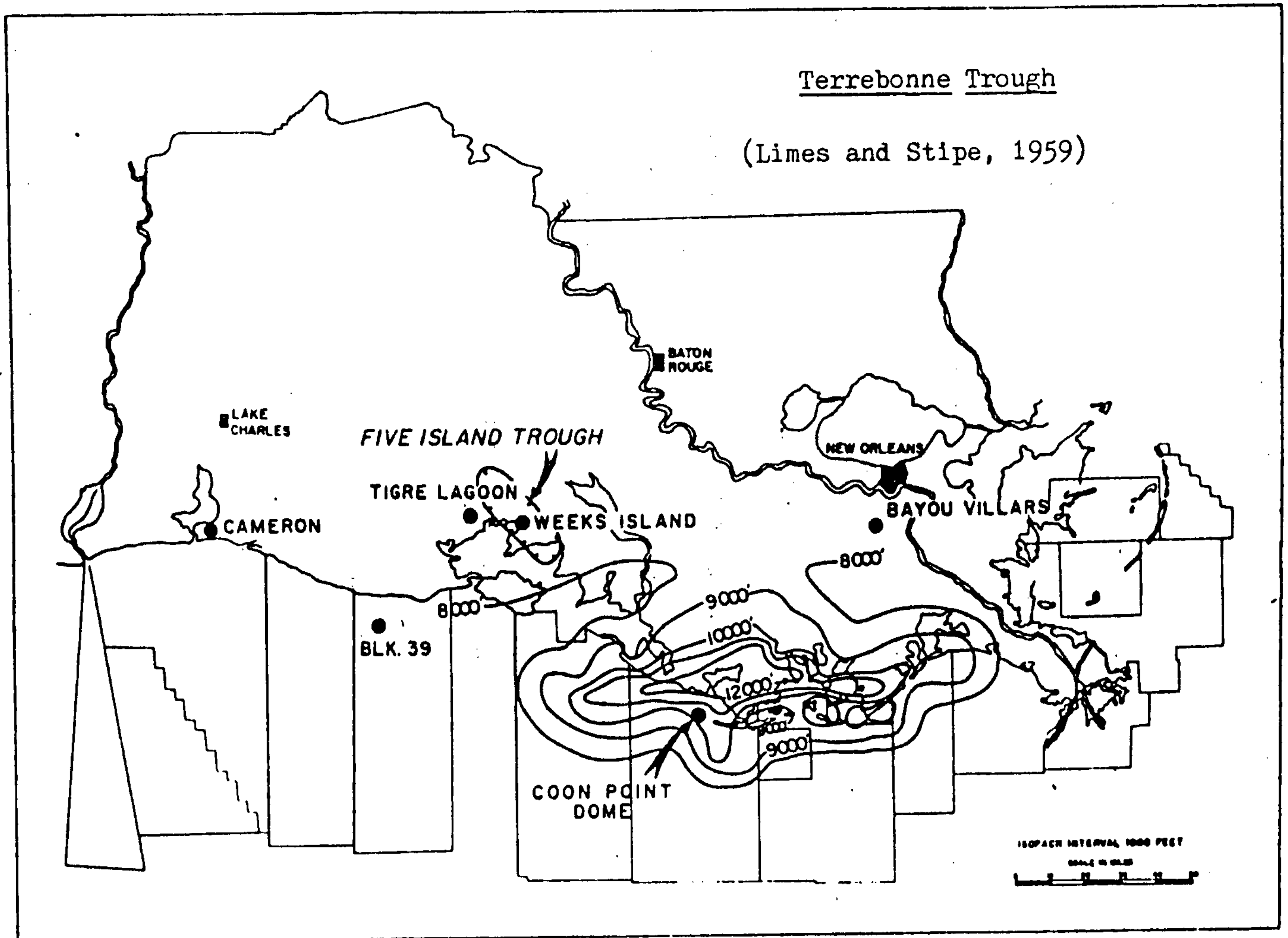
Some concern has also been raised over the validity of the terms lower, middle, and upper Miocene (Mclean, 1957). Since the terminology may be misleading, Murray (1961), has followed the suggestions of Mclean (1957), and renamed the lower, middle, and upper Miocene as Napoleonville, Duck Lake, and Clovelly Stages respectively.

The Miocene was a time of continuation of the gradual outbuilding of the continental shelf that had been characteristic of the Eocene and Oligocene epochs in the Louisiana and Texas Gulf Coast (Limes and Stipe, 1959). Many local transgressions and regressions of the shoreline punctuated an overall regressive cycle of predominantly deltaic sedimentation. Local transgressions and regressions were probably due to abandonment and construction of a great many delta lobes. Some transgressions of larger extent can be correlated regionally and interregionally, however, These are thought to be the result of either continued subsidence during periods of low sediment supply (Rainwater, 1964), or of eustatic sea level changes which are now known to have occurred during the Miocene (Vail et al., 1977).

Although the exact positions of major rivers and their deltas are not known, the positions of the major depocenters during the Miocene have been deduced through isopach mapping. From these it is evident that during the earlier Miocene the main depocenter was located in southwestern Louisiana. During the upper middle and upper Miocene, however, this depocenter shifted to southeastern Louisiana depositing sediments in what is now known as the Terrebonne Trough (figure 3).

The Miocene section thickens sharply southward into the Terrebonne Trough. This thickening occurs on the downthrown side of a set of large regional en-echelon growth faults. These large fault zones, with great increase in bed thicknesses on the downthrown sides, mark flexures or hinge lines in the Gulf Coast and their location marks the location of the shelf break during the time of deposition of the beds affected (Hardin and Hardin, 1961). Regional south dip also increases across these zones. This dip, although interrupted by local structure, increases from 300 feet per mile to 800 feet per mile in the thick shales beyond this hinge line (Limes and Stipe, 1959).

Figure 4 is a North-South regional cross section of the



Thickness of massive sands in the "Terrebonne trough" of South Louisiana.

Figure 3. Miocene sediments in the Terrebonne Trough are extremely thick. The excessive expansion of section occurred across a large flexure zone which was active during the late-middle and late Miocene. The massive sands above are almost entirely late Miocene in age.

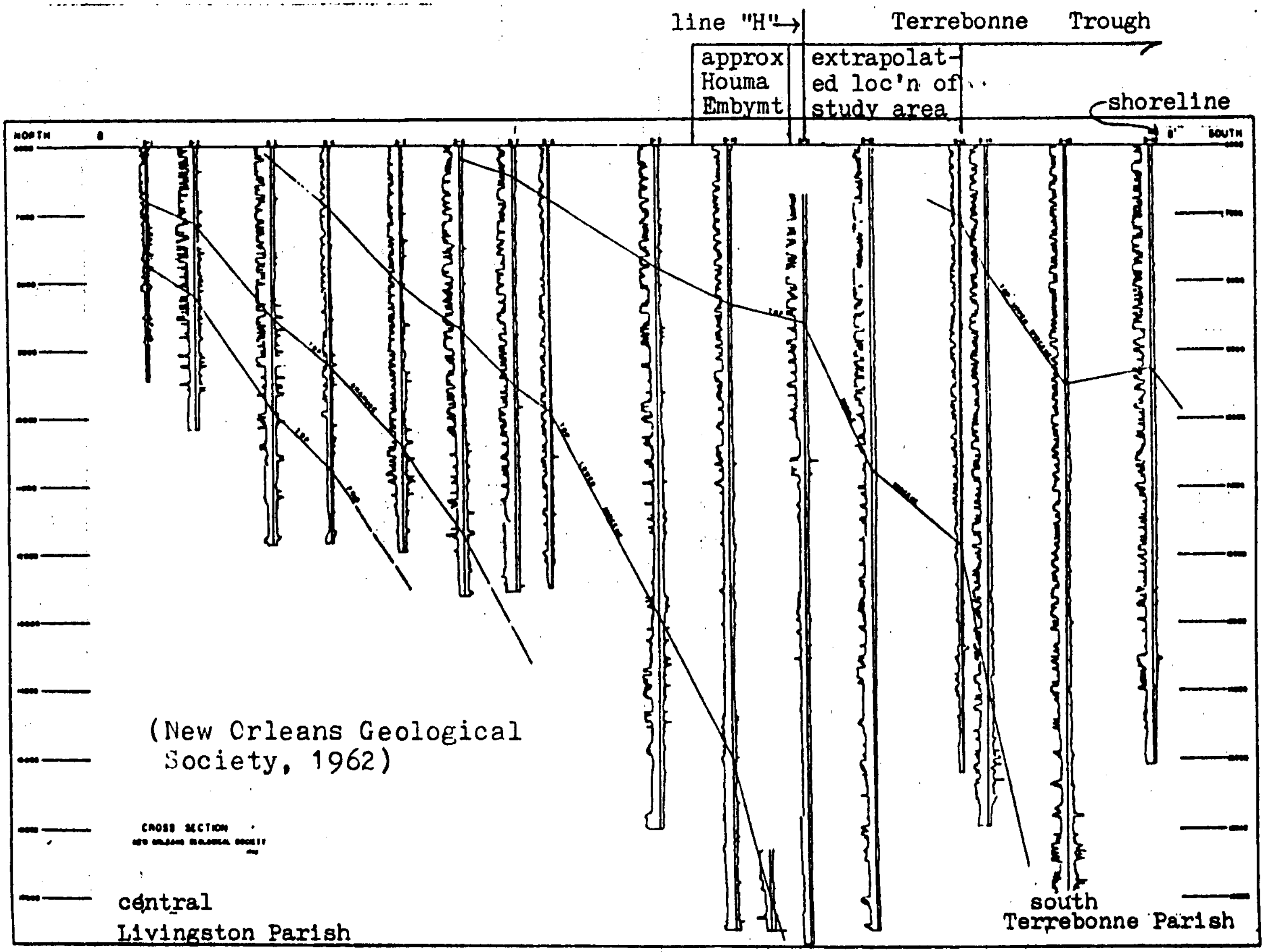


Figure 4. North - south regional cross section of southeast Louisiana. Extreme expansion of middle Miocene begins south of line "H".

Miocene across southeast Louisiana. The southern portion of this cross section, in fact, lies just to the east of the study area of this report. In this illustration the Miocene section is observed to expand in a southward direction; however, expansion is very rapid south of line "H" into the Terrebonne Trough due to the effect of the contemporaneous hinge-line faults.

As discussed in a later section, this flexure zone was found to have been most active during the last of Cristellaria I deposition through the end of Bucella mansfieldi deposition. This period of faulting somewhat overlaps and immediately postdates the Houma Embayment event. The Houma Embayment, according to Sloane (1966), was a sedimentary basin which formed due to a foundering of the outer shelf along large arcuate north bounding down-to-the-basin contemporaneous faults. This shelf-edge embayment was formed just to the north of the present study area. Activity in the embayment began no later than Cibicides carstensi opima time and was complete by the end of Bigenerina humblei deposition. Thus, the event primarily predates most of the structural activity associated with the initiation of the formation of the Terrebonne Trough fault systems to the south.

Sediments of the Houma Embayment exhibit strong north dip and northward thickening toward the embayment faults. The sediments thin in wedge-like fashion to the south where structural activity was at a minimum (Sloane. 1966). The fields of Lake Hatch, South Sunrise and South Houma lie at the very southern featheredge of the Houma Embayment sedimentary wedge. These fields also lie on the northern fringe of the Terrebonne Trough.

Sediments delivered to the area after the Houma Embayment episode were deposited over the embayment, burying it. Simultaneously, to the south (in the current study area), activity began along the previously described flexure zone. The thin sediments which constituted the seaward edge of the Houma Embayment were downfaulted and the great thickening of the upper Duck Lake-lower Clovely stage section into the Terrebonne Trough began to occur. Except in extreme northern portions of the study area, Houma Embayment sediments have been faulted to depths below well control. Regional development of the area is discussed further in a later section.

LOCAL STRATIGRAPHY

Sediments of the stratigraphic section studied in this report were deposited during the later-middle and early-late Miocene epoch. The section is biostratigraphically characterized by the occurrence of the Cristellaria "I" through Bigenerina "A" faunal zones but only those zones from the top of Cristellaria "I" to the base of Bigenerina "B" were examined in detail.

Paleontological marker picks and paleoecological zonation interpretations over most of the study area were made by Paleo Data Inc., New Orleans, Louisiana. According to Dunlap (1970), Paleo Data uses the general paleoecological criteria and depth zonations suggested by Gulf Coast S. E. P. M. committees on paleoecology. A diagramatical presentation of these ecological zones and respective water depths is given in figure 5.

From oldest to youngest, the major regional biostratigraphic zones present in the section detailed are Cristellaria "I", Bigenerina humblei, Textularia "W" stapperi, Bigenerina "2" nodosaria var. directa, and Textularia "L" articulata. As previously mentioned, many other fauna are used as local markers and a more detailed chart showing their stratigraphic position relative to the major biostratigraphic markers needs to be constructed for a local study. The local correlation

CLASSIFICATION OF MARINE ENVIRONMENTS

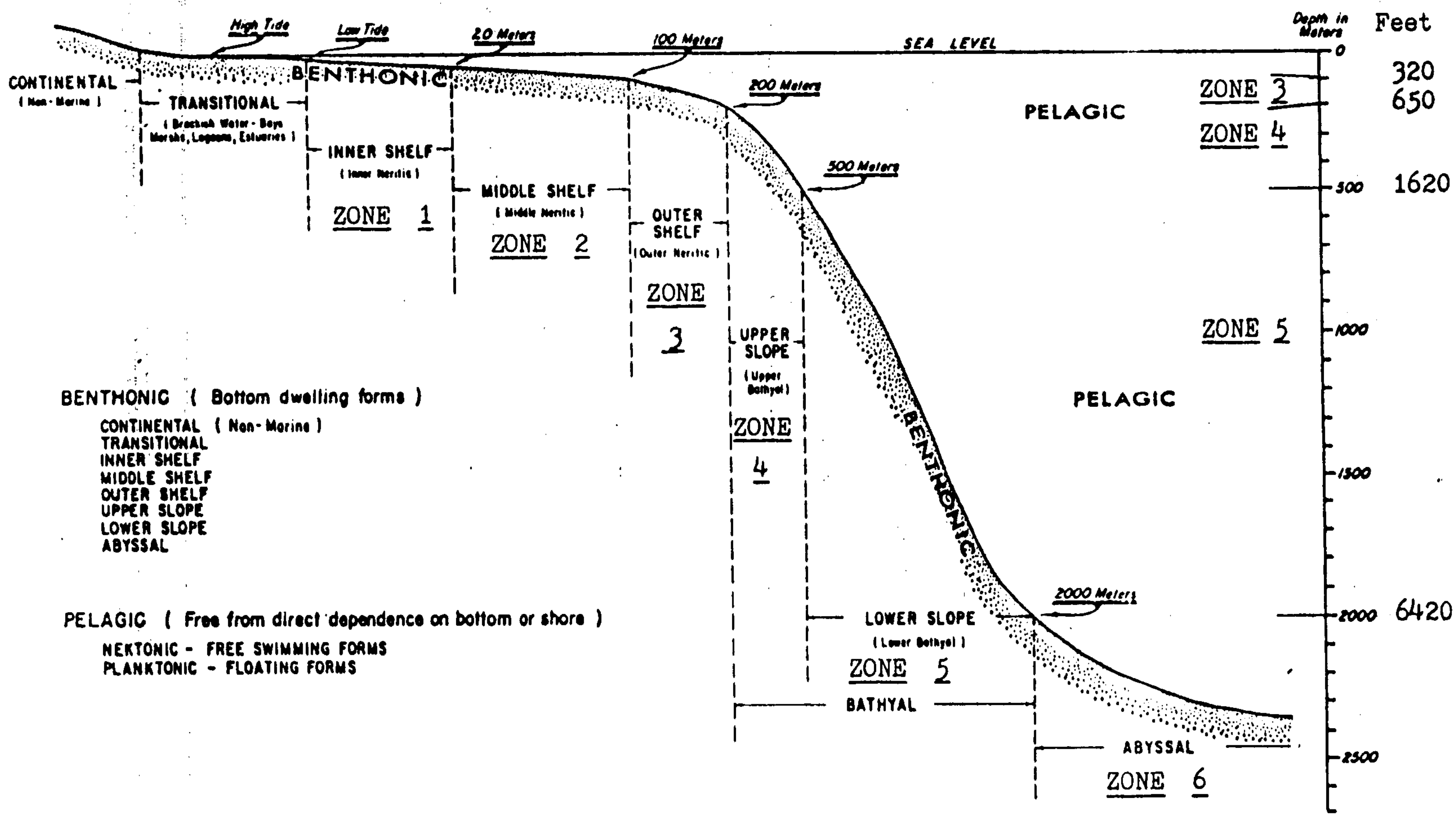


Figure 5. S.E.P.M. suggested paleontological envioronmental and water depth zonation for the Gulf Coast.
(Modified from Tipsword, et al.,1966)

chart used in this study is given in figure 6.

The sedimentary section expands greatly from wells on the northern fringe of the study area to the wells on the southern fringe. This expansion takes place across several large east-west trending growth faults which, in general, become progressively younger and climb the section from north to south. To the north of the northernmost of these faults the section from the top of the Cristellaria "I" faunal zone to the top of the Textularia "L" faunal zone is approximately 4,700 feet thick. South of the southernmost of the faults the thickness of the same section cannot accurately be estimated but must at least be in excess of 9,000 feet. The section between the estimated top of Textularia "W" and the top of Textularia "L" alone has increased in thickness by about 2,500 feet.

This rapid thickening in fact represents the beginning of the extreme expansion of the Miocene section into the Terrebonne Trough. The faults mentioned just above, therefore, represent the hingeline or shelf break during the time of their development, as previously discussed. North-South cross section E-E' (plate 1) was constructed without regard for faulting to show this southward thickening and the overall regressive, progradational pattern of the middle and later Miocene slope and shelf across the study area.

As illustrated by the cross section, the activity of the faults in the northern and central parts of the area most

STRATIGRAPHIC CORRELATION CHART
FOR CURRENT AREA OF STUDY

SERIES	STAGE	DIVISION	INDEX FORAMINIFERA
PLIOCENE			undifferentiated
MIOCENE	CLOVELLY		undifferentiated Uppermost Miocene
		A	Bigenerina "A" floridana Amphistegina "E"
		B	Discorbis "12" Bigenerina "B" = Bucella mansfieldi Textularia "L" articulata Eggerella sp.
	DUCK LAKE	C	Bigenerina "2" nodosaria directa = local Cib. carst. Uvigerina "3" Robulus "5" Globorotalia fohsi robusta
		D	Textularia "W" stapperi Globorotalia fohsi lobata Globorotalia fohsi fohsi
		E	Bigenerina humblei Cristellaria "I" (= Krumbhaar fauna) Planulina harangensis Cibicides carstensi opima

Figure 6. Compiled from McClean (1957), Murray (1961), Butler (1962), and Rainwater (1964).

greatly affects the thickness of sediments deposited during *Bigenerina humblei*, through *Textularia* "W", and into *Bigenerina* "2" time. The thickening is markedly slowed after *Bigenerina* "2" in this area. To the south, however, the effects of another younger thickening episode are observed; the result of the activity of younger faults along the southern boundary of the study area.

The base of the massive Miocene fluvio-deltaic sands is correlated across the cross section and is observed to stratigraphically ascend the section in a downdip direction. This situation is typical of the normal seaward facies change produced through time in a regressive situation.

Most of the actual mapping done for this project was restricted to an area which was bounded on the north and south by large regional hingeline growth faults which were part of the middle Miocene flexure. The northern mapping-area-boundary-fault is actually the first and oldest of the hingeline faults. Much of the sedimentary section examined in this study initially develops across this fault and to the south is further expanded by other similar faults. The southern mapping-area-boundary-fault is one of extreme size and therefore a good place to bound the study area. Additionally, though, the geopressure horizon, with which much of this report is concerned, becomes depressed deeply across this fault and prospects which may exist to the south of it are not as promising due to their increased depth.

Because of the expansion of section across the mapping area and between the boundary faults, it is necessary to use at least two type logs to characterize properly the interval studied. The updip type log; the Placid Oil Co. Laterre D-4 of TD 17,845 feet (sec. 65, T-19-S, R-18-E), is fairly representative of the northern portions of the study area (figure 7). Correlations may be made from this well to a great many wells in the northern area but because of the many stratigraphic and structural changes that occur, these correlations are not immediately evident and a lengthy study of the area has been required to establish these relations. The well is cut by no faults and has the most complete section of any in the area. Some section is missing due to the presence of three unconformities but at least the stratigraphic positions of the unconformities are known in this well and can be tied to a seismic line in the immediate vicinity.

The D-4 well bottomed in thick lower zone 4 shales that were deposited during the middle Miocene, as indicated by the presence of the Bigenerina humblei faunal assemblage. These deposits are roughly time-equivalent thin extremities of the final Houma Embayment deposits. From this point upwards, sand percentages increase and water depth zonations decrease reflecting the overall regressive pattern of the Miocene in the area.

UPDIP TYPE LOG

PLACID OIL COMPANY

LATERRE D-4

65 T-19-S R-18-E

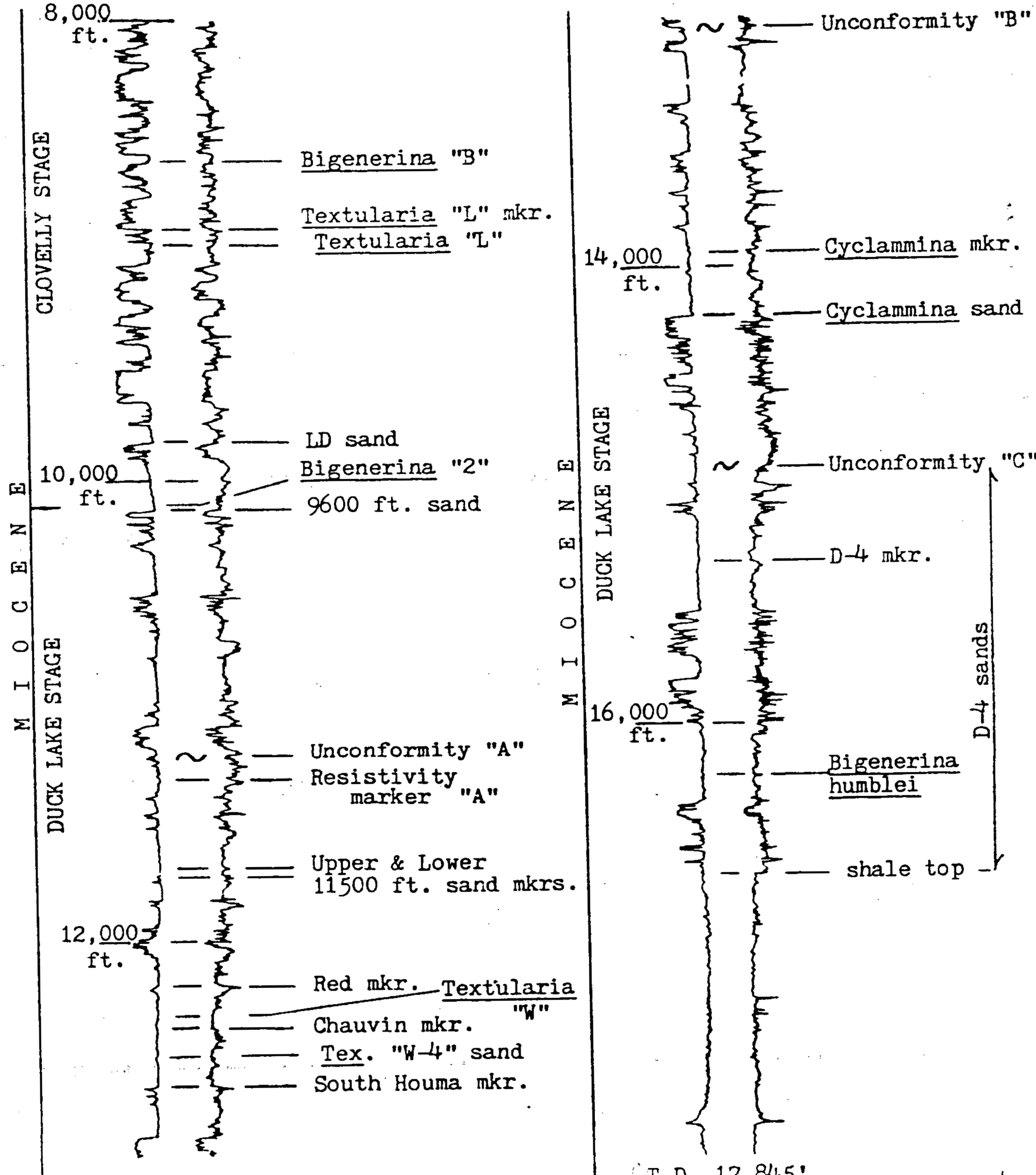


Figure 7

The D-4 sands which lie just above *Bigenerina humblei* are significant in that they are only found in wells immediately to the south of the South Chauvin structure, such as in the type well. As detailed in a later section they are probably truncated updip by unconformity "C" which is found above the D-4 sands in this well at 14,880 feet. No precise estimation of missing section is possible here since all other wells are missing a greater amount at this unconformity but from data compiled from other cross sections and the Amoco seismic line it would appear that the section missing in the type well is rather nominal. Unconformities "B" and "A", found at depths of 12,980 feet and 11,220 feet respectively, are likewise sites of only minor amounts of missing section. All of these unconformities become more pronounced over positive structural features.

A set of important resistivity markers occurs on the type log at the top of the *Textularia* "W" biostratigraphic zone. These are known as the South Houma, Chauvin, and Red markers in ascending order and were essential in establishing subregional correlations in the northern part of the mapping area. Deep structure is also mapped over part of the northern area on the Chauvin marker.

Two important sands are also traced throughout the northern mapping area by virtue of the aforementioned markers. These are the *Textularia* "W" and *Textularia* "W-4" sands, which seem insignificant in the type well but become important elsewhere. Both sands are discussed in greater detail in a later section but for now it is sufficient to point out that the Textularia "W-4" sand is used as a deep mapping horizon in the northeastern portions of the study area where it is developed.

A second set of extremely important resistivity markers occurs at about 11,700 feet in this well. The 11,500 foot sand markers, lower and upper, are probably the most regionally correlative markers to be found in the mapping area. After much exhaustive study, it was realized that these were the only deep markers that persisted downdip across large faults in the area, allowing an estimate of throw at depth on these faults. One of these, the lower 11,500 foot sand marker, was used to map deep structure in the southern part of the study area.

Several other important markers and sands exist above the 11,500 foot sand markers, but detailed discussion of most of them is not necessary. It is worthwhile to discuss the marker used for the uppermost mapping horizon, though, because it is truly an exceptional one. Unfortunately, the marker is perhaps most poorly displayed by the D-4 well log. In most cases, the marker is found in a distinct shale break close to the Textularia "L" paleontological marker. Normally it consists of two very small but extremely consistent "bumps" of the S. P. curve, perhaps in response to a thin bentonite layer in a thin but regionally persistent shale break. In this well, though, it is nearly obliterated by an erosionally-based sand and amounts to little more than a nearly undistinguishable resistivity marker at 8,900 feet.

What makes the marker so unusual is that it and the shale break in which it is found are in the massive fluvio-deltaic sands of the Miocene, where few correlations persist for any distance. Two other similar extremely persistent shale stringers known as the Amphistegina "E" and Bigenerina "A" breaks are also found somewhat higher in the massive sand section. Further study is required to deduce the origin and nature of these shale breaks but probably they were the result of minor transgressions which occurred because of short-lived diversions of the sediment supply and subsidence.

To the south, the stratigraphic section becomes expanded and changes almost entirely across a large growth fault which extends across the south-central part of the mapping area; therefore, a downdip type log was a necessity. Unfortunately, there are few logs which could be selected as representative of this southern area due to the many structural complexities which exist.

The log chosen to represent the section in the southern areas is the Quintana Production Co. Aurelie Eschete No. 1 of TD 17,324 feet (figure 8). The selection of this log was a

DOWNDIP TYPE LOG

QUINTANA PRODUCTION COMPANY

AURELIE ESCHETE # 1

30 T-19-S R-18-E

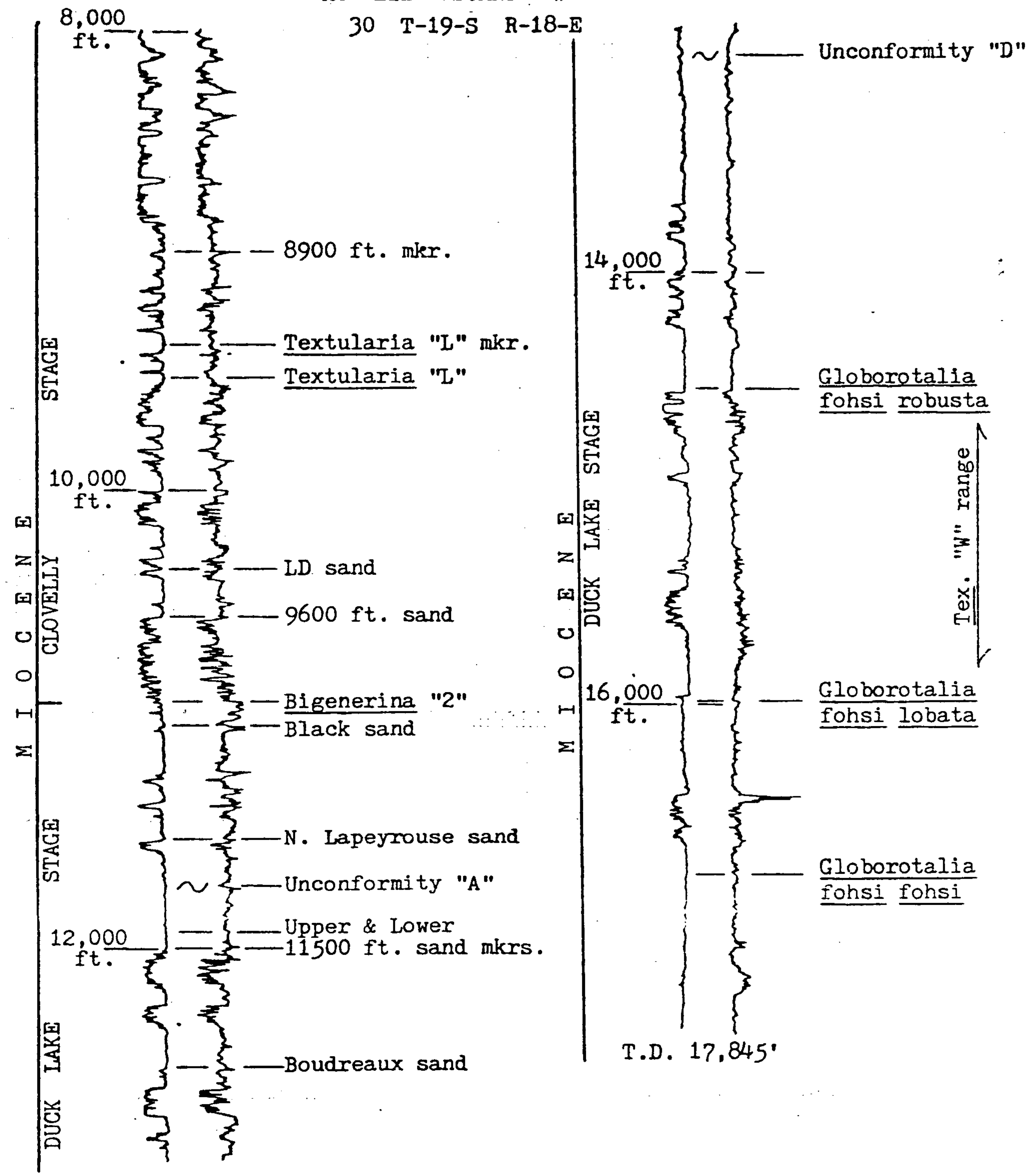


Figure 8

comprimise, however. The well from which it came was drilled over a structure that was actively growing during much of the deposition of the section with which this study is concerned. Thus, the section represented by this log is thinned and contains at least two unconformities. Nevertheless, this log represents the only deep well in the area which is not faulted and has a full slate of paleontological information.

The Eschete No. 1 was terminated in thick overpressured Zone 6 shales characterized by the occurrence of <u>Globorotalia fohsi fohsi</u>, a paleontological marker ordinarily found locally at 200 or 300 feet above <u>Bigenerina humblei</u>. From this point upward this well, like the D-4 well, also reflects the overall regressive sedimentation pattern and shallowing of water depth typical of the Miocene section in southeast Louisiana. The first sands encountered above TD are of low lateral continuity and in accordance with their depth zonation, are probably portions of turbidite deposits. The sedimentary pattern does not appear to change considerably until just above unconformity "D" at 13,030 feet.

Closely overlying the unconformity is the Boudreaux sand. Deposited in Zone 3, it was the first sand of good lateral continuity to be spread over the southern portions of the study area. The 11,500 foot sands follow and are of similar nature.

Just above these sands, at a depth of about 12,000 feet, the 11,500 foot sand markers, upper and lower, can again be recognized. As discussed previously, the lower marker was used in this area as the deep structural mapping horizon.

Unconformity "A", as identified in the D-4 well, is again found in this well at 11,730 feet. The shale interval in which it lies is considerably thicker in downdip, off-structure areas but no sands have been removed by the unconformity.

An interesting large sand body is found at a depth of 10,500 feet in this well. Known as the 9,600 foot sand in Lirette field, this sand was deposited very near the end of Bigenerina "2" time. The deposit shows significant stratigraphic variation and is discussed in more detail in a later section.

Of importance above the 9,600 foot sand is a more typical occurrence of the Textularia "L" marker at 9,355 feet and the usual occurrence of the Amphistegina "E" and Bigenerina "A" shale breaks at 7,150 and 6,740 feet in the massive Miocene sands.

Seismic Stratigraphy

Amoco seismic line 68-202 (plate 2) was used in this study primarily to aid in structural interpretation. Interestingly, several unconformities are recognizable on the seismic line. Unconformities on seismic record sections are recognized by systematic reflector terminations at or near the unconformity surface and by discordance of reflector attitudes above and below the unconformity. When present on a regional scale, seismic unconformities, called seismic sequence boundaries, are interpreted to divide major depositional sequences (Mitchum, et al., 1977).

The unconformities found on the seismic line used in the study area have been found to agree with the locations of suspected unconformities on a nearly parallel structural cross section. At least one of these unconformities (unconformity "A") is recognizable throughout the study area. In many of the other areas, however, the unconformity is slight and may be reduced to a correlative nondepositional surface or disconformity. This and other unconformities are discussed in relation to structure in a later section on structural geology.

Although the subregional nature of unconformity "A" has been established in the present study area, other studies in the surroundings have not recognized a specifically equivalent unconformity. There are a number of good reasons for this. For instance, the unconformity is fairly slight and is not easily recognized in standard geologic mapping. In addition, on the upthrown side of the north-bounding fault of the present study, the section is so much thinner that the unconformity might be included as normal thinning on the upthrown side of a large growth fault, and be missed. Also to the north, the unconformity lies at stratigraphic positions which are shallower and are not as interesting to subsurface exploration and is therefore probably overlooked often. In areas to the south, unconformity "A" may be lost in the heavy accumulations of sediments on the downthrown sides of other major growth faults.

The small size and apparently low regional extent of unconformity "A" coupled with the fact that it is recognizable in the study area primarily over structurally uplifted areas leads to the conclusion that the unconformity is a local feature which formed in conjunction with structural uplifts and marks no seismic sequence or depositional sequence boundary. Probably the other unconformities recognized on the record section are similar.

STRUCTURAL GEOLOGY

Structural elements of the study region were determined through standard subsurface structural mapping procedures. Two structural maps were prepared on five subsurface horizons. Of these horizons, two represent relatively shallow structure, while the remaining three depict structure at depth. Additionally, three structural cross sections were also prepared in conjunction with the mapped structural horizons to assist in the structural interpretations.

Of considerable aid in deducing structure below and outside good well control was Amoco Seismic Line 68-202. The reprocessed, migrated and interpreted record station is shown on plate 2. Its approximate surface location is shown on both deep and shallow structure maps, plates 3 and 4 respectively. The important correlation markers discussed previously and used throughout the study area are shown on the type logs and are located approximately on the seismic section. Depth estimates given with the section are based on estimates by Amoco and on estimates suggested by the relative stratigraphic positions of features deduced from well log correlations.

The shallow structural horizons were prepared using primarily the extremely persistent Textularia "L" correlation marker which is approximately located at 2.38 seconds on the seismic line over the South Chauvin structure. Loss of the marker in extreme southwest portions of the area necessitated a slight datum change of approximately 400 feet to the 8,900 foot resistivity marker (see figure 8).

As previously indicated, few, if any, regionally extensive correlation markers exist in the deeper subsurface. Any correlations downdip across major faults are often accomplished only with great difficulty. For this reason, deep structure was mapped on three different horizons whose updip and downdip boundaries consist of large faults. The northernmost areas were mapped at depth on the Textularia "W-4" sand marker. The central areas use as their map datum the Chauvin resistivity marker. Southern areas were mapped using the lower 11,500 foot sand marker, best developed in the southern type log, figure 8. These two markers are located at approximately 3.02 and 2.94 seconds respectively on the seismic line over the South Chauvin structure.

Structure in the study area is dominated by a large, northwest trending continuous anticlinal feature which is surrounded by structural lows and other minor positive features. Here termed the Lirette-South Chauvin anticline, this structure is the trapping feature for most of the hydrocarbons in the area. Also dominant, especially at deeper horizons, are large subregional faults which are part of larger regional growth fault systems.

Detailed discussion of both deep and shallow structure will proceed on a township and range basis to lessen confusion.

Township 18 South, Range 18 East

The northwestern half of the Lirette-South Chauvin anticline and faults "F" and "K" are the major structural features found in this township. These are revealed best on plate 3, the deep structural map. Fault "K" is the north boundary to the mapping area. Dip on the fault plane is approximately 55° to the south and prior to bifurcation, maximum throw on the *Textularia* "W-4" marker mapping horizons is estimated to be around 600 feet. This fault is a major growth fault which forms a natural northern boundary to the study area because many of the sands prevalent in the mapping area initially developed across this fault.

In the area, fault "K" forms two large arcuate recesses, typical of large regional growth faults. This fault extends into the Sunrise fields in township 18 south, range 17 east to become fault "F-1c" in maps constructed by Pradidtan (1982).

The stratigraphic section further develops in Chauvin field across fault "F". This very large growth fault dips southward at approximately 45 degrees and at the deeper mapping horizons has a maximum throw of about 1,150 feet. There are numerous major bifurcations of this fault, some of which have become important in hydrocarbon and geopressure considerations. In addition, a bifurcation of fault "K" joins fault "F" in Chauvin to boost its throw somewhat. Fault "K-F", as it was named, is possibly formed along a plane of weakness which exists at depth where perhaps the arcuate legs of the major recesses in fault "K" are distinct.

Both "K" and "F" exist, albeit with much less throw, at the shallow mapping horizon. Fault "F", however, is seen to have a maximum throw along the eastern mapping border of about 800 feet before bifurcation into faults "F" and "F-G". The throw of fault "F" continues to decrease on this horizon to the northeast. Where crossed by the seismic line, the throw is about 300 feet.

The Lirette-South Chauvin anticline extends into this township from the southeast and noses out to the northwest of Bayou Chauvin field. Although hardly evident on shallow structure maps, this structure is well defined at the deeper Chauvin marker mapping horizon, having structural relief of more than 700 feet. The north flank of this structure dips at about 6½ degrees and, although the anticline is itself not a "rollover" feature, this steeply dipping north flank has been created by roll into fault "F". The south flank of the structure, on the other hand, is not nearly so steep, averaging only about 4 degrees as it dips into a syncline to the south. These descriptions are clarified by examining the northern half of structural cross section A-A' and the north-south seismic record section (plates 5 and 2 respectively).

The area was not mapped for structure below the Chauvin marker due to sparse deep well control; however, it is apparent from the Amoco seismic line (plate 2) that the structural complexity of this anticlinal feature increases dramatically with depth. From the seismic line and from the wells that were drilled deeply in the area, the complex deeper structure of the anticline was deduced. The north-south structural cross section A-A' (plate 5) is virtually coincident with the seismic line in this area, and the seismic interpretation has been carried directly to the section with no difficulty.

The Chauvin marker mapping horizon occurs at approximately 3.02 seconds directly over the crest of the South Chauvin anticline. The prominent reflector beneath it may be followed with ease northward to growth fault "F", where its upthrown correlation is believed to be at 2.88 seconds. Below the crest of the anticline, at depth, are found several faults which are antithetic to fault "F". Additionally, below 3.36 seconds, is a buried down-to-the-south fault (fault "Z") which appears to plunge to and become parallel with the south flank of some chaotic events which begin at about 3.68 seconds beneath the structure. Furthermore, a prominent unconformity is seen over the south flank of structure at about 3.54 seconds. This unconformity may be correlated southward on the seismic section along distinct truncations of more steeply dipping reflectors which lie beneath it, especially along the blanks of structural uplifts.

Several lines of evidence lend credibility to the seismic interpretation. First, the D-4 sand series, shown on the Placid D-4 type log and on the A-A' cross section, are a group of laterally continuous, distinct sand bodies which are easily correlated in southern, off-structure wells. These sands are absolutely absent in every deep well to the north, perhaps suggesting the presence of an unconformity over the South Chauvin structure. Second, sands overlying the D-4 sands which can be easily correlated to on-structure positions are abruptly lost in some wells, suggesting the presence of fault "Z". Third, correlations of sands overlying the D-4 sands from some deep wells on structure show extremely rapid expansion of section in a southward, off-structure direction, indicating perhaps an expansion of section across a contemporaneous fault. Deep well control in the area is insufficient to prove the seismic interpretation; however, the interpretation of the data in terms of an unconformity-fault combination satisfies the previously unexplainable well log data in a geologically feasible fashion. Cross section A-A' presents an ideal example of the problem as observed through well logs and its resplendent solution as interpreted from the seismic record section.

In addition to unconformity "C", at least two other unconformities are found on the seismic section. Unconformities "B" and "A" lie stratigraphically above the Chauvin marker and are found over the South Chauvin anticline at 3.18 seconds and 2.91 seconds respectively. Like unconformity "C", these unconformities are also recognized on seismic section by angular discordance between super and subjacent reflectors and by reflector terminations.

Unconformities "A" and "B" are also interpreted on structural cross section A-A'. Both are probably important subregional unconformities; however, due to structural complexities in other areas, the regional extent of unconformity "B" cannot be documented. Unconformity "A", on the other hand, can be traced throughout the mapping area. In several other parts of the mapping area which are discussed later, this unconformity is also held responsible for the reduction and/or creation of localized subsurface relief.

The shallow structure map, plate 4, reflects the effects of the unconformities and the cessation of structural growth in the Chauvin area. For example, the high rate of dip on the north flank of the Lirette-Chauvin anticline has been eliminated, except for the sharp rollover very close to fault "F". In fact, a very slight anticline is found on this flank of structure where before was found only uniform steep north dip. Possibly this is the result of topography on unconformity "A" or "B" or perhaps it is due to preferential sedimentation behind fault "F" and/or differential compaction in predominantly deltaic sediments found at this horizon. The seismic line is less helpful at these shallower horizons.

In another significant example, both the A-A' cross section and the seismic line show marked reduction of the central synclinal feature south of South Chauvin to near uniformly southward dipping reflectors. Truncation of structure at unconformities "A" and "B", cessation of structural growth and preferential sedimentation are responsible for the changes observed.

The stratigraphic thinning and presence of angular unconformities associated with the South Chauvin structure are evidence that the structure was a positive feature for some length of time and was not solely the result of rollover into fault "F". Since this is so, something must be held responsible for the uplift. Some writers (Piaggio, 1961; Butler, 1962; Silvernail, 1967) have theorized that major uplifts in the area (specifically, the Lirette structure) are the result of the movement of deep-seated salt diapirs. In the Chauvin area and even at Lirette, this may not be the case, however.

On the seismic line, the core of the South Chauvin uplift appears to exist at approximately 3.65 seconds (c. 15,000 ft.) where a sudden loss of coherent reflectors is observed to occur. These noncoherent reflectors, however, do not define any mass or body which might be interpreted as a salt intrusion.

Moreover, wells such as the Shell Oil Co. James Fanguy 1-A have been drilled in positions directly over the South Chauvin structure to depths in excess of 16,000 feet without encountering salt. Additionally, deep structural mapping in the area has failed to show any development of a radial fault pattern. This type of deformation is commonly found at depth above uplifts associated with diapiric salt. These salt masses have originated from a very deep source, especially in South Louisiana, and have penetrated an extremely thick sediment pile. Thus, if salt formed the core of the uplift, more deformation, including some semblance of a radial fault pattern, might be expected to exist at the horizons studied. Possibly there is an alternate explanation which can be offered concerning the origins and cores of these uplifts.

Significantly, thick, low-density, high-pressure shales have been encountered over the South Chauvin structure by every deep well drilled in the area. These are the thick, fine-grained deposits of the slope outer shelf, and prodelta. Overlying these soft shales are clastics of higher density which were rapidly deposited on the downthrown sides of growth faults "K" and "F". The diapiric nature of such shales in response to this type of sedimentary loading is well documented (Bruce, 1972; Roach, 1962; Musgrave and Hicks, 1968; Gilreath, 1968). Uplifts which are generated in this fashion cease when the rapid loading is terminated. The coincidence of the end of rapid fault growth with the end of structural uplift at South Chauvin has already been noted.

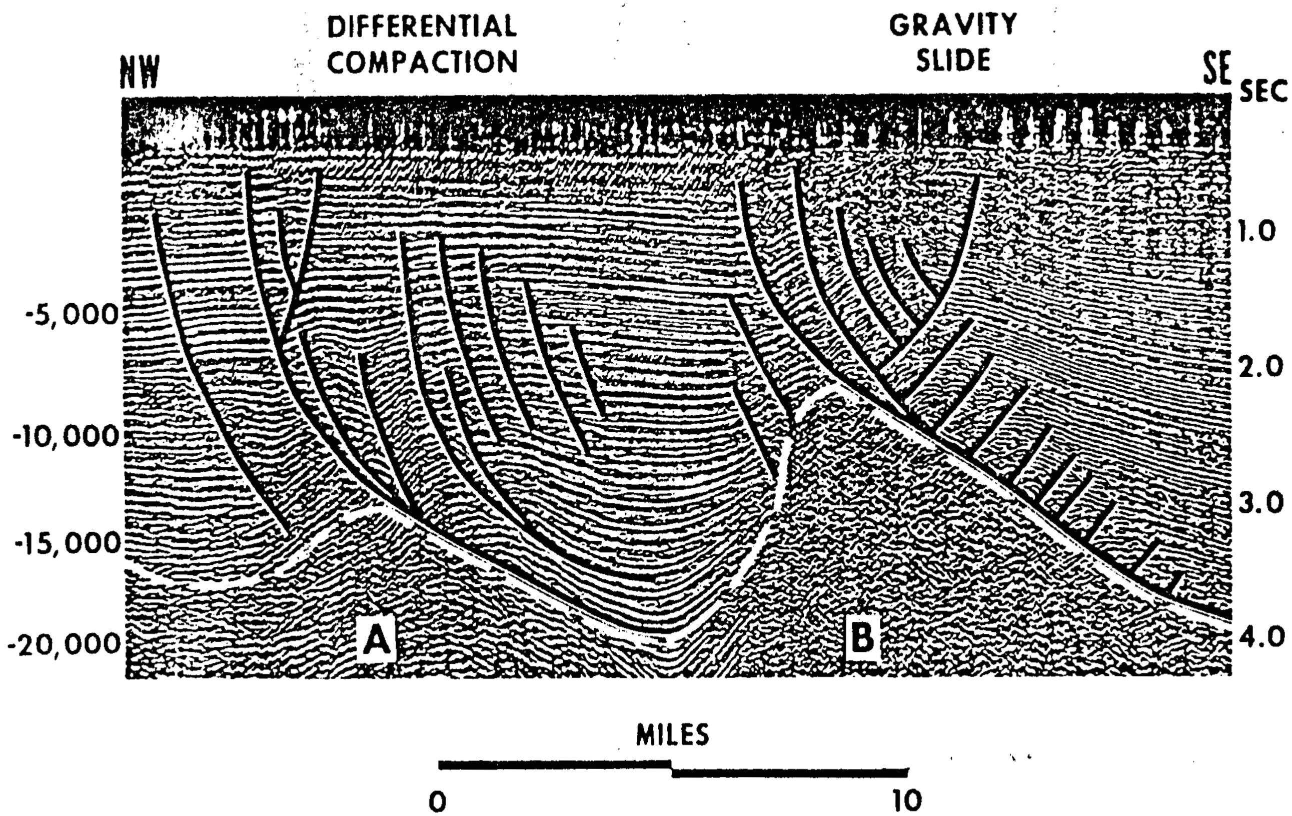
Unlike diapiric salt bodies, uplift-forming shale masses have sources which closely underlie the sediments they deform. Thus, these uplifts affect much less of the sedimentary section than do intrusive salt masses whose source is quite deep. Therefore, sediments overlying a shale-cored uplift might be less extensively deformed than those overlying a salt-cored uplift, even at depth and close to the uplift core. In addition, since these shale-cored structures form contemporaneously, or nearly contemporaneously, with deposition, sediments deposited over the developing structure were probably still very plastic during their deformation. These sediments might be able to resist the formation of a radial or complex fault network whereas sediments penetrated by salt might be somewhat more lithified and unable to resist brittle failure.

It seems probable, from the evidence presented in the last few paragraphs, that the South Chauvin anticline is a shale-cored structural ridge which formed from the thick, soft, overpressured shales of the upper slope or outer shelf in response to rapid sedimentary loading. This anticlinal structure and the fault which parallels the south flank of the structure (fault "Z") are very similar, although on a smaller scale, to gravity-slide structures reported in south Texas by Bruce (1972) (compare South Chauvin seismic structure with that of figure 9b). Interestingly, the loss of coherent reflectors on the seismic line occurs quite precisely at the same depth where the thick, overpressured shales described above are encountered by the drill. Thus, it would seem that mobile shale is almost certainly the cause of the South Chauvin uplift.

Township 18 South, Range 19 East

Deep structure in most of this area is mapped on the *Textularia* "W-4" sand marker. Plate 3, the deep structure map, shows a decrease in complexity in this area but the major features still include the continuations of large regional growth faults "K" and "F" plus a larger basinal structure. This basinal feature has about 1,000 feet of structural relief between faults "K" and "F". Its southern flank dips north, away from the Lirette-South Chauvin anticline about 4 degrees, whereas the northern flank dips south from the Lake Long dome a bit more steeply at around $5\frac{1}{2}$ degrees.

Fault "K" extends through this township and range in a large arcuate recess. At this lower horizon fault throw remains at around 600 feet with few bifurcations. Fault "F", on the other hand, undergoes many bifurcations as it curves sharply southward along the border between Townships T-18-S, R-18-E and T-18-S, R-19-E. One such bifurcation begins in Chauvin as 400 foot fault "F-2" which itself bifurcates into eastward-trending faults "F-2n" and "F-2s". These faults die



– Seismic illustration showing differences between fault systems formed by differential compaction and gravity slide. Dashed white line shows configuration of shale masses.

Figure 9. Gravity slide faulting (on right) associated with shale diapirism similar to that found at South Chauvin.

(Bruce, 1972)

out rapidly toward the basin, however.

Fault "F" further bifurcates into faults "F" and "F-3". Then, after being rejoined by fault "F-3", fault "F" proceeds nearly due east along the border of townships T-18-S, R-19-E and T-19-S, R-19-E with throws averaging around 600 to 700 feet. Along this border, fault "F" forms the major trapping mechanism for hydrocarbons which would have otherwise migrated up the north dip to the Lirette structure.

The shallow structural horizon, plate 4, again reveals the reduction of both the faulting and structural relief, as might be expected. Fault "K" probably has a throw of about 200 to 300 feet while that of fault "F" is 250 feet at Chauvin where it bifurcates into faults "F" and "F-3". Beyond this point fault "F" remains the larger of the bifurcations with about 150 feet of throw until they rejoin at Montegut.

The northern half of structural cross section B-B' (plate 6) traverses the Montegut and North Montegut petroleum fields. From this section, the increase in throw of faults "K" and "F" with depth is evident. Mild stratigraphic thinning in a southward direction is noted below unconformity "A", the result of growth of the Lirette-South Chauvin ridge discussed earlier.

Unconformity "A" is traced by correlation of resistivity marker "A" at Chauvin. Distinct bed discontinuity is not recognizable in the Montegut area; however, a reduction of structural dips and fault throws occurs somewhere in the vicinity of this marker and may be the result of both this unconformity and preferential sedimentation in the basinal area. The cessation of structural thinning also appears to be associated with the stratigraphic location of the unconformity.

Township 19 South, Range 19 East

South of fault "F" north dip continues at both deep and shallow mapping levels from the crest of the large Lirette structure. This northern flank of Lirette was again mapped at depth on the Chauvin marker. Dip on this horizon is north at approximately 6 degrees and is interrupted by fault "E" which has a maximum throw at this depth of about 300 feet. This fault intersects fault "F" to the west and may be traced to Lake Boudreaux in the east.

The northwestern flank of this large uplift becomes the structural ridge that extends into South Chauvin, as previously discussed. The curving axis of this ridge can be followed southeast from South Chauvin to the crests of the Lirette and Bay Baptiste structures. It is because of ths alignment and fusion of uplifts along this northwestward curving axis that the structures are collectively termed the Lirette-South Chauvin anticline.

Just to the south of fault "E" on the lower mapping horizon a change of mapping horizons occurs. This change results from the inability to correlate the Chauvin marker across fault "C", a large growth fault located near the crest of the Lirette structure. In order to get some idea of the throw across this fault near this horizon it became necessary to change mapping horizons to one whose downthrown correlation could be traced. The lower 11,500 foot sand marker, which on the upthrown side of fault "C" is found some 900 feet above the Chauvin marker, is the deepest recognizable correlation across this major fault. Sand development across this fault and substantial stratigraphic thickening of section below the 11,500 foot sand marker makes correlation of the Chauvin marker downthrown an impossibility.

The correlation of the 11,500 foot sand marker in this area is by no means direct, however. The stratigraphic changes that occur with the 11,500 foot sand just below the marker are significant. On the downthrown side of the fault the sand is expanded dramatically over its upthrown counterparts, making the correlations difficult. The correlation is, in fact, accomplished with relative certainty only by "tying it around" from correlations made across the same fault at Lake Boudreaux, where correlations are more easily made.

Fault "C" at this depth is bifurcated into fault "C-n1" and "C-s2", each of which possesses a throw of about 300-350 feet. Fault "C-n1" dips more steeply than does fault "C-s2", a point of possible larger significance to be discussed later.

For now, it is important to note that this dip difference results in a joining of the two faults at shallower depths combining their throws to form the single large fault seen at the *Textularia* "L" mapping horizon (plate 4). This vertical convergence is best displayed on the structural cross section B-B' (plate 6). An antithetic fault "C-r2" is also seen to have formed from fault "C" at the shallower horizons.

To the south of the "C" faults, at either structural horizon, is formed the northernmost of two highs that make up the Lirette structure. At the deeper levels, the northern and southern highs are distinct, separated from one another by a structural sag. Structural uplift in the northern high seems to have been most strongly concentrated in the northwest corner of section 32 where a horst-like fault block stands as a structural high. To the west of this horst block and south of fault "C", dips steepen to 7 degrees as the horizon descends some 1,200 feet to Lake Boudreaux field. Throw along fault "C" increases quickly as a result of discordance between the dip rates of beds on opposing sides of fault "C".

At the upper mapping horizon, the distinction between the two uplifts is lost, although a vestige of the structural sag between the two remains. Uplift still seems to be most concentrated in the northwest corner of section 32, except that by this level the faults which had produced the horst block at lower depths have died out and become buried. Also noteworthy is the reduction of dip discordance between correlative horizons upthrown and downthrown of fault "C". Both upthrown and downthrown horizons dip west toward Lake Boudreaux at about 5½ degrees.

The cessation of growth along fault "C" and the topographic smoothing produced at the surface of unconformity "A" are instrumental in causing these observed changes in shallower structure. Some of the smoothing effects of unconformity "A" are demonstrated in cross sections B-B' (plate 6) and C-C' (plate 7), both of which traverse Lirette field in this area.

The southernmost of the two Lirette uplifts is best seen on the deepest mapping horizon (plate 3). It is a larger more broadly uplifted dome cut at the crest by fault "D" whose maximum throw at this horizon is about 200 feet. This fault dies out off structure several miles to the west and shows only minor growth with depth. Probably this fault and some of its minor bifurcations are normal faults produced due to uplift tension over the dome. Only a sliver of this fault remains at the shallowest mapping horizon.

At the extreme south end of township 19 south, range 19 east is fault "A". It is an extremely large regional growth fault which at the deepest mapping horizon has a throw of approximately 1,500-1,600 feet, and forms the southern mapping boundary. At the shallowest horizon, throw on this fault is still as large as 600 feet. A pronounced rollover anticline is also formed south of this fault. This anticline forms the trapping structure for hydrocarbons discovered at Bay Baptiste field.

Fault "A" turns to the south along the western border of this township and apparently joins another very large growth fault (fault "B") of similar age in Lapeyrouse field (Township 20 South, Range 18 East), according to an independent study by Sticker (1979).

The major uplifts at Lirette, as mentioned previously, were thought to be the result of deep-seated salt movement. This assumption has apparently been based on the fact that major salt uplifts exist about 15 miles to the south at Lake Barre and Lake Pelto. This interpretation is open to some question. Salt tops had previously been estimated at less than 20,000 feet. Pennzoil Producing Company has since drilled a well directly over the top of the southern Lirette structure to a depth of 20,225 feet without hitting salt. Several other wells in the area have been drilled to depths of around 19,000 feet without encountering salt. Additionally, the structures again lack any hint of a developing radial fault pattern at the deepest mapping horizon.

Instead, these deep wells over Lirette have again encountered high pressure-low density plastic shales. The diapiric nature of these shales is less well documented beneath Lirette on cross section B-B' than it is on cross section A-A' beneath the South Chauvin uplift; however, the alignment of these structures with those extending through Chauvin and similar movement timing suggest the possibility of a similar origin.

Township 19 South, Range 18 East

The geology of this township and range is complex, especially at depth. Fortunately, Amoco seismic line 68-202 (plate 2) traverses the area and is helpful in the interpretation. At the south end of this area and at the deepest mapping horizon is located a structural ridge which crests in three domal features. The central and eastern of these features make up the North Lapeyrouse field. Just to the south of these structures is located fault "N" which is the southern mapping boundary in this area. With one possible exception, no cuts from this fault have been established in wells of the present study area. Substantial stratigraphic changes are observed to occur along the southern mapping area boundary and studies done at Lapeyrouse field (Sticker, 1979) show this fault; thus, its presence has been inferred and placed on maps of the current study area.

Fault cuts of smaller proportions have been detected in the Texaco M. B. Daspit No. 1 well located at the southeast end of the North Lapeyrouse structural ridge. These fault cuts and associated bed discordances have led to the interpretive positioning of faults "P" and "P-1". These faults, however, are large enough to have been expected to cut other nearby wells at shallower horizons, but they do not. Apparently these faults have been either terminated at or truncated by unconformity "A" and are not observed at shallower horizons (see south end of cross section A-A', plate 5). These faults are older than fault "B" and probably represent a plane of weakness along which fault "B" propagated.

Unfortunately, due to an unsuccessful experimental adjustment of shooting geometry, Amoco seismic line 68-202 is virtually useless in the southern quarter of this township and range and cannot aid in this interpretation. On the other hand, there exists much well log evidence for unconformity "A" over the North Lapeyrouse structure and the observed truncation of some beds at the unconformity has been interpreted in structural cross section A-A'. Apparently the effects of unconformity "A" were enhanced due to contemporaneous movement of the North Lapeyrouse structure. At least one other similarly formed unconformity appears to exist below the deepest mapping horizon as well (see A-A' cross section, plate 5). The significance of these interpretations is again deferred to a later discussion.

North of these structures, the deepest mapping horizon (lower 11,500 foot sand marker) dips rather steeply to the north, descending 1,000 feet at about $8\frac{1}{2}$ degrees before encountering fault "C-s1". Where this lower horizon approaches fault "C-s1", resolution begins to return to the seismic line and on it, this steep north dip can just be detected.

Fault C-s1" is a southern bifurcation of growth fault "C" which was previously discussed in relation to Lirette field. Fault "C-s1" attains a maximum throw of 900 feet at this horizon where intersected by fault "C-T1", a second bifurcation of fault "C". Where traversed by the seismic line, however, the fault displays 800 feet of throw. Also found along fault "C" at this deeper horizon are two small positive features which interrupt and flatten the strong north dip.

North of fault "C", a datum change occurs and deep structure is once again mapped on the Chauvin marker. Although it is possible to trace the lower 11,500 foot sand marker back to Chauvin field (see cross section A-A'), a datum change at this point was convenient.

North dip continues from the datum change at about 3 degrees to 300 foot fault "E". From fault "E", the Chauvin marker descends some 350 feet more to the axis of a syncline produced between the uplifts at Lake Boudreaux and Chauvin.

At the shallow mapping horizon, plate 4, some substantial changes are evident. Although the structural configuration remains basically the same, all of the strong dips have been greatly reduced and several faults have disappeared. Despite the large throw of fault "C-s1" at the deeper horizon, only a sliver of this fault remains at the upper horizon and it dies out in section 15 shortly after bifurcation from fault "C". Fault "E" and its minor contributaries have likewise been eliminated.

Most of the reduction of steep dip on the north flank at the North Lapeyrouse structure occurs as fault "C-s1" dies out. Minor amounts of the dip are removed by unconformity "B", below the lower mapping horizon, and some is removed above by unconformity "A". Occasionally, minor irregularities observed at the upper mapping level may be the result of slight topography developed on unconformity "A". Additionally, some of the throw of Lake Boudreaux faults may be reduced slightly during the formation of unconformities "B" and "A". These structural arrangements are perhaps best displayed by cross section A-A' (plate 5).

Fault "C", unlike "C-s1" and "E", does not die out into the upper section quite as rapidly. In fact, it cuts the upper mapping horizon with about 325 feet of throw along the A-A' line of cross section whereas the others have become buried. Discussion of the significance of this difference is again postponed.

In this area, the A-A' cross section again agrees well with the seismic data (plate 2). One apparent difference between the two is that the seismic line displays four major faults at Lake Boudreaux whereas the cross section, only three. This is due to the fact that some unavoidable separation between the paths of the cross section and the seismic line has occurred. The A-A' cross section crosses the fault zone where fault "C-T1" and fault "C-s1" are joined relatively high in the stratigraphic section, nearly where the two become buried. Where the seismic line crosses the fault zone, however, the two are well separated and fully developed.

In this area unconformities "A" and "B" are best observed from the seismic data just to the north of fault "E". Both unconformities may be recognized in this area as terminations of reflectors at 3.02 seconds and 3.30 seconds respectively. Unconformity "C" is a most pronounced set of systematic reflector terminations found behind fault "E" at 3.62 to 3.65 seconds. Since there is no well control in the immediate area, no attempt has been made to extrapolate unconformity "C" to the cross section in the vicinity of Lake Boudreaux.

One other point of interest on the seismic line in this area is that fault "C" is indeed observed to extend up into the section beyond 2.25 seconds (approximately 8,000 feet) while the other faults do not.

DEVELOPMENT OF STRUCTURE IN THE STUDY AREA

Structural activity began first along the northern boundary to the study area. Fault "K" became active by no later than late Cristellaria "I" time. The fault was in the waning stages of activity by early Bigenerina humblei time, though, since from this point upwards, the fault is observed to lose displacement rapidly.

Fault "F" was active by at least mid to late Bigenerina humblei time and continued through Textularia "W" time. Accumulated downthrown of faults "F" and "K" and just south of the South Chauvin structure are the early Textularia "W" D-4 sands (see cross section A-A', plate 5). These sands were probably the first to develop across the aforementioned faults and upthrown equivalents of these sands remain so thin as to be unrecognizable.

Thinning of the D-4 sands and later sediments occurs to the west, as seen on the D-D' stratigraphic section, plate 8. This is perhaps due to early stages of growth of the South Chauvin anticline. The anticline apparently began its growth somewhat later where traversed by the seismic line and cross section A-A', however, because the D-4 sands show little thinning onto the present structure in that area.

Structural movement was begun in the area of cross section A-A' at South Chauvin during approximately middle *Textularia* "W" time. The early *Textularia* "W" D-4 sands were uplifted, faulted by fault "Z" and subsequently bevelled. Fault "Z" remained only slightly active for a short time after the renewed deposition over the truncated beds created angular unconformity "C". The structural movements at South Chauvin were possibly caused in response to rapid loading of the plastic shales by higher-density elements which accumulated on the downthrown sides of growth faults "K" and "F".

Uplift continued over the South Chauvin structure until late *Textularia* "W" time. Growth of the structure slowed substantially after formation of the late *Textularia* "W" unconformity "B". Meanwhile structural activity continued at fault "F" into *Bigenerina* "2" time, until unconformity "A" was created. At this point expansion of section across fault "F" was substantially reduced. Movement at the Chauvin structure also ceased at the time unconformity "A" was produced.

Major faulting and uplift had also begun prior to *Textularia* "W" time to the south, at Lake Boudreaux and North Lapeyrouse. The faults at Lake Boudreaux remained active through *Textularia* "W" time but began losing throw thereafter. By the last of *Bigenerina* "2" time, most of the faulting in the area was complete, except for fault "C".

Structural uplift at North Lapeyrouse was long-lived.

The ridge began being elevated structurally by no later than *Textularia* "W" time and continued until the end of *Bigenerina* "2" time. Uplift here had been affected only to a slight degree by unconformities "D" and "A" produced during the uplift but structural elevation ceased at North Lapeyrouse at the end of *Bigenerina* "2" time, at least temporarily. Some very late movement of this structure is also thought to have occurred.

Evidently the "P" fault system was established just to the south of the North Lapeyrouse structural ridge sometime during its uplift. Subsequently, faults "P" and "P-1" were bevelled or at least terminated at unconformity "A" somewhat later in *Bigenerina* "2" time.

At Lirette, by virtue of deep well control, stratigraphic thinning is observed over the southernmost structure, in sediments of later *Textularia* "W" through middle *Bigenerina* "2" ages. This thinning reflects movement there which occurred prior to the deposition of the 11,500 foot sand markers. Thinning does not occur over the Lirette structure along either North-South cross section B-B' (plate 6) or east-west cross section C-C' (plate 7) above the 11,500 foot marker in the sedimentary interval studied.

Growth of fault "C" at Lirette is also curtailed during the same period of *Bigenerina* "2" time. Thickening of stratigraphic units across the fault does not occur later than the deposition of the 11,500 foot sand; at least not for a while. Unconformity "A" is again found to be temporally associated with the cessation of structural movements in the area.

At Montegut and North Montegut areas, structural movements were most active during late Bigenerina humblei time, through Textularia "W" and into Bigenerina "2" time. Significantly less structural movement has occurred after formation of unconformity "A" in this area also, indicating that the unconformity was probably formed near the end of structural activity in the area.

Fault "F" and associated faults were similarly most active from the end of late Bigenerina humblei deposition, until the time of unconformity "A" near the end of Bigenerina "2" deposition. Fault "K" in North Montegut, being an older fault, had slowed significantly by latest Bigenerina humblei or early Textularia "W" zone deposition, as was observed at Chauvin. Fault movement persisted on both faults "F" and "K" until after the end of Textularia "L" deposition, however.

Growth faulting along fault "A", the southern border to the mapping area, began no later than middle to late Bigenerina "2" zone deposition and therefore is younger than any other unrelated faulting in the study area. Expansion of section across the fault continued throughout the deposition of Textularia "L" and Discorbis "12" zones and hence the fault reaches higher into the section than does other faulting to the north, except in special cases. Fault "B" in Lapeyrouse displays the same characteristics and according to Sticker (1979) the two are linked in Lapeyrouse. These younger faults are thought to represent the typical basinward advancement of major growth faulting with time and continued facies progradation.

Interestingly, some faults in the study area other than fault "A" carry an exceptional amount of throw far into the shallow stratigraphic section. Other time-equivalent faulting associated with these faults, however, does not. These faults which persist as described do so despite the cessation, or apparent cessstion of structural movement that is tied to their earlier activity. The extension of these faults into shallower section is well displayed on the Amoco seismic line by faults "C" and "F".

In certain areas, some renewed thickening of section across these extended faults is just noticeable before leaving the stratigraphic interval studied. For example, on both north-south cross sections A-A' and B-B' it is evident that stratigraphic thickening across fault "C" had stopped around the end of _Bigenerina_ "2" deposition. Then, very shortly afterward, it resumes with section becoming slightly thickened again through the deposition of the _Textularia_ "L" zone, and beyond. Rollover is also seen again at the _Textularia_ "L" horizon along fault "C" at Lirette and along fault "F" at

Chauvin. Apparently, these extensions of faulting into the shallower subsurface and renewed periods of thickening are the result of reactivation of particular fault zones.

Additionally, certain faults such as fault "C-n1" at Lirette and fault "F-3" at Montegut show little or no thickening at depths where other faults grew; moreover, these faults dip at slightly different angles than do other faults. Possibly the faults were created during these later structural movements as bifurcations from faults that were being reactivated, namely faults "C" and "F".

The recognition of similar early and late stage movement timing on subregional faults "C" and "F" coupled with the observation that the two are structurally linked in western Lake Boudreaux suggests that the faults are probably just large bifurcations of a master regional fault found in western Lake Boudreaux (see plate 3).

The reactivation of faults "C" and "F" may have been tied to the formation of the new faults "A" and "B" along the southern border of the mapping area. The basinward advance of younger growth faulting established new faulting ("A" and "B") in the study area proper. To the west, however, this new episode of downwarping preferred to follow the prominent zone of weakness provided by the regional master fault creating superimposed phases of fault activity. Most of this renewed movement on the regional fault was suddenly diverted from it at western Lake Boudreaux by the simultaneously forming new bifurcation, fault "B". Additionally, fault "A", which was linked to fault "B" at Lapeyrouse, developed at the same time and all formed a new large regional fault system.

Not all of the renewed movement on the master fault was carried along fault "B", however. Some was apparently perpetuated along the older bifurcations of the master fault (faults "C" and "F") resulting in the observed second growth phase of these older faults and causing their extension into the younger sedimentary section. Two-stage fault activity in this vicinity has also been suggested by Thorsen, 1963, in his study of the ages of growth faulting in southeastern Louisiana. Fault "K", although extending high into the section also, seems to show a slow-dying trend and no reactivation. It is probably significant in this regard that fault "K" does not link in with the master fault to the south.

Some late moving positive features may be associated with the late faulting. For instance, at Lirette, doming due to rollover undoubtedly occurred along fault "C" during its early stages of movement. This activity had ceased, though, by the deposition of the 11,500 foot marker, the deepest mapping horizon. Yet, there is evidence of strong structural uplift in section 32 in the form of a horst-like fault block and some fairly steep dips. At the upper mapping horizon, substantial uplift is still centered in section 32 and, despite the presence of the larger southern dome at greater depths in the southern areas of Lirette, the northern structure is dominant at the shallower Textularia "L" mapping horizon. Furthermore, there appears to be no structural thinning observable on the B-B' cross section over the northern structure prior to the end of Textularia "L" deposition. Thus, it seems that strong, late movements may have also formed further uplift at the Textularia "L" mapping horizon at northern Lirette despite cessation of earlier structural movement there by the end of Bigenerina "2" deposition.

In rapid summary of structural activity in the study area, development of structure and stratigraphic section began initially across north-bounding fault "K" during late Cristellaria "I" deposition at the latest. Most structural uplifts including the Lirette-South Chauvin anticline and younger growth faulting had begun during the deposition of the Textularia "W" zone and had ceased by mid to late Bigenerina "2" deposition. Unconformity "A" was produced at this time on at least a subregional basis and helped to terminate most remaining structural activity. Growth faulting began then to the south along faults "A" and "B" no later than mid to late Bigenerina "2" deposition and continued until after the end of Discorbis "12" deposition.

Reactivation of some faults and minor renewal of structural growth in some areas began about the end of Bigenerina

"2" deposition. The massive fluvio-deltaic sands of the Miocene deltas were deposited subsequently in most areas and prevailed over all of the study area by the end of Textularia "L" deposition.

The development of structure and stratigraphy in the study area is diagrammatically represented in relation to the formation of other regional features such as the Houma Embayment and Terrebonne Trough in figure 10.

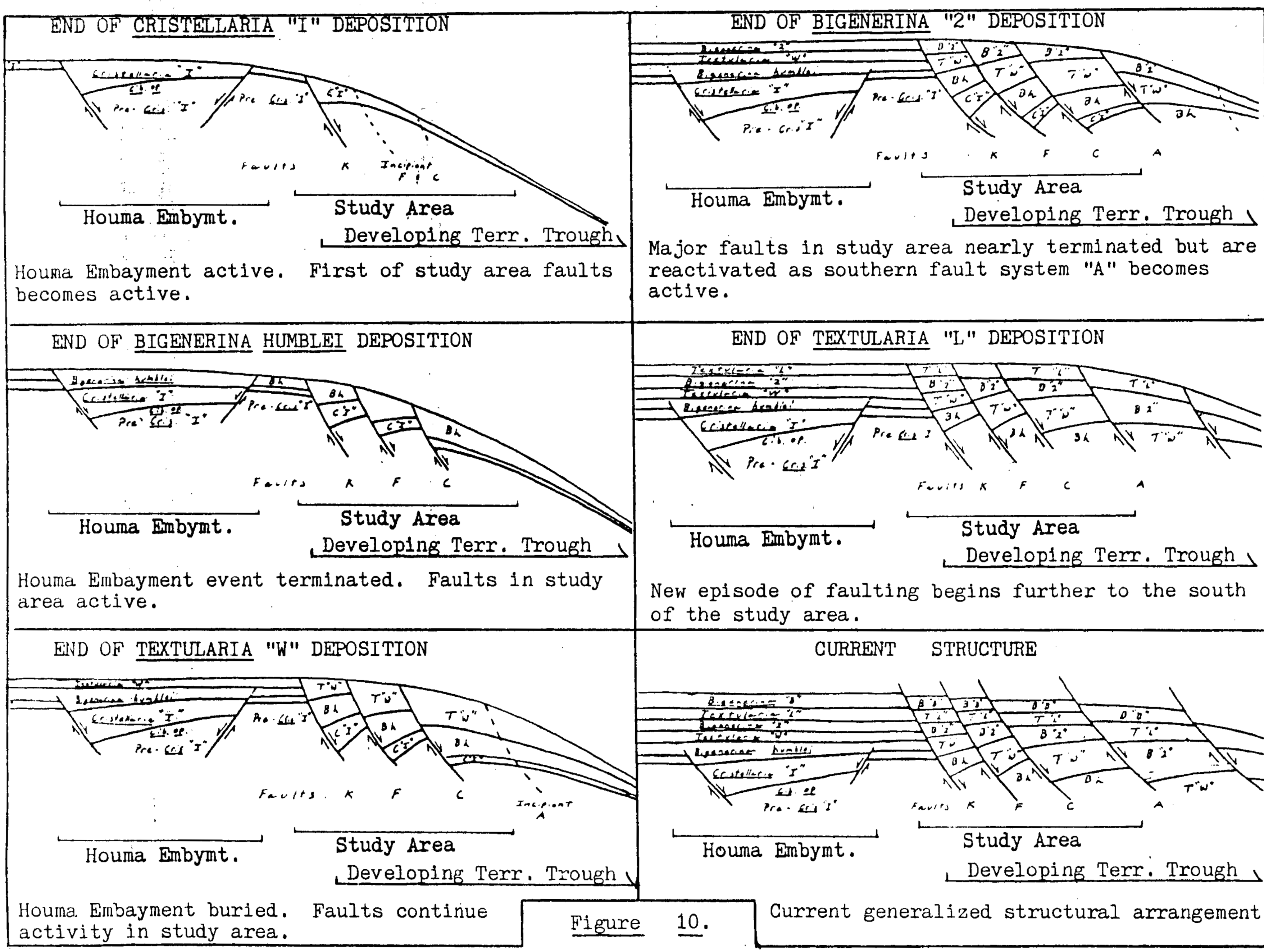

END OF CRISTELLARIA "I" DEPOSITION
Houma Embymt.
Study Area
Developing Terr. Trough
Houma Embayment active. First of study area faults becomes active.
END OF BIGENERINA "2" DEPOSITION
Houma Embymt.
Study Area
Developing Terr. Trough
Major faults in study area nearly terminated but are reactivated as southern fault system "A" becomes active.
END OF BIGENERINA HUMBLEI DEPOSITION
Houma Embymt.
Study Area
Developing Terr. Trough
Houma Embayment event terminated. Faults in study area active.
END OF TEXTULARIA "L" DEPOSITION
Houma Embymt.
Study Area
Developing Terr. Trough
New episode of faulting begins further to the south of the study area.
END OF TEXTULARIA "W" DEPOSITION
Houma Embymt.
Study Area
Developing Terr. Trough
Houma Embayment buried. Faults continue activity in study area.
CURRENT STRUCTURE
Houma Embymt.
Study Area
Developing Terr. Trough
Current generalized structural arrangement.

Figure 10.

SEDIMENTATION PATTERNS IN THE STUDY AREA

Estimation of the volume and distribution of any type of reservoir sand from well logs is commonly accomplished by determining the type and origin of the deposit through isopach mapping and the use of well log signatures and paleoenvironmental information. From these interpretations some predictions may be made concerning the places where the reservoir might be volumetrically prospective.

In this study, our interest is focused on overpressured geothermal water reservoirs. Drilling operations in any area are often ceased at the depth where overpressured sediments are encountered because of the higher drilling risks and costs which are incurred beyond this point. This is especially true where no known petroliferous targets exist below the pressure horizon. Where possibly prospective overpressured water reservoirs exist in the study area, this was the case. The result is that normally-pressured sand bodies were frequently penetrated but the fairly closely underlying overpressured sands were not. Consequently, most prospects in the study area lie below the well control required to make direct estimates of their volume and distribution.

It is possible to make some indirect predictions of these reservoir properties using slightly different means, however. Over most of the area studied, structural activity is known to have persisted until the time of formation of unconformity "A". Although somewhat lessened toward the end of pre-unconformity "A" time, the effect of structure on sedimentation remained similar throughout pre-unconformity "A" time. Thus, the sedimentation and sand distribution patterns of younger pre-unconformity "A" sediments should, in a general way, mimic the sedimentation patterns of older pre-unconformity "A" sediments.

In the areas where possible prospects exist, younger pre-unconformity "A" sediments are normally pressured and have been penetrated frequently. Below these lie the older, overpressured sand bodies which may be prospective but which were infrequently penetrated. According to the logic described above, several normally pressured pre-unconformity "A" sands were studied in order to get a "feel" for the pre-unconformity sand-depositional patterns. Later, in another section, some predictions concerning the volumes and distributions of prospective reservoirs are made based on the patterns of these younger deposits.

The sands which were studied in the northern part of the mapping area are best displayed on the stratigraphic cross section D-D' (plate 8). In ascending order, they are as follows: the upper _Textularia_ "W" sand, the _Textularia_ "W-4" sand, Montegut "B" sand, and the Montegut "A" sand.

The oldest sand body studied is the upper *Textularia* "W" sand, deposited in late *Textularia* "W" time. Water depth in the area during the time was around 600 feet according to paleoecologic zonation. By the generally accepted scheme shown in figure 5, the zonation implies that the sand was deposited in the vicinity of the shelf break.

In places, the sand exceeds 240 feet in thickness; a rather high volume of sand to be found in an environment which is supposed to be sand-poor. Sands which reach this area are usually carried by turbidity or density flows enroute to the base of the slope. Somehow, though, sands have become deposited here as well.

From the isopach map (plate 9) and the deep structure map (plate 3) it is apparent that the upper *Textularia* "W" sand in general is thickened in structurally low areas and thinned over structural highs. These highs and lows were actively forming during *Textularia* "W" time, as previously discussed. Bouma, et al. (1978), Martin and Bouma (1978), and Ewing and Antoine (1966) have recognized the occurrence of intraslope basins caused by diapiric structures and suggested that these areas could be sites of sand deposition. Additionally, active growth faults may form scarps on the sea floor and reduce the dip of the slope for short distances, creating small depositional sites. Perhaps in similar fashion, structural activity in the study area was forming small depositional sites near the shelf break during late Textularia "W" time.

Almost immediately above the upper Textularia "W" sand lies the Textularia "W-4" sand (plate 10). The deposit is much thinner, is less widespread, and appears to have a more distinct morphology than the upper Textularia "W" sand. Deposited in similar water depths and during the same interval of geologic time, the Textularia "W-4" sand generally responded similarly to sea-floor topography. All of this topography was not structurally produced, however. While generally thickened into the Montegut structural low, the sand has thick areas that lie slightly to the north and south of the thick axis of the sand below. Greater compaction of the underlying deposit occurred where it consists of fewer net feet of sand and more of shale. Conversely, areas of the deposit which have more sand compact less and might be expected to remain as slight highs on the sea floor, controlling the deposition of the sediments deposited directly over them.

About 400 feet stratigraphically above the Textularia "W-4" sand is the Montegut "B" sand which was deposited during early Bigenerina "2" time (plate 11). This sand is spread over much of the area in a thin sheet. In the area of Montegut field, however, it develops linear trends which thicken rapidly to axes consisting of up to 180 feet of sand.

Possibly these represent former gullies or channels in the shales of the outermost shelf similar to those discussed by Coleman and Prior (1980, pp. 98-112). Through these conduits density flows travelled on their way to deeper water, scouring the shales more deeply as they passed. The channels then became occupied by topography-filling sheet sands which were subsequently spread over the area. The eastern side of stratigraphic cross section D-D' displays these sand bodies well.

Just above the previous deposit lies the Montegut "A" sand (plate 12). Again the sand-depositional pattern appears controlled by structurally-produced sea-floor topography. Linear thick trends are also formed in this sand, suggesting that its development may have been similar in some ways to that of the "B" sand below it.

Two sand deposits south of fault "C" were also studied. The oldest of these, the 11,500 foot sand, was deposited approximately simultaneously with the lower Bigenerina "2" zone, Montegut "B" and "A" sands. The 11,500 foot sand marker just above the Montegut "A" sand can be correlated across fault "C", thus the deposit seems at least correlative with the "A" sand. The 11,500 foot sand is greatly expanded over its upthrown equivalents, however, and cannot be designated as the sole downthrown, equivalent to the "A" sand or "A" and "B" sands with any certainty.

Though the 11,500 foot sand is spread over the entire study area south of fault "C", relatively few wells completely penetrate the deposit and hence, no isopach map of it was prepared. Generally, though, the sand is observed to thicken greatly over fault "C". Additionally, at Lirette, the deposit is thick but contains many stringers of shale. To the west, at Lake Boudreaux, the unit thins and becomes consolidated into two vertically separated, less shaley units. The lack of control on this sand is not a serious problem, however, because, as discussed in a later section, the deposits which lie in the overpressured zone below it are not considered prospective geopressured/geothermal reservoirs.

A second sand body studied in the southern portion of the mapping area is the upper zone 3, late Bigenerina "2" 9,600 foot sand. The deposit is not considered for its relation to possible overpressured reservoirs but is interesting from a purely geologic viewpoint. The isopach of this sand (plate 13) shows that the sand thickness maxima occur in relation to fault "C" and its bifurcations, which remained active until the deposition of this sand was complete.

The sand is distributed differently in areas other than along fault "C". At Lirette, for instance, the sand is observed to be a shelfal sheet-like sand which thins slightly over structurally high areas. In Lake Boudreaux, however, the sand is greatly developed, reaching thicknesses in excess of 430 net feet. Much of the thickness is due to sand deposition on the downthrown side of fault "C" but thick, elongated tongues of sand extend perpendicularly away from the fault. Perhaps this is due to the action of shelf currents or large scale tidal effects which spread the sand accumulation to the south.

From the study of these and other sand bodies throughout the section, one observation may be made in general concerning sedimentation in the study area; the sedimentary section south of fault "K" is very sandy. Much of this sand was deposited over broad areas in water depths as deep as lower zone 4. In the study area, the volume of sand observed to have reached environments of the outer shelf, slope, and beyond is exceptional.

Water depths in the area shallow continuously throughout this part of Miocene time, according to Paleo Data depth zonations. Furthermore, fairly high volumes of sand are present in the section from the close of *Bigenerina humblei* time. Additionally, Vail et al. (1977) suggest from their charts of global sea-level changes that sea level had been at relative highstand during the deposition of much of the section with which this study is concerned. Therefore, it seems unlikely that these sands are reworked from sediments deposited on the shelf during periods of lower sea level.

Alternatively, the shelf during this portion of the Miocene may have been very narrow so that a copious sand source was close to the shelf edge. Dunlap (1970) has suggested that the shelf during the Miocene was very narrow and that the topography of it and of the continental slope was quite rugged. The present study seems to agree with these interpretations.

GEOPRESSURE

Geopressured rocks are those that contain abnormally high pore fluid pressures. In normally-pressured strata, pore fluids (water, oil, gas) are free to move and can adjust to changes in the volume or arrangement of the rocks in which they are contained. The matrix materials of the rocks themselves support the overlying rock material while the contained fluids support only themselves. The pressure exerted on any part of the rock at a given depth due to the weight of the overlying rock column is known as the lithostatic pressure. The rate of increase of lithostatic pressure with depth is the lithostatic pressure gradient. For rocks of the Gulf Coast whose average density is 2.31 g/cc, this gradient is .535 psi per foot of depth (Fertl, 1976).

Just as the pressure on an object increases with the increasing depth of any body of water, so too does the pressure due to fluids contained in the communicating pores of normally-pressured rocks. This pressure, caused by the unit weight and vertical height of a column of this fluid from the depth in question to the surface, is known as the hydrostatic pressure. The rate at which this pressure increases with depth is the hydrostatic pressure gradient. This gradient, and thus the pressure at a given depth, is affected by the concentration of dissolved solids and fluids in the column as well as by the temperature gradients which also exist (Fertl, 1976). In the normally-pressured sediments of the Gulf Coast embankment, the hydrostatic pressure gradient averages .465 psi per foot of depth based on an average salinity of 80,000 ppm total dissolved solids at 25°C (77°F).

The combined weights of the rock and contained fluids give rise to the total overburden pressure at any given depth. The rate of increase in total overburden pressure with depth is the overburden gradient. For the rocks of the Gulf Coast Tertiary section, this gradient averages 1.0 psi per foot of depth (Fertl, 1976).

Abnormally-pressured strata have fluid pressure gradients in excess of .465 psi/ft. Provided that there were no fluid leakages from the overpressured strata, the fluid pressure gradient in the abnormally-pressured section could theoretically reach a maximum of 1.0 psi/ft., at which point the fluids would be totally supporting the overburden. In the Gulf Coast fluid pressure gradients as high as 0.8 psi/ft. in geopressured strata are uncommon however, due to the imperfection of the various pressure-sealing mechanisms (Fertl, 1976).

The causes for this geopressure are many, but in all cases, the effect is the same; the pore-fluid pressures partially support the weight of the overlying rocks. In other words, the lithostatic pressure at the depth in question is less than normal whereas the fluid pressures are greater than normal. This indicates that these fluids are part of a closed or at least greatly restricted system and are not free to move and flow to a position with lower potential. If this were not the case, the abnormally high pressures would be dissipated.

The coexistence of normally- and abnormally-pressured strata, therefore, requires that the highly-pressured strata be isolated from the permeable, normally-pressured systems by some permeability/pressure barrier (geopressure seal) (Fertl, 1976). Of the many mechanisms which are thought to act as geopressure seals, those most frequently cited in Gulf Coast examples are shales of more than a hundred feet or so in thickness (Dickenson, 1953; Rubey and Hubbert, 1959; Dickey, et al., 1968; Harkins and Baugher, 1969), secondary pore-filling cements (Jones, 1969; Kurth, 1981); and osmotic pressure phenomena (Jones, 1967).

In the Miocene of south Louisiana, seals to geopressured zones are most frequently the thick shale type. The seal forms along the boundary between normally-pressured permeable strata and thick, undercompacted shale. Where these two types of deposits are found next to each other, the first hundred to several hundred feet of shale closest to the permeable strata (or stratum) is allowed to compact and expel its pore waters. Additionally, those shales which are closest to the permeable strata compact most easily first. As compaction proceeds vertical and lateral migration of fluids from the shale becomes increasingly restricted. Eventually, after a certain thickness of shale has become compacted, expulsion of shale pore fluids into outside permeable strata is greatly restricted and the seal is formed. Thus, if no other permeable pathways to normally-pressured permeable strata exist, the remaining majority of the shale deposit will remain porous and undercompacted, allowing fluid pressure to build.

The shale seals just discussed are most frequently envisaged as the pressure cap at the top of the geopressured zone. Undoubtedly, though, this type of seal also forms where highly-pressured, undercompacted shales have been faulted into direct contact with normally-pressured, permeable strata (figure 11). Where this occurs, the porous shales expel their pore waters into the adjacent permeable, normally-pressured strata and compact. A shale seal similar to that previously described is thereby formed along the fault between the permeable, normally-pressured strata and the porous, abnormally-pressured strata. This sort of seal must exist along the fault in this situation because the pressure differential between the unequally-pressured rocks across the fault boundary can easily exceed 3,000 psi.

Formation of Geopressures

Geopressures in the Miocene sediments of the Gulf Coast

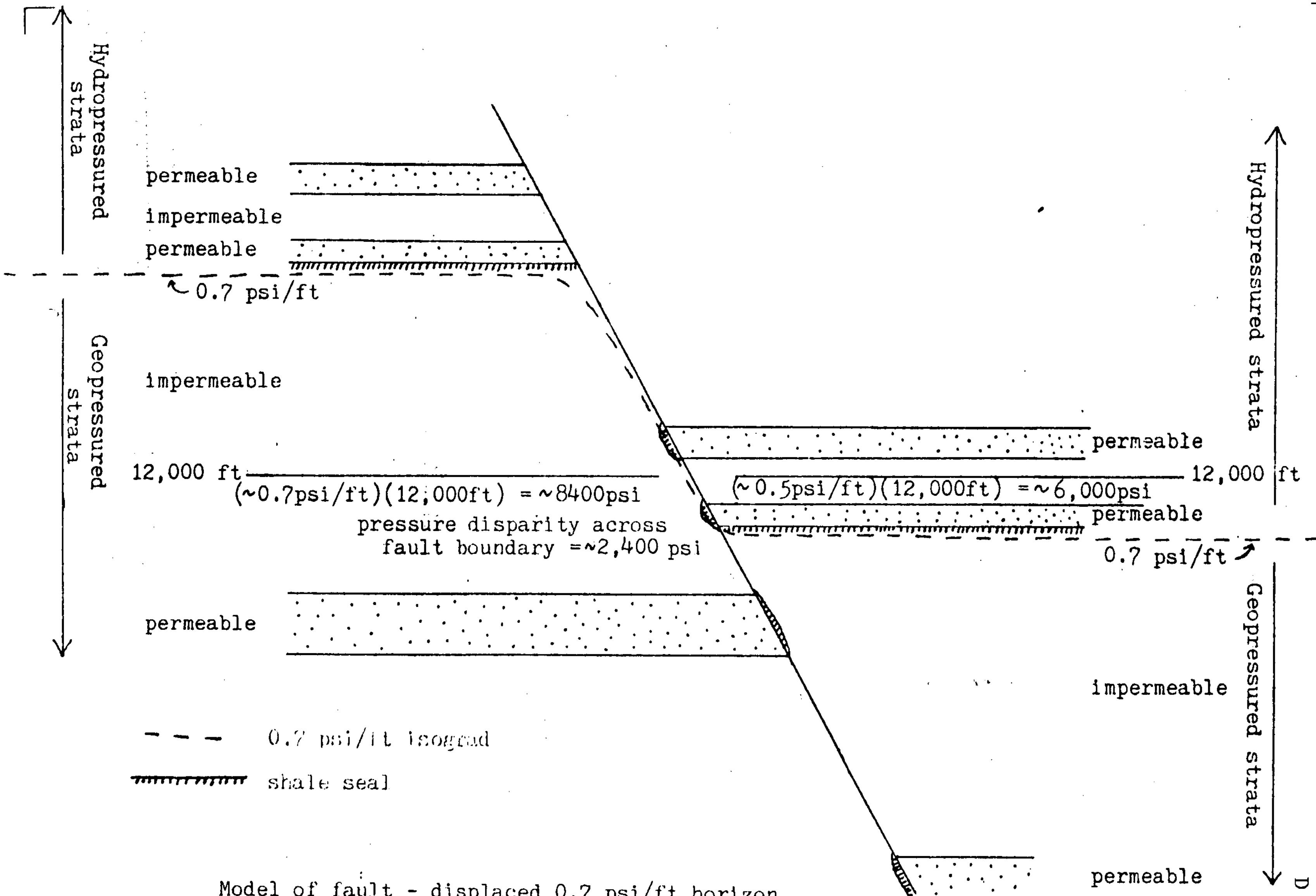


Figure 11. Model of fault - displaced 0.7 psi/ft horizon. Note the juxtaposition of abnormally and normally pressured strata which gives rise to large pressure contrast across fault boundary. Overpressured shales must be practically impermeable despite high porosity.

have arisen due to sedimentary loading of incompletely compacted thick shale sequences and encased sand bodies. These original pressures have been supplemented and maintained by clay mineral diagenesis, aquathermal pressuring and, possibly, osmotic phenomena.

The primery formation of high fluid pressures is heavily dependent upon the lack of compaction of a very thick shale sequence and encased sand bodies. For geopressure to occur in this fashion, a seal over the thick shales must be formed, as previously discussed, and alternate fluid escape pathways must not exist to any great degree. The primary escape routes for fluids which are removed from shales during compaction are provided by permeable sand bodies. In the hydropressured section, sands are usually abundant and widely distributed. Through faulting or by stratigraphic arrangement, each of these sands is in communication with others, theoretically, all the way to the surface. Any fluids which have been expelled from shales and sands in this part of the sedimentary section have been redistributed within the aquifer system and fluid pressures in the system have remained hydrostatic as loading and compaction proceeded.

Conversely, in the geopressured section, sands are less abundant and tend to be of low lateral continuity, frequently remaining discrete and restricted from communication with other sand bodies. Sands in this regime, therefore, have not provided avenues of escape for waters contained in the thick shales around them and, as loading has proceeded, pore waters have not been removed from the sediments by compaction except at the shale seals. Consequently, most of the shale has remained porous but impermeable and the fluids contained in the strata have been forced to bear some of the load which ordinarily would have compacted the sediments. As the load increased, so did the fluid pressure in the section.

From the preceding discussion it may be apparent that the occurrence of geopressure is governed strongly by sedimentation and stratigraphy. Geopressure in the Miocene of the Gulf Coast is found associated with sediments of low sand/shale ratio and areally restricted sand distribution patterns. Harkins and Baugher (1969), for instance, have recognized that the top of the abnormally-pressured zone in the Gulf Coast is found almost exclusively in conjunction with sediments containing less than 35 percent sand.

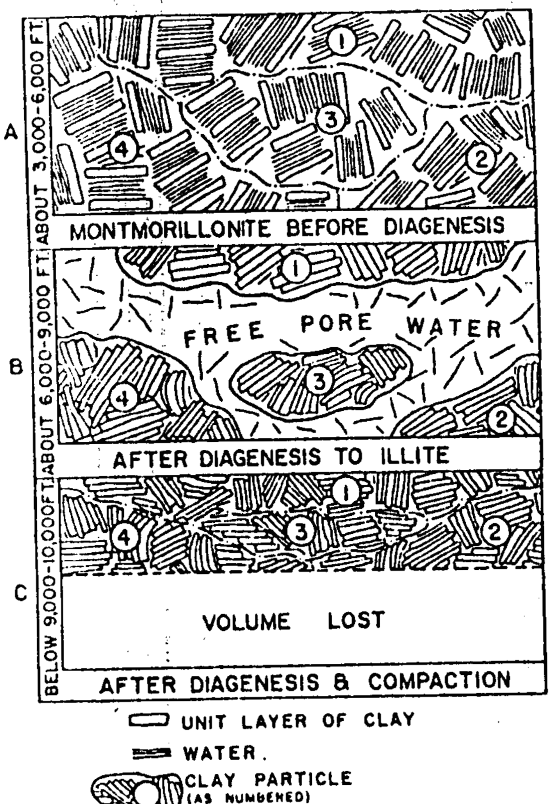
Sand/shale ratios and depositional distribution patterns are, in turn, determined by the depositional environment and, therefore, the eventual formation of geopressure is also dependent upon depositional environment. Sedimentation in abyss, slope, and outermost shelf environments is characterized by low overall sand percentages, areally restricted sand distribution patterns, and thick shale accumulations. After burial the arrangement and distribution of sediments of these environments are conducive to the formation of high fluid pressures as the weight of the overburden increases.

The stratigraphic position of the hydropressured section is also environmentally dependent. The high overall sand percentages and good lateral continuity of sand bodies in this section are typical of sedimentation patterns of inner shelf and nearshore depositional environments. Because of this arrangement and distribution of permeable pathways in this part of the sedimentary section, geopressures are not allowed to develop as compaction proceeds.

The transition zone between the hydropressured and geopressured zones will occur most frequently just below one of the older of these shallower water sands of the hydropressured section. In this zone, the uppermost portion of the sealing shale unit has been compacted because fluids have been allowed to be squeezed from it into the first sand of good lateral continuity which is in communication with the overlying section.

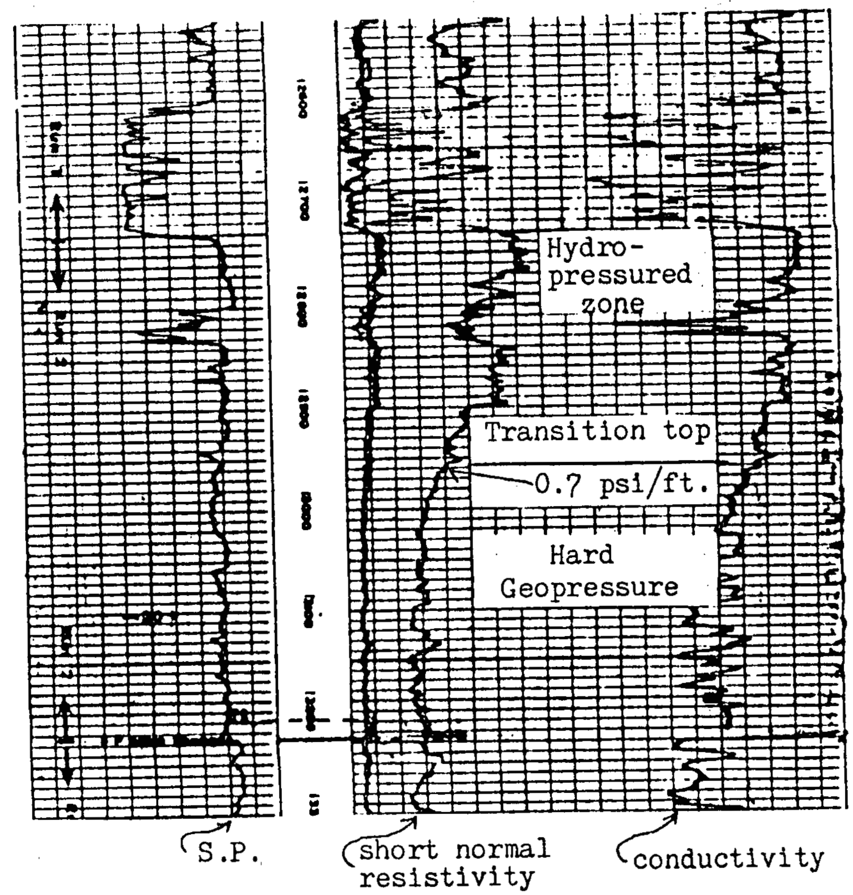
The formation of high fluid pressures from loading of incompletely compacted sediments is, however, a one-time event. Slowly, fluids are being released from the geopressured section and one would expect that high fluid pressures might be reduced through time. Many geopressured sections in the Gulf Coast which are greater than Miocene in age are known to be under the same very high pressures, however. Therefore, other sources of pressure apparently exist which supplement and maintain the originally formed high pressures of the geopressured zone.

In this respect, clay mineral diagenesis is probably extremely important because the conversion of montmorillonite to illite releases very significant quantities of water. Gulf Coast shales contain 50 to 80 percent montmorillonite at initial deposition (Jones, 1969). If sufficient pathways for fluid escape exist, most water removed by mechanical compaction (first stage dehydration) occurs in the first few thousand feet of burial (Burst, 1969). However, large quantities of oriented water (up to 30 percent of the rock by volume) remain adsorbed to basal surfaces of unit layers of montmorillonite. This water occurs stacked at least four monomolecular layers thick between unit layers of the clay (Powers, 1967) (see figure 12). This water cannot be squeezed out by overburden pressure but may be removed by a thermal dehydration of the montmorillonite lattice which occurs at a critical temperature of 200°F-230°F. Powers (1967) argues alternatively that the water might be desorbed during the exchange of potassium for sodium in the conversion of montmorillonite to illite. Here the electrostatic attraction forces associated with this exchange exceed the repulsive forces between unit layers of clay, collapsing the expanded clays and squeezing out adsorbed water layers.



. .—Effect of clay diagenesis on compaction of wate. from mudrocks. It is assumed that same number of particles, "books," and unit layers of clay occur in each compaction stage represented. A.—no effective porosity or permeability; virtually all water is "bound" water. B.—most "bound" water becomes free water; effective porosity and permeability thereby produced. C.—free water squeezed out; effective porosity, permeability, and original volume are greatly reduced. (Powers, 1967)

Figure 12. Release of bound water from shales.



Rapid reduction in short normal resistivity which occurs frequently upon entering the geo-pressured zone.

(Figure 13.)

Whether or not the fluid-release mechanism is thermally or chemically controlled, the quantity of fluid delivered to the pore spaces of the rocks is considerable, amounting to approximately one half of the volume of montmorillonite altered (Burst, 1969). Kerr and Barrington (1961) have recognized that the montmorillonite content of clays in the Gulf Coast basin sharply decreases in geopressured zones. The fluids released from the montmorillonites are probably in large part responsible for the maintenance, and perhaps even creation, of high fluid pressures.

An additional factor in clay mineral conversions probably contributes to the large volume of water released into pore spaces. Grim (1962) has shown that water adsorbed on clays has an abnormally high density (1.4 g/cc for fewer than seven monomolecular layers), while free waters have a normal density of 1.0 g/cc. The volume increase of water that results as it is desorbed from the clays may be as much as 40 percent. This too could add quite significantly to the pore pressures of rocks in a closed system.

Another source of pressure to closed subsurface systems is that of aquathermal pressuring. As temperature increases with depth of burial of a closed system, the expansion of pore fluids results in an increase of pressure in the system. The fluid pressure increase depends both on the depth to which the system becomes buried and the geothermal gradient after the system has become isolated (Barker, 1972).

Finally, Jones (1969) has suggested that osmotic phenomena might also add water to the geopressured section, causing a pressure increase.

Pressure Release and Movement of Geopressured Fluids

As previously discussed, any fluid movement from and through the shales of the geopressured zone into permeable hydropressured strata must be extremely low due to the presence of geopressure seals. Movement of fluids from the geopressured zone does occur in sizeable quantities under particular circumstances, however. These fluids must be escaping from permeable reservoirs, though, since movement through the shales is restricted. The flow of these fluids from a closed reservoir cannot continue at a rate higher than the rate of flow of fluids from the overpressured shales for an indefinite period of time. Eventually, in such an instance the pressure within the leaking reservoir would be relieved sufficiently to allow the conditions causing the release to become equalized and the flow would stop. Depending on the situation, this equalization may either occur when the fluid pressures have been fully released or the pressures have been lowered enough to become balanced.

Full pressure release occurs where porous, high-pressured strata are brought into communication with porous low-pressured strata in some fashion (i.e. through faulting). This release is a one-time event and formation pressures in such a situation soon reach a near static equilibrium at the lower pressure.

Where normally and abnormally pressured strata are not brought into direct communication, a partial release of pressure may occur and continue until the fluid pressures of the closed high-pressure reservoir decrease sufficiently to become balanced. This situation may occur where a fault plane is unsealed and fluids can escape up the fault plane from overpressured reservoirs. The high pressures may, in fact, help keep the fault plane escape route open until the pressures in the reservoirs are reduced enough to allow the fault to reseal.

The pressure in a closed reservoir that has become resealed may build again, however. As montmorillonite to illite conversions continue to force water into the shale pore spaces, the displaced pore waters are eventually moved through the shales and into the reservoir. The depleted reservoir is slowly repressurized until the fluid escape routes again become opened.

Fluid escape from geopressured reservoirs is therefore probably not continuous. Periodic "burping" of hot fluids from overpressured reservoirs may occur along escape avenues, such as faults, throughout geologic time, provided some replenishing source of fluid pressures exists.

LOCAL GEOPRESSURE STUDIES

To be considered as a potential energy source, abnormally pressured porous strata must at least have fluid pressure gradients equal to or in excess of 0.7 psi/ft (Westhusing, 1981). This pressure drive is required to produce the geothermal resource waters. Since this is so, a structure map was prepared for the entire study area which presents the depth from sea level to the point where 0.7 psi/ft fluid pressure gradients would be encountered. Later in this report porous reservoirs below this horizon are examined for their resource potential.

Commonly, the depth at which this high-fluid pressure gradient occurs can be determined from shale resistivity values selected from the amplified short normal curve of an induction electrical log (Hottman and Johnson, 1965). Shales in the hydropressure zone exhibit normal compaction and water loss with increased depth. This water loss results in steadily increasing values for shale resistivity. Upon entering the geopressure zone, the situation becomes reversed. Abnormally pressured shales are undercompacted and contain more water causing a substantial reduction in shale-resistivity values (Hottman and Johnson, 1965). The transition can be recognized at a particular depth or over a range of depths on the electric log.

This change from hydropressured strata to strata of the hard geopressure zone occurs through a transition zone. The width of the zone is a measure of the effectiveness of the sealing mechanism. If hard geopressure is sealed by a thick shale, this transition zone is likely to be quite short. The corresponding drop in resistivity is easily recognized on the electric log (figure 13p). If, however, the seal is created across a number of shales, as may be the case where osmotic phenomena are active, the transition zone will be extensive and the corresponding drop in resistivity may be so gradual as to be virtually unrecognizable. Fortunately, the former is most frequently the case, especially in the present study area.

The depths of the occurrence of 0.7 psi/ft fluid pressure gradients in the study area were picked from induction electrical logs. The procedure used may be summarized as follows: First, the log was examined below 10,000 feet for a considerable reduction in short normal resistivity associated with a good shale break. Then, resistivity values near the base of the short normal reduction were plotted on a resistivity versus depth chart (figure 14) to provide accurate and consistent selection of the 0.7 psi/ft gradient depth. Finally, the casing points and mud weights were checked for agreement.

Plots of resistivity as a function of depth for

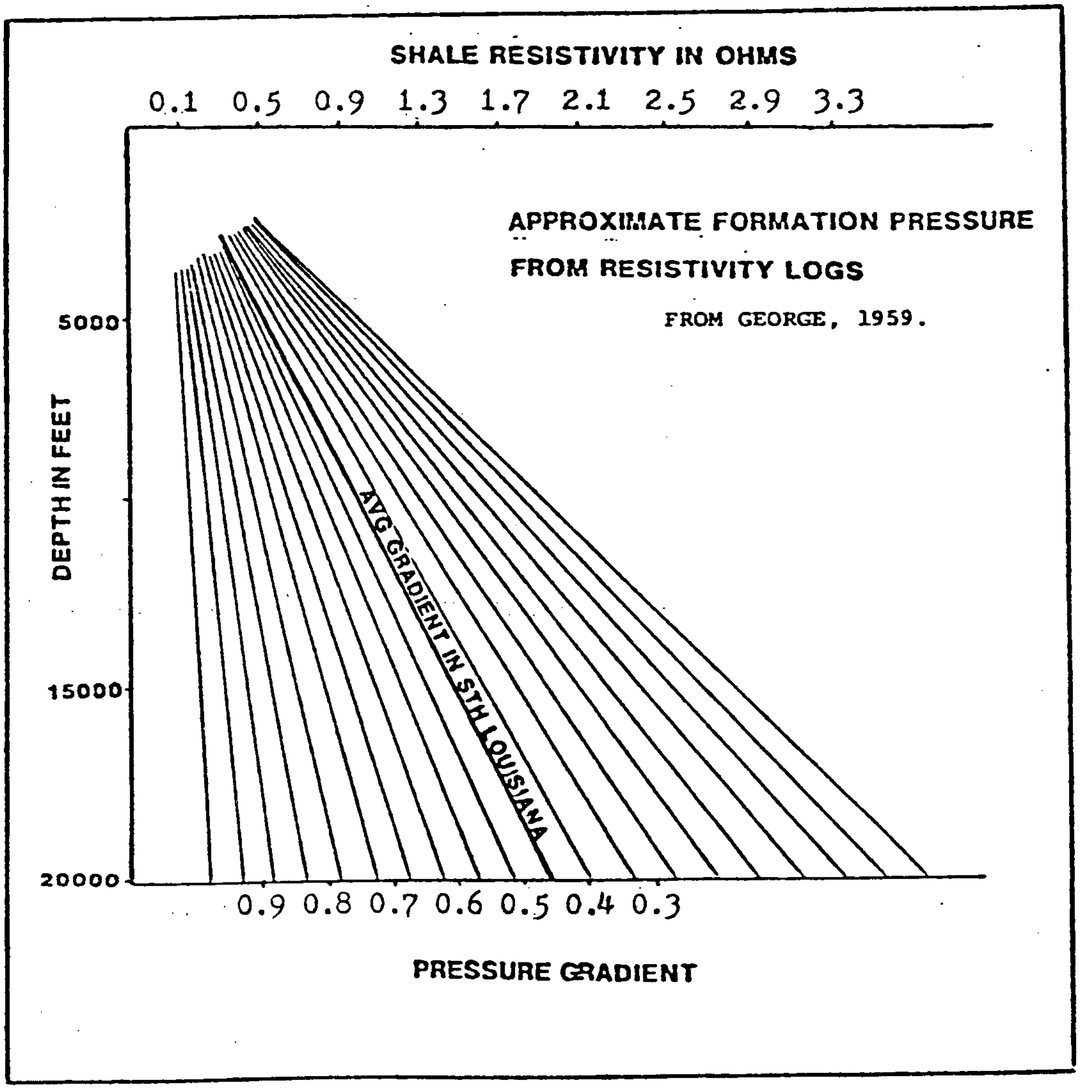
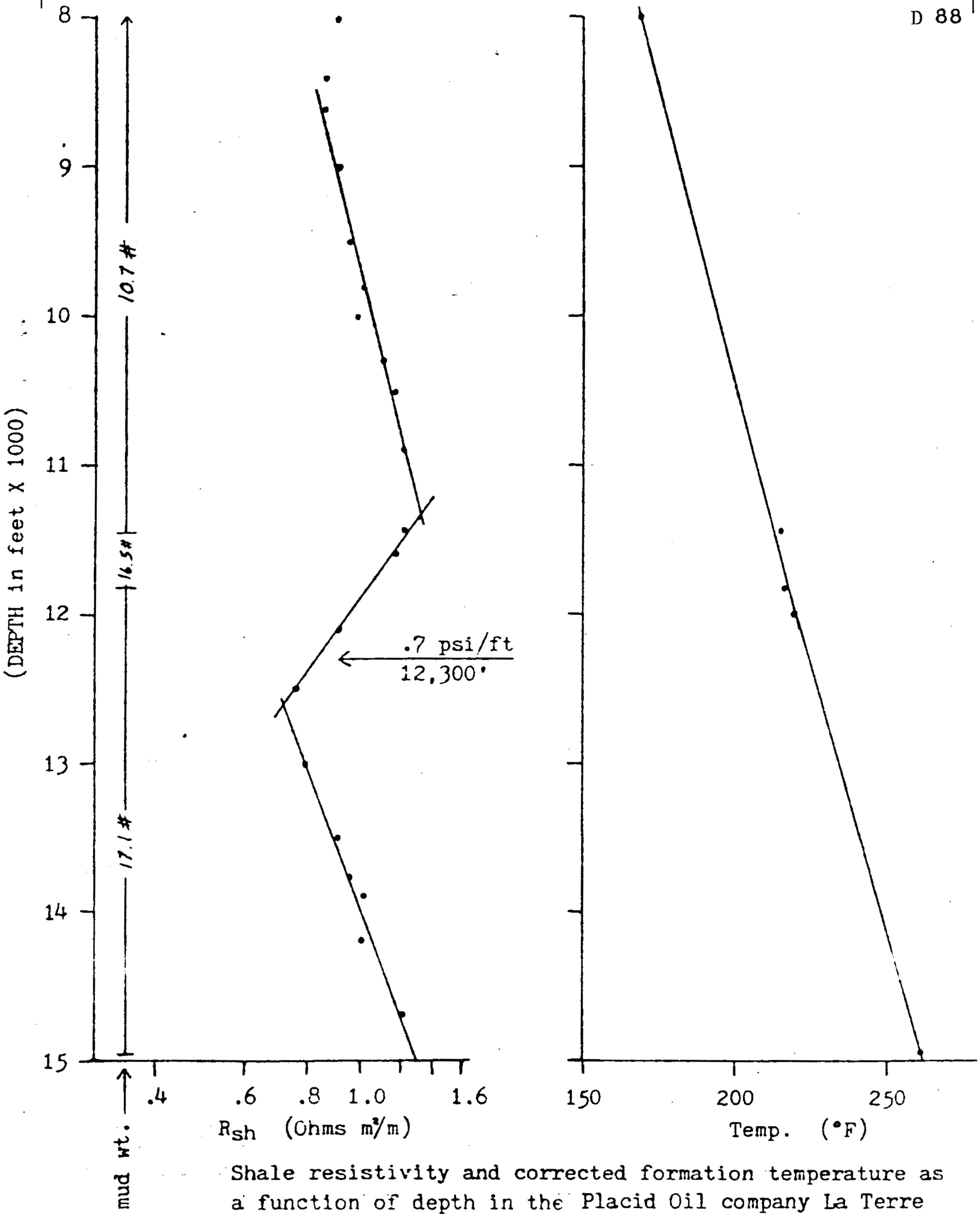


Figure 14. Resistivity vs. Depth chart for estimation of fluid pressure gradients.

representative wells in all major fault blocks are shown in figures 15 through 20. Sharp reductions of resistivity shown on these graphs are found to correspond precisely with geopressure picks selected using the previously described method.

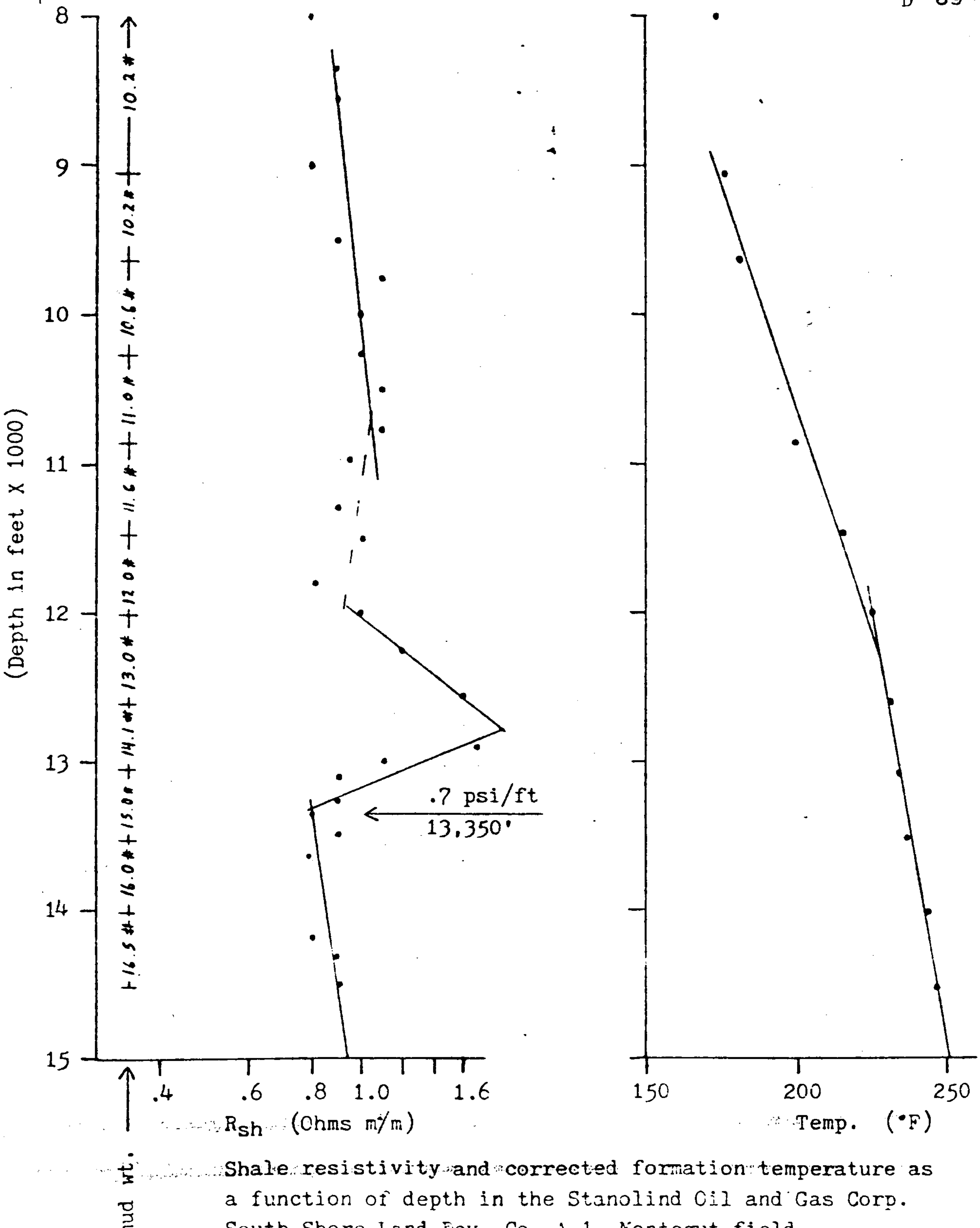
For a sedimentary unit, such as a shale or series of shales, to be an effective seal to geopressures, it must be laterally continuous. Since this is so, changes in the depth to the sealing geologic unit will also be represented by the same variation in the depth to hard geopressure, except in unusual situations. In other words, the map constructed on the top of hard geopressure is itself a geologic structure map showing the subsurface configuration of the horizon at which geopressure is sealed. Therefore, it should resemble a structural map contoured on a closely under or overlying surface. Most changes in the subsurface elevation of a geopressured horizon will therefore be gradual, following normal structure. Where faults are encountered in the subsurface, though, changes in the geopressure horizon will be abrupt, and be manifested by tight contours.

The geopressured horizons in the study area are illustrated in plate 14. There is considerable structural relief on this surface. The shallowest geopressured horizons are encountered at Bayou Chauvin field (T-18-S, R-18-E) where abnormal pressures may be found at about 11,000 feet. Geopressure south of Lake Boudreaux, on the other hand, is depressed



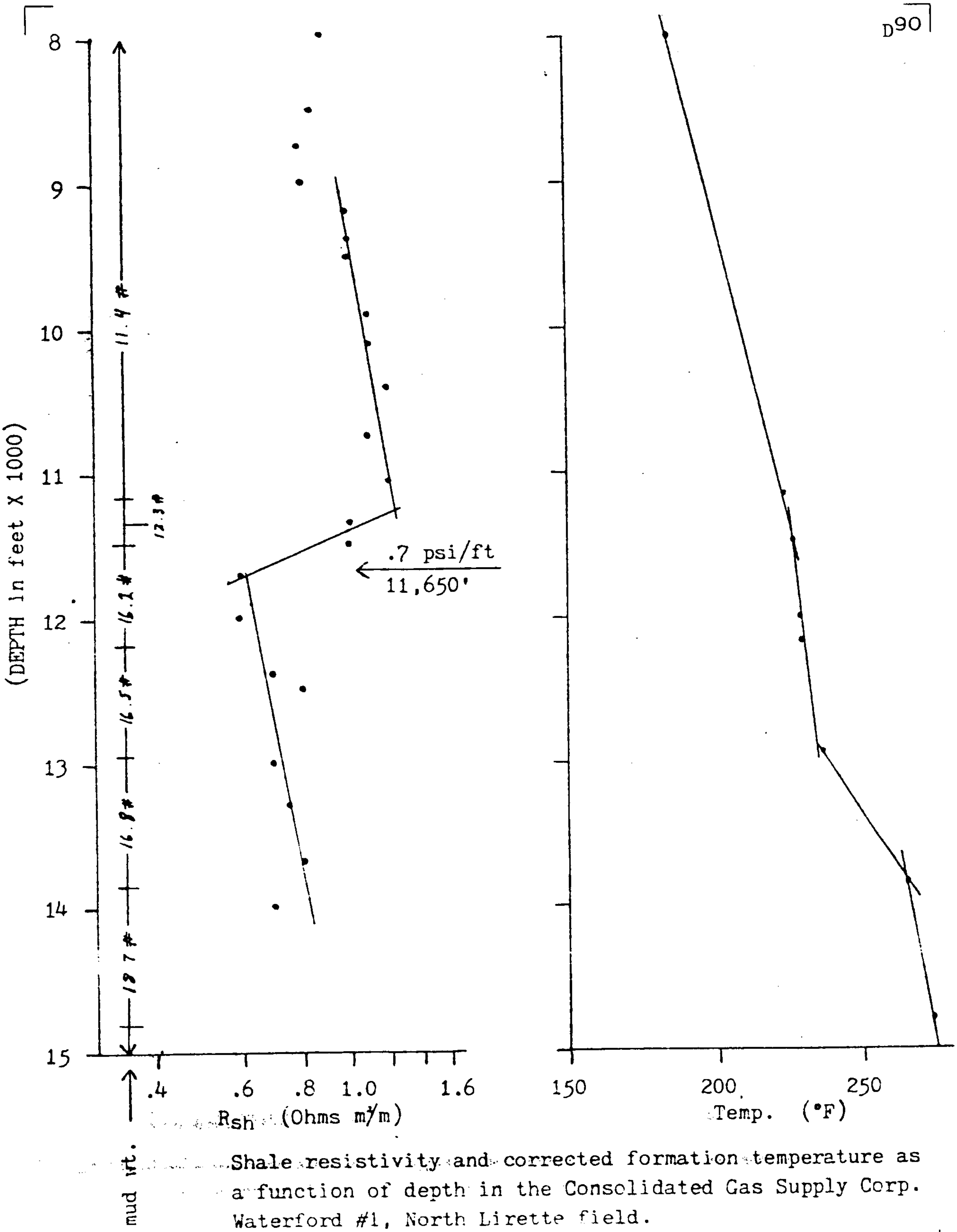
Shale resistivity and corrected formation temperature as a function of depth in the Placid Oil company La Terre Co. D-4, South Chauvin field.

(Figure 15.)



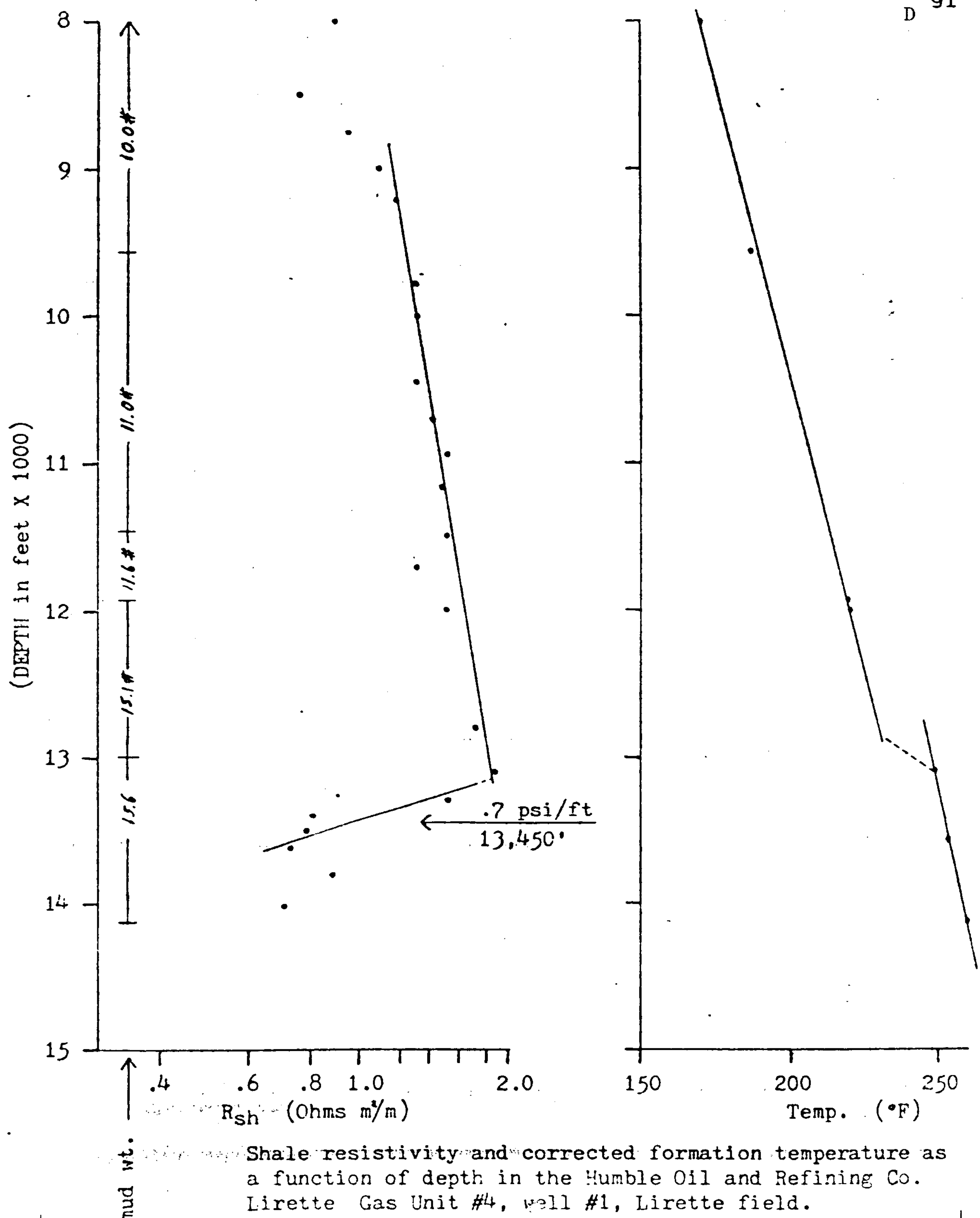
Shale resistivity and corrected formation temperature as a function of depth in the Stanolind Oil and Gas Corp. South Shore Land Dev. Co. A-1, Montegut field.

(Figure 16.)



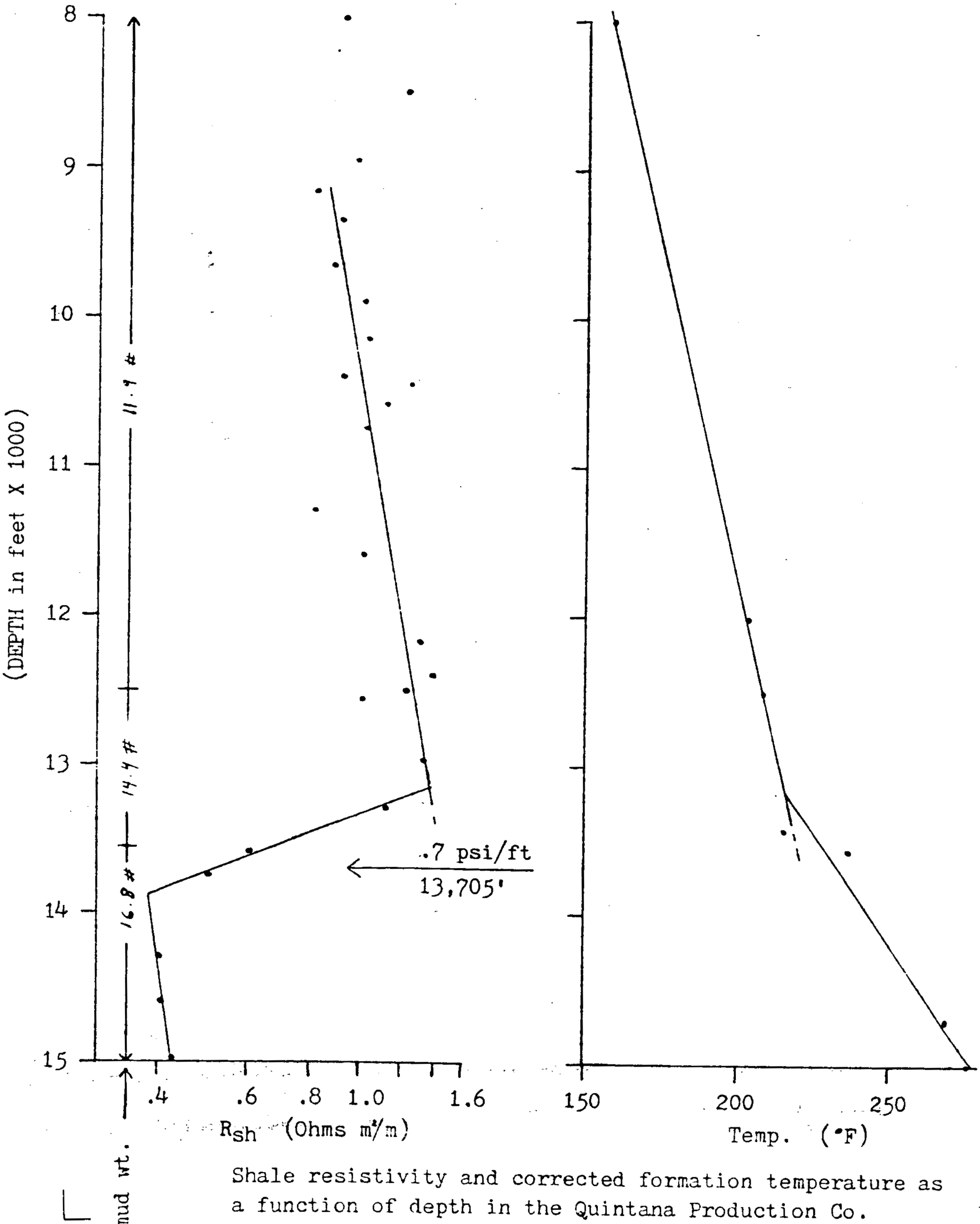
Shale resistivity and corrected formation temperature as a function of depth in the Consolidated Gas Supply Corp. Waterford #1, North Lirette field.

(Figure 17.)



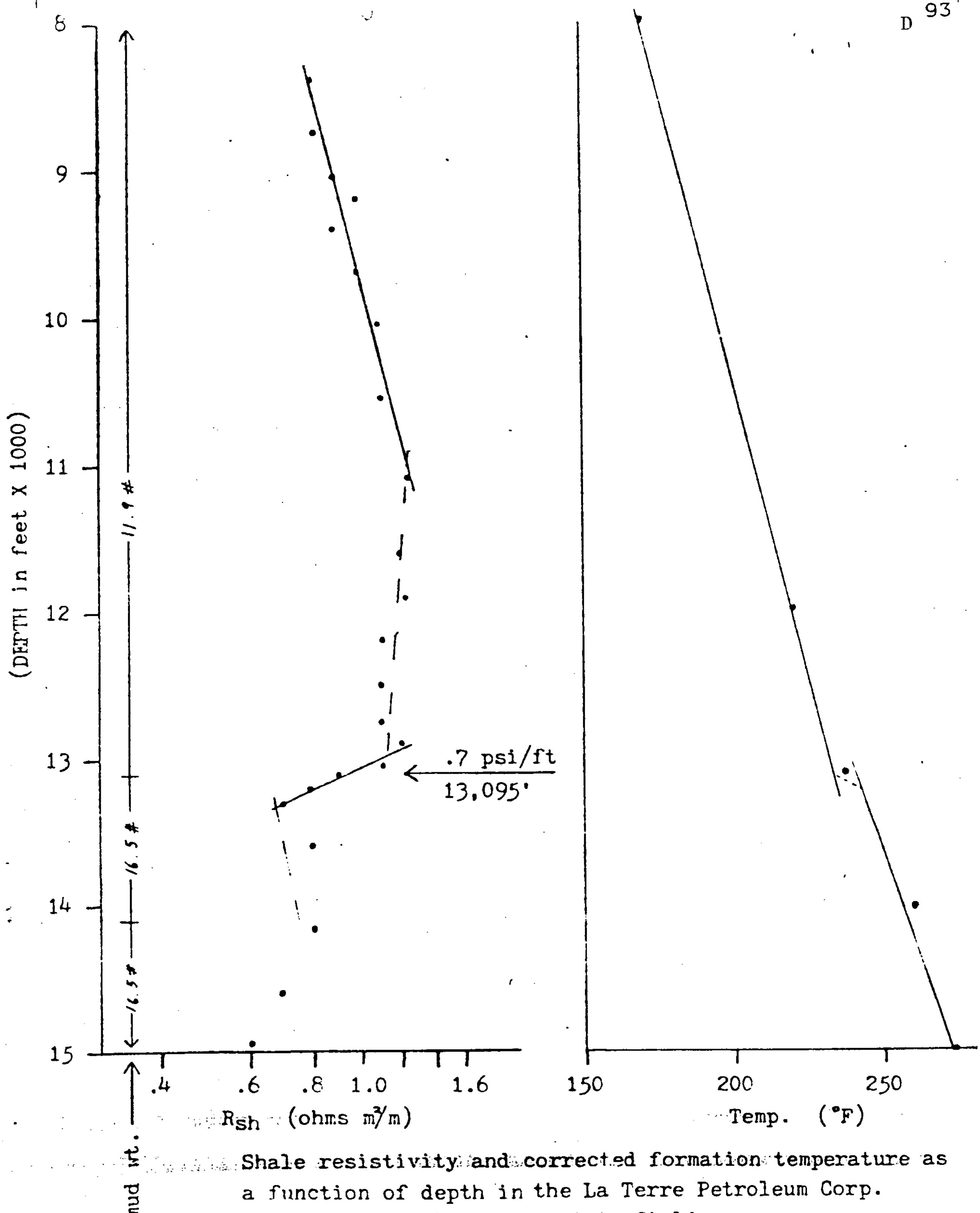
Shale resistivity and corrected formation temperature as a function of depth in the Humble Oil and Refining Co. Lirette Gas Unit #4, well #1, Lirette field.

(Figure 18.)



Shale resistivity and corrected formation temperature as a function of depth in the Quintana Production Co. State Lease 6082, Lake Boudreaux field.

(Figure 19.)



Shale resistivity and corrected formation temperature as a function of depth in the La Terre Petroleum Corp. La Terre Co. D-1, Bay Baptiste field.

(Figure 20.)

deeply, to about 14,000 feet.

Changes in the geopressured horizon over most of the area correlate well, if not exactly, with structural changes observed on the deepest mapping horizons, as expected. Good examples include the geopressure highs which follow the Lirette-South Chauvin anticline and the geopressure lows in the surrounding synclines and basins.

The most striking features on the map are the tightly-contoured areas. The rapid changes observed in these areas result from faulting and correspond very precisely to faults found on the lower structural mapping horizon. The change which results is often similar to the change in structural arrangement. An excellent example exists along the location of fault "C" from Lake Boudreaux through Lirette. Even the main bifurcation of fault "C" at Lake Boudreaux may be observed. Examination of cross section A-A' (plate 5) shows that the changes correspond almost exactly to the structural arrangement. The geopressured horizon is simply displaced by the faulting.

Ideally, where the top of hard geopressure is only displaced by faulting and no leakage is occurring along the fault, the contours should become so tight as to copy the fault plane. Where leakage occurs, however, the contours along the fault plane will be somewhat more spread out due to the pressure release along the fault. Ideal situations are seldom represented on contoured pressure maps, though, because of the lack of closely-spaced well control.

A paradox occurs at fault "C-s1" in Lake Boudreaux along the A-A' cross section (plate 5). It would appear that at least one, and possibly a second, high-pressure sand on the upthrown side of fault "C-s1" is in direct contact with a low-pressure sand on the downthrown side of the fault. This situation was studied quite closely because of its possible implications. The upper sand body lies at the Robulus "5" pick in the upthrown well, the Coastal States L. L. & E. No. 1. This sand, however, cannot be correlated with sands in any downthrown well. In fact, its correlation with upthrown sands can only be inferred. The sand immediately below it is even less correlative, having no inferred upthrown or downthrown correlations.

The two sands seem almost out of place stratigraphically and I suspect that the two may be channel-like sand bodies or lenticular topography-filling sand pods which shale-out before reaching fault "C-s1". Alternatively, the sands were perhaps rapidly pinching out onto the North Lapeyrouse ridge, which was very actively growing at the time.

The changes in the elevation of the geopressured horizon produced across fault zones does not always mimic the resulting structural arrangement. If the two sand bodies just discussed had come in contact, for instance, pressure would have been released and there would be much less, if any, displacement of the geopressured horizon across the fault. Such may be the case along fault "K" north of Chauvin field, where little displacement of the pressure horizon is indicated.

Another situation quite different from those discussed so far is observed along faults "F" and "F-3" in Montegut field (plate 13, T-18-S, R-19-E). Here a very steep gradient is observed along the fault zone. The structural arrangement of the geopressured horizon, interestingly, is opposite that of the geologic structural arrangement. The geopressured horizon drops from a high south of the fault to a low north of it along a steep north-dipping gradient. Geologically, the north side of the fault is upthrown and the south is downthrown along a south-dipping fault plane (see structural cross section B-B', plate 6). The steeply north-dipping pressure plane is probably produced by what, in reality, is an overhang of pressured levels. A simplification of the situation is given in figure 21.

Besides the types associated with faulting, another anomaly is found in the study area. This anomaly, also in Montegut field, seems unrelated to structure. It is a slight high in the surrounding pressure plane that appears as a domal feature centered in the northwestern corner of section 57. Two possible explanations exist. First, it is conceivable that the structural horizons could be re-contoured to

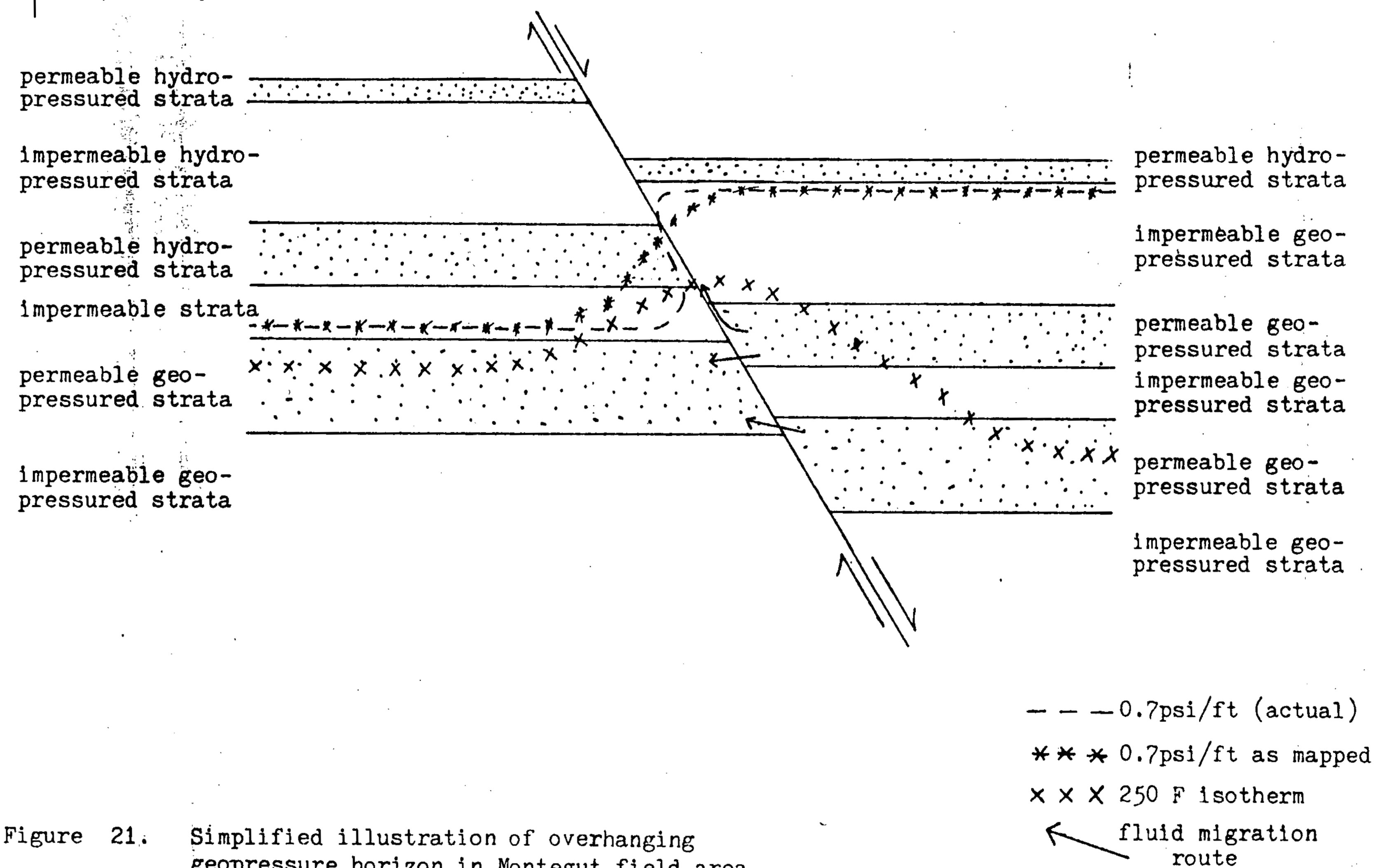


Figure 21. Simplified illustration of overhanging geopressure horizon in Montegut field area.

show a slight domal feature here. On the other hand, if structure is as presently contoured, perhaps the anomaly might be due to slight changes in stratigraphy. Examination of the Goldking D. Ellender #1 and surrounding wells indicated that in this area the geopressure top has changed its stratigraphic position somewhat. The chart (figure 14) was always used to verify the occurrence of the 0.7 psi/ft depth. Therefore, it may be that the shale which now forms the pressure caprock may have been deposited in this area with fewer coarse impurities than in surrounding areas for some reason. The result is that here the shale forms a more efficient cap, allowing the 0.7 psi/ft gradient to be more quickly reached than in surrounding areas.

THERMAL CONCEPTS AND LOCAL TEMPERATURE STUDIES

To be economically feasible as energy sources, geopressured reservoirs must possess significant heat energy. Recent guidelines established by the United States Department of Energy (D. O. E.) recommend that true reservoir temperatures exceed or at least equal 250°F (Westhusing, 1981). Therefore, understanding the distribution and intensity of temperature in the subsurface is a requirement for the current project.

The temperatures of formation waters usually increase with depth but in hydropressured strata, formation waters are free to circulate upward and dissipate heat to the surface at a maximum rate of efficiency. In the geopressured section, however, the total thermal conductivity of the rocks is reduced. This occurs primarily because the upward movement of formation waters in the geopressured zone is restricted and heat dissipation is slowed. As a result, the geothermal gradient is greater in the geopressured zone than in the hydropressured zone.

The most rapid increases in geothermal gradient are found in the shale seal at the top of the geopressured zone. According to Jones (1969), geothermal gradients may be as high as 6°F/100 feet in these shales due to the inability of these strata to transfer heat. This caprock transition zone is often short and its high gradient is averaged with the geopressured/geothermal gradient, masking it in most temperature studies.

Geothermal investigations in south Louisiana are conducted using well log temperature data. Formation temperatures are recorded on the log at the bottom of each logging interval. These temperatures are lower than the true value of the formation temperature due to the circulation of drilling mud which is done to prepare the hole for logging. Kehle, 1971, developed a quadratic function whose parabolic graph can be used to correct these reduced temperatures with relative ease (figure 22). Once corrected, the data are used for maps, graphs, and statistical studies.

The change in the geothermal gradient which occurs upon entering the geopressured zone can be recognized from corrected well log temperatures plotted as a function of depth. The temperature-depth plots of figures 15 through 20 were constructed in an effort to show a correlation between the top of geopressure and an increase in the geothermal gradient in selected wells from different fault blocks in the study area. Unfortunately, too few data points exist from any one well to show this change but a study of the neighboring Sunrise fields by Pradidtan (1982) shows that it does exist. On his graphs data points from many logs in one fault block

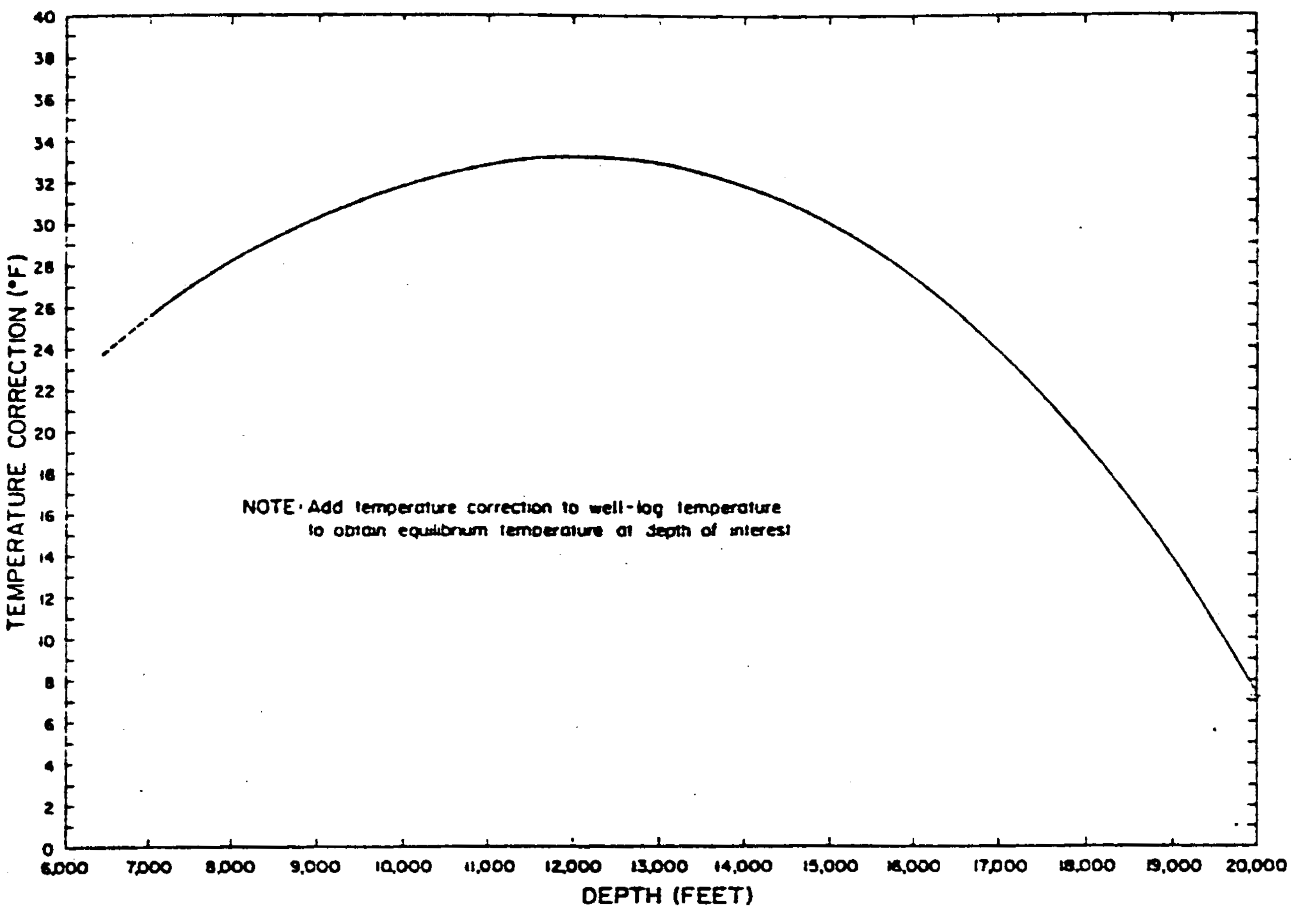


Figure 22. Temperature corrections as a function of depth for adjusting well-log bottom hole temperatures to approximate equilibrium formation temperature.

(after Kehle, 1971)

were plotted and the gradient increase was found to concur with the top of geopressure (figure 23). For the present study area, geothermal gradients in the hydropressured zone averaged 1.26°F/100 feet whereas in the geopressured zone the gradient averaged 2.20°F/100 feet.

Corrected temperature data were also used in the study area to make temperature maps. Two types were constructed; one of temperature distribution with respect to a planar surface of 12,000 feet and one of the subsurface elevation of the 250°F isotherm.

The two are related, of course, and a high temperature on the planar map should correspond to a shallow depth of the 250°F isothermal surface and vice versa.

A planar temperature map is believed to be the better of the two at displaying thermal anomalies. Such a map was made over the study area at a planar depth of 12,000 feet. It was felt that this would be of sufficient depth to expose thermal anomalies and yet maintain good well control. Over much of the area the 12,000 foot plane is at or above the top of the geopressured zone. The temperature at 12,000 feet was determined simply by establishing a linear hydropressure temperature gradient from corrected well log temperatures and interpolating or extrapolating to the 12,000 foot depth. Where the 12,000 foot plane was below the top of geopressure, the higher geothermal gradient had to be accounted for in the

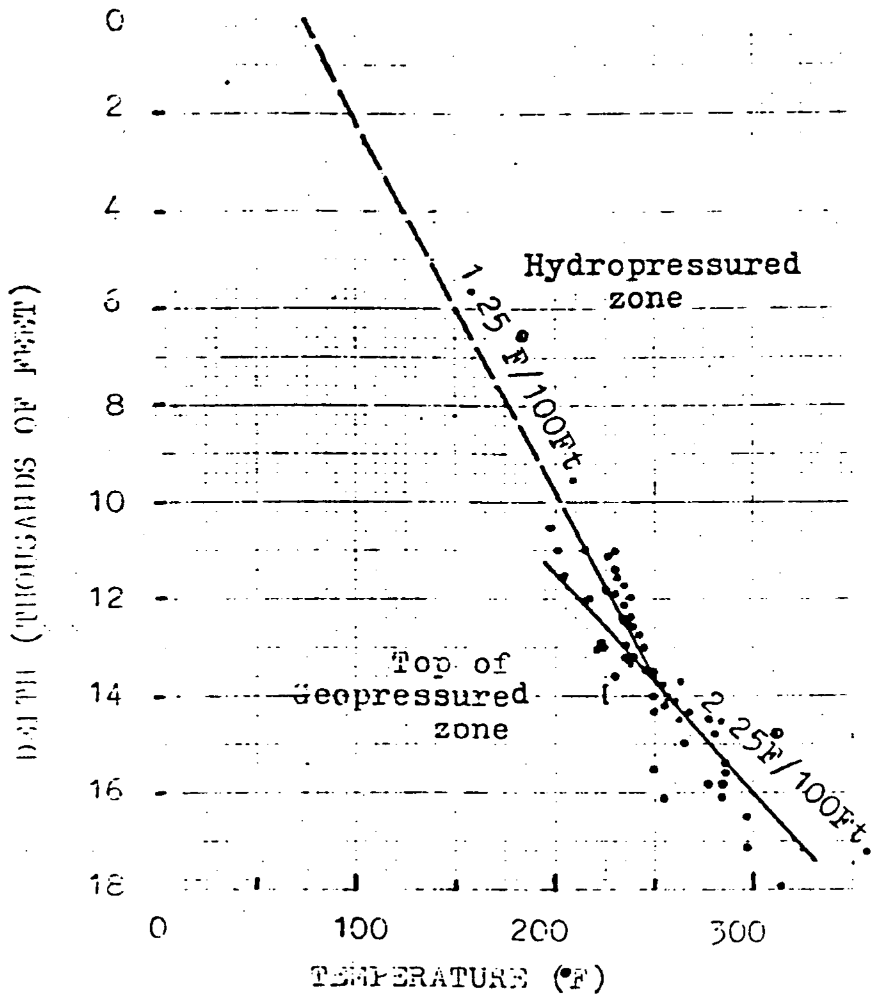


Figure 23. Corrected bottom hole temperature (BHT) of the Sunrise field, showing the average temperature gradients of the geopressured and hydropressured zones. (Pradidtan, 1982)

temperature estimation. This is accomplished by establishing a linear gradient within the geopressured zone and extrapolating or interpolating it back to the 12,000 foot horizon.

The distribution of temperature at 12,000 feet is displayed by plate 15. Temperature at this depth varies from a low of 195°F recorded in the northwestern area of T-18-S, R-19-E to a high of 255°F recorded in the southwestern area of T-18-S, R-18-E. The average temperature at 12,000 feet is 220.5°F among wells in which geopressure was at or below 12,000 feet. Of those in which geopressure occurred above 12,000 feet, the average temperature at 12,000 feet is 229°F.

With respect to the above average temperatures, there are a number of high temperature anomalies. These are local areas at a depth of 12,000 feet where an abnormally high rate of heat flow is occurring. The highs could result from the release of hotter fluids from the geopressured zone. Occasionally, faults act as conduits for fluid escape from the geopressured zone. Abnormally high temperatures at the 12,000 foot horizon might be expected to be found in association with faults that are unsealed; therefore, the 12,000 foot contour lines of all fault planes were traced onto the temperature map to assess the possibility of this occurrence in the study area.

Linear temperature highs are observed to coincide well with fault zones in several areas. The best examples occur in association with fault "F". All along this fault zone temperatures above average are encountered, suggesting an unsealed fault zone. It appears from the temperature maps, pressure map and cross section that faults "F" and "F-3" are leaking in several areas creating elevated temperatures at 12,000 feet and rises in the 250°F isotherm (see plates 15, 16, 14, and 6). The observed displacement of the top of hard geopressure alone does not indicate an unsealed fault zone but the thermal anomalies found along this fault zone suggest such an interpretation. Similar anomalies also occur in western Lake Boudreaux, Bay Baptiste and North Lapeyrouse.

Also observed in the study area are anomalously high temperatures which are not associated with fault zones. Extremes of high temperature found around Bayou Chauvin and South Houma fields may be caused by structurally uplifted warmer sediments in conjunction with an intersection of the 12,000 foot plane with the geopressure zone. Additionally, possible fluid leakage around fault "F" in this area may have some influence. The same sort of situation might be the cause of an extension of the high temperature anomalies southwestward from fault "F" into the northwest area of Lirette.

In general, temperature highs and lows should correspond to structural highs and lows. In the study area temperature lows crudely coincide with structural lows but in many cases temperature highs cannot be correlated with positive structural elements. For instance, no continuous high is found in connection with the Lirette-South Chauvin anticline. In fact, temperatures above the structure in much of the South Chauvin area are relative temperature lows. Possibly the many thermal highs which surround it create a "false" relative low here. The one thermal high which does exist over structure in South Chauvin is probably the result of the intersection of the shallow geopressure zone with the 12,000 foot horizon.

Another anomaly found on this map and worthy of brief mention is a thermal high found centered close to the northwest corner of Section 57 in Montegut field. Perhaps there is some correlation between it and the strange high found on the pressure map (plate 14) in the same vicinity.

Thermal behavior in the area was further explored by studying the 250°F isothermal surface. The 250°F isotherm lies below the top of hard geopressure nearly everywhere in the mapping area. Only two minor exceptions occur where the top of geopressure is exceptionally deep. The 250°F isothermal map (plate 16) was therefore constructed to give some indication of the depth to which any proposed well in the mapping area would have to be drilled in order to reach strata that meet these most basic geopressured/geothermal resource requirements. Additionally, the map allows the 250°F isotherm to be placed on the cross sections so that its relation to structure and geopressure can be visualized easily.

Generally the 250°F isotherm should follow structure and geopressure. Exceptions occur where faults are unsealed causing temperature and pressure anomalies. Shallow 250°F isotherm depths should correlate with thermal highs on the 12,000 foot plane and vice versa. Plates 14, 15, 16, and all structural cross sections show the above generalities to be true, usually. Relative shallowing of the isotherm is noted over structural and geopressure highs. Other shallow areas are indeed located where temperature highs have been found at 12,000 feet.

Exceptions to these generalities exist. The most significant of these occurs at eastern Montegut field along fault "F" where the isotherm plunges to a sharp low despite the thermal high which persists above it. Since well control is good, the observed anomaly is probably real. Perhaps the inversion is caused by the heated waters which are leaking up the fault plane to the west, as discussed, and which are spreading laterally to the east through porous formations at shallower depths.

Loss of well control is considerable at the depths which the 250°F isotherm is reached and some of the other more minor disagreements between the isothermal map and other maps may therefore be due to this lack of control. Erroneous temperature data may also have contributed to the minor problems observed. Because of these possibilities, the significance of the smaller discrepancies is questionable and interpretations are withheld.

GEOPRESSURED/GEOTHERMAL RESOURCE POTENTIAL OF THE STUDY AREA

The following is a list of currently accepted minima regarding potential geopressured/geothermal reservoirs (Westhusing, 1981):

1) fluid temperatures of at least 250°F,

2) fluid pressure gradients of 0.7 psi/ft or greater,

3) porous reservoirs of at least one cubic mile volume with 100 or more essentially continuous net feet of sand, totally saturated with water,

4) water salinity of less than 75,000 ppm total dissolved solids,

5) reservoir permeabilities of at least 20 md.

The 250°F isothermal map (plate 16), as previously discussed, provides a good estimation throughout the study area of the depths that need be reached by the drill to satisfy the first two criteria presented above. Over most of the study area, though, these depths are in excess of 12,500 feet and may be considered below economic feasibility by some. Moreover, where minimum prospect depths are relatively shallow, sands of the required volume rarely exist. Few areas in this study, therefore, hold the promise of an ideal geopressured/geothermal prospect.

Some exceptions or, more appropriately, compromises exist. Geopressured sands of significant volume lie below the 250°F isotherm at Montegut field and south of South Chauvin field. The stratigraphic cross section D-D' (plate 8) was in part constructed to display these sands.

The first, and best developed of these sands, is the Cyclammina sand. Along the D-D' line of section, the top of this sand is found between 13,000 and 14,300 feet and elsewhere at elevations in between. As a result well control is intermittent and direct volumetric estimations can be made in only a few wells. The Cyclammina sand can be traced over the South Chauvin structure where it thickens into a dying fault "Z" (see A-A' cross section, plate 5). Beginning at a depth of 13,750 feet in the Shell Oil Co. James Fanguy 1-A well about 250 net feet of this sand exists, the upper 100 feet of which is fairly continuous. The sand can be followed to the west where it is found in the Shell Oil Co. Peters No. 10 well downthrown of faults "F" and "F-G" at a depth of 12,700 feet and on the upthrown side of the two faults in the Shell-Humble Laterre A-3 at about 12,050 feet. The sand can also be found in several other wells in this vicinity. These western equivalents are of some interest because the geopressured sands consolidate into two continuous bodies each of 100 net feet with temperatures averaging 252°F downthrown and 250°F upthrown. No isopach maps of the reservoir are practical, though, due to limited well control; therefore, volume estimations are not made.

In following the Cyclammina sand to the east on the stratigraphic cross section D-D' it is apparent that the sand develops into a fairly thick sequence at Montegut. In the Pan Am. Southshore F-1 well, in western Montegut, the Ciclammina sand has a net thickness of about 200 feet. Where it is again completely penetrated in eastern Montegut by the Southern Natural Gas Waterford A-1 well, the sand has thickened to over 450 net feet.

The top of the Cyclammina sand is traceable to the north of Montegut field but unfortunately is penetrated completely by only one well, the Stanolind Oil and Gas Corp. South Shore Land A-1. In this well the Cyclammina sand is entered at 13,550 feet and has a nearly continuous net thickness of about 420 feet. However, due to the low number of complete Cyclammina sand penetrations no isopach map of the reservoir is practical in this area either. Equivalent tops of this sand were reached by a number of other wells in this area, however, and the presence of these tops suggests that this sand is laterally continuous north of fault "F" in Montegut and into North Montegut. From the few isolated complete penetrations at Montegut, it appears that the thickness and continuity of the Cyclammina sand also improves in an easterly and northerly direction.

Temperatures in the sand in this area are not extremely high but are marginally acceptable. Where they may be estimated directly from the well logs, fluid temperatures in the reservoir average just above 250°F. Additionally, the 250°F isothermal map indicates that temperatures a little above 250°F should be expected for the sand over much of the Montegut-North Montegut area.

The Cyclammina sand has been followed to the south of fault "F" in a few wells. The sand becomes more shaley in this direction, probably due to the activity of the Lirette structure during its deposition. The deposit is also less attractive in these areas due to its increased depth. The sand also apparently shales-out toward Lake Boudreaux since no correlative sands appear to exist there. Equivalents of the sand become lost to the south across fault "C".

No definitive correlations of the Cyclammina sand were made north of the study area but some light supportive work conducted north of fault "K" indicated that the sand developed most of its thickness on the downthrown side of fault "K", as do other sands of the study area.

The Cyclammina sand is a zone 4 deposit which appears to have a depositional distribution pattern similar to the upper Textularia "W" sand. The upper Textularia "W" sand, which was studied in some detail in an earlier section, is spread over much of the northern mapping area and is thickened to the north of Montegut. Using the upper Textularia "W" sand isopach as a predictive tool, as previously discussed, I can estimate that the *Cyclammina* sand reaches optimum thickness in the North Montegut structural low, just to the north of the Mecom Petroleums South Shore #1 well. A well drilled here would encounter the sand at about 14,000 feet and penetrate about 500 feet of a reservoir whose high pressure fluids would have a corrected temperature of about 250°F.

The fluid temperatures in this sand appear to be marginal. However, Kurth (1981) found that temperature estimations in Chloe geothermal prospect area were 3°F to 5°F lower than true formation temperatures. Additionally, Dungan and Duhon (1979), in a study of the Abbeville area of south Louisiana, found that their temperature estimations were probably as much as 20°F to 30°F lower than true formation temperature. It is not unlikely that the *Cyclammina* sand is a little hotter than the 250°F estimate, considering this information.

As indicated at the start of this section, parameters such as reservoir permeability, and fluid salinity also need to be considered before a sand can be labelled as prospective. In addition, a possible geopressured/geothermal reservoir cannot be producing hydrocarbons in updip areas, since the pressure drive is required for the hydrocarbon production.

With respect to this latter requirement, the *Cyclammina* sand is probably ideal. Hydrocarbon production is not obtained from this sand anywhere in the study area. For this reason however, the sand was infrequently penetrated and estimations of other criteria (such as salinity and permeability) are limited.

Salinity was calculated from well log resistivity values for the sand in the few places where it was penetrated, however. Values in the areas considered possibly prospective ranged from an average of 62,300 ppm in the Bayou Chauvin area to an average of 89,530 ppm in Montegut. Although the figures are somewhat promising, caution should be used in evaluating these results. The accuracies of such calculations are questionable, especially where high density muds were used. Kurth (1981) explains that under such conditions, salinity estimates may be low by as much as 100 percent. The validity of these data is also questionable since so few logs were evaluated for salinity.

The reliability of log-derived estimates of permeability are also questionable if calculated from electric log data. More accurate estimations of porosity and permeability may be made from formation density logs. No logs of this type were run in the study area, however. No other information was available concerning the salinities or permeabilities of the *Cyclammina* sand. In Lirette field, Flournoy (1980) has found that sands just above the geopressured zone (but well above any *Cyclammina* equivalent) average 28 millidarcys and that porosity improves with depth. Additionally, these studies have found that salinities in the geopressured zone at Lirette average around 30,000 to 40,000 ppm total dissolved solids.

The high estimates of reservoir volume, lack of producing hydrocarbon accumulations, and relatively low initial estimates of reservoir fluid salinities offer some hope for the geopressured Cyclammina sand as a possible energy source. Over most of the area, however, the depths and marginal fluid temperatures of the sand diminish its potential as geopressured/geothermal resource.

Another sand of some size exists below the Cyclammina sand. In the Pan Am. South Shore F-1 (stratigraphic cross section, plate 8), this deposit consists of over 600 net feet of sand. Correlative bodies to the east and west consist of much less sand, indicating that the deposit is rapidly shaling-our laterally. Deposited in lower zone 4, it is probably a density-flow sand of some sort. The depth of the deposit in all areas is excessive (generally greater than 15,000 feet) and it is considered a nonprospective geopressured reservoir.

Other geopressured sand bodies exist in the study area but all of them are thinner deposits of poor lateral continuity and considerable depths. They are also considered to be nonprospective.

In general, the study area shows low potential for geopressured/geothermal energy under current D. O. E. guidelines and site-specific studies within the present study area are not recommended. To the south of the study area, prospects get worse because the depth to the top of hard geopressure increases substantially. Deep well control to the east and west of the study area is poor and the top of hard geopressure remains fairly deep along strike, except under certain uncommon circumstances.

It is recommended from observations made in this study, that any further investigations of geopressure in this area be conducted to the north of fault "K" and its equivalents to the east and west. Geopressure will generally be much shallower in these areas.

CONCLUSIONS

Sedimentation and structural development in the study area was controlled primarily by the activity of depositional hinge-line faulting. The oldest of these faults, initiated no later than late *Cristellaria* "I" time, forms a natural north boundary to the study area since much of the stratigraphic interval studied becomes developed across this fault. This fault also forms the south boundary to the Houma Embayment and began to form during the close of the Houma Embayment event. Major faulting in the study area generally shifted southward through time. The youngest episode, which began about the end of *Bigenerina* "2" deposition, produced the major fault system which forms the south boundary to the mapping area.

The stratigraphic section becomes greatly expanded in a southward direction also as a result of the activity of these shelf-break faults. The extreme expansion of the Miocene section into the Terrebonne Trough immediately to the south begins across the major faults of the study area.

The activity of faults and other structures has allowed considerable amount of sand to be deposited in the study area throughout the geologic interval studied. Unfortunately, higher sand percentages in combination with excessive structural activity most frequently result in poor geopressured/geothermal prospects.

The geopressured/geothermal portion of the study identified several scientifically interesting aspects of the study area but, unfortunately, energy prospects may not be one of them under present D. O. E. guidelines. One marginal possibility, the *Cyclammina* sand, exists in the northeastern part of the study area. A large, continuous volume is expected for this reservoir but due to somewhat low fluid temperatures and fairly deep depth of occurrence, it may not be prospective. Site specific studies are not currently recommended for this or other geopressured sands within the study area. Should D. O. E. minimum standards change, however, the *Cyclammina* sand may be more attractive as an energy reservoir.

Finally, the results of this study indicate that future geopressured/geothermal research should be concentrated to the north of the north-bounding fault to the present study area and its eastern and western equivalents.

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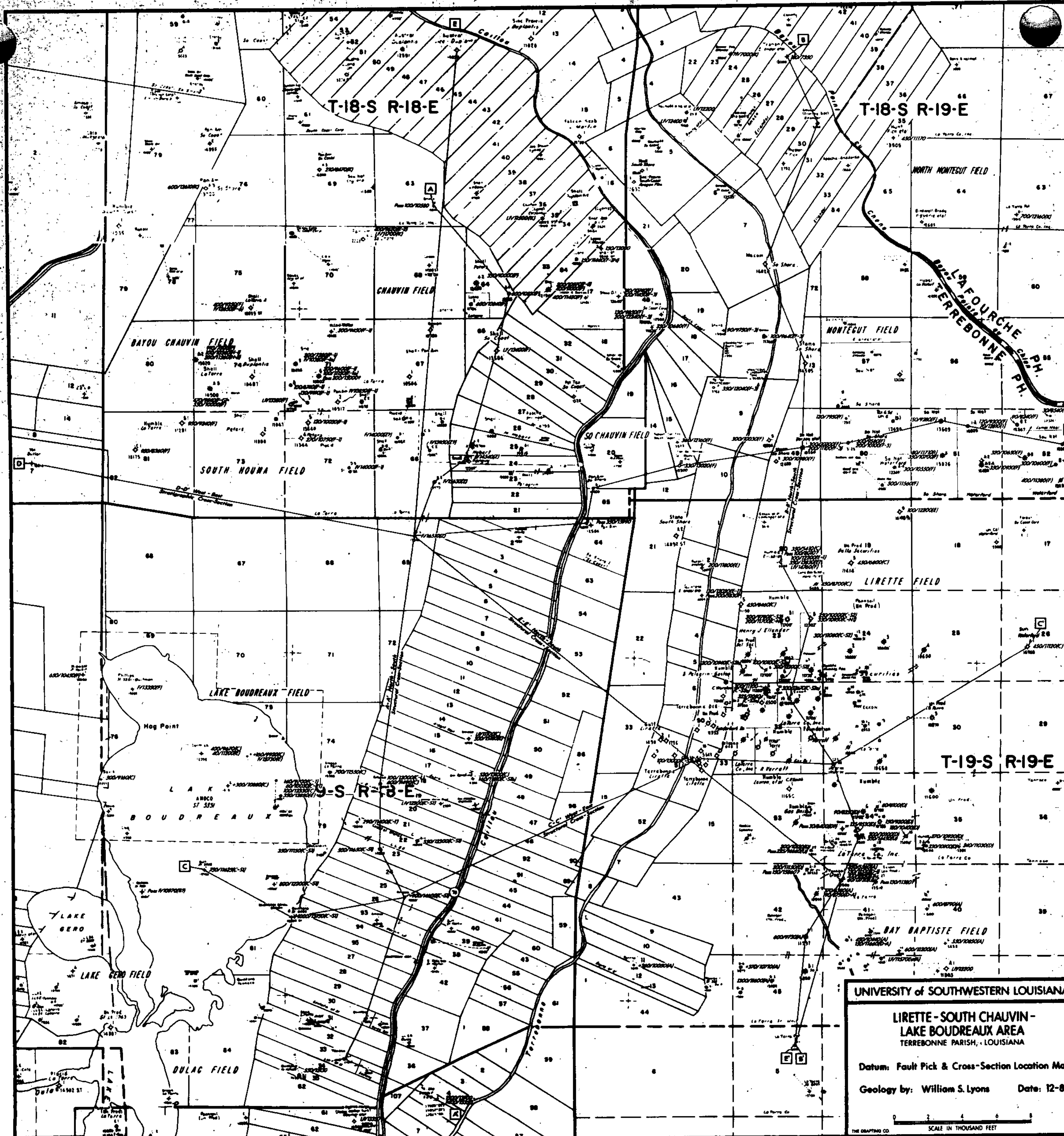
BIOGRAPHY

William S. Lyons was born in Rochester, Minnesota, on July 21, 1957. After moving to Lake Barcroft in Northern Virginia, he graduated from Flint Hill Preparatory School in Fairfax County. Later, in May, 1980, he received a Bachelor of Science degree in Geology from Radford University in southwestern Virginia.

In the Spring of 1980, the author accepted a graduate assistanship at the University of Southwestern Louisiana and in August, 1980, began completing requirements for a Master of Science degree in Geology at the University.

After receiving the Master's degree, the author plans to begin work with Texaco, U.S.A., in Tulsa, Oklahoma.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MONTEGUT FIELD
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
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LAKE BOUDREAUX FIELD
Hog Point
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BAY BAPTISTE FIELD
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UNIVERSITY of SOUTHWESTERN LOUISIANA
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LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
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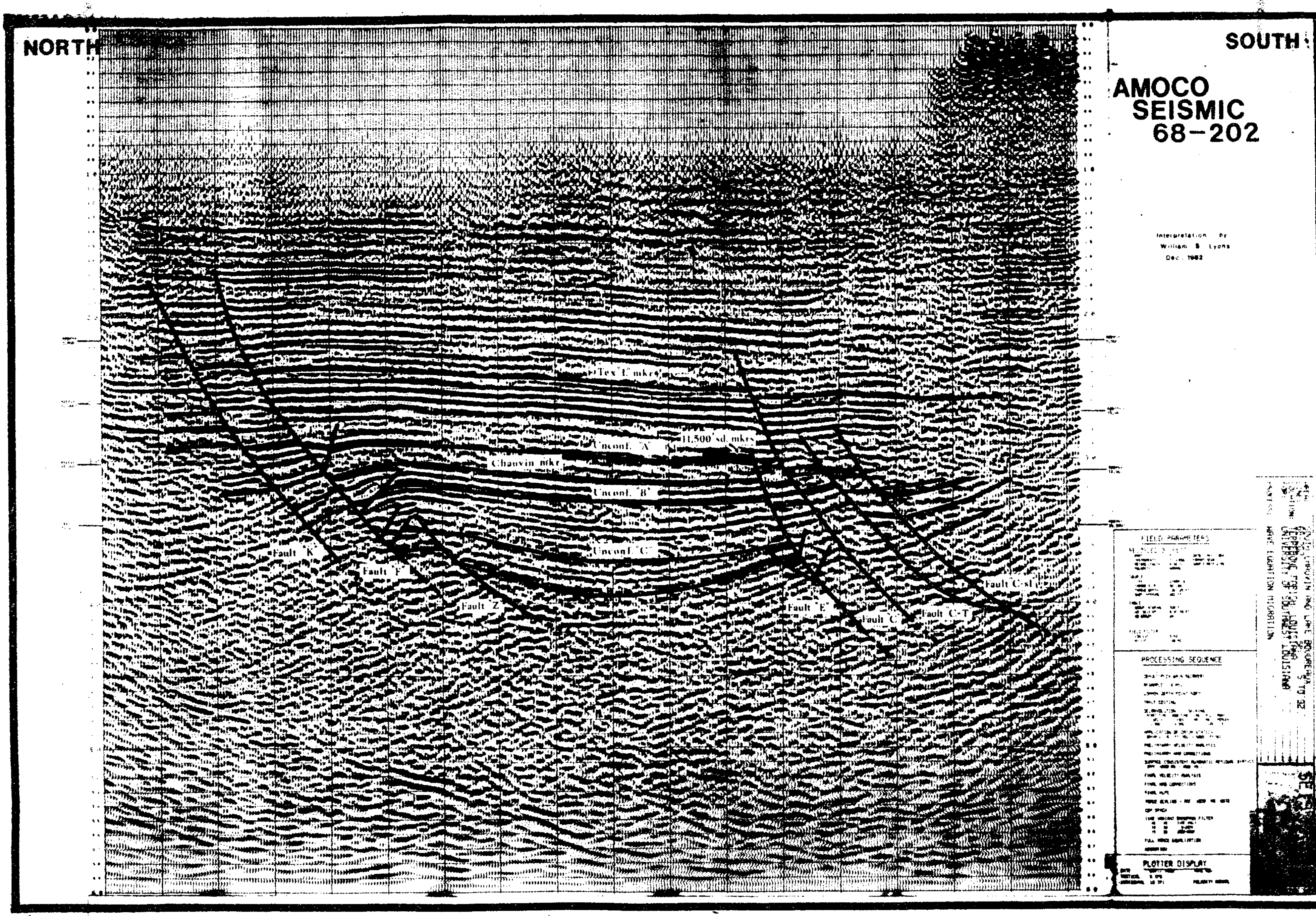

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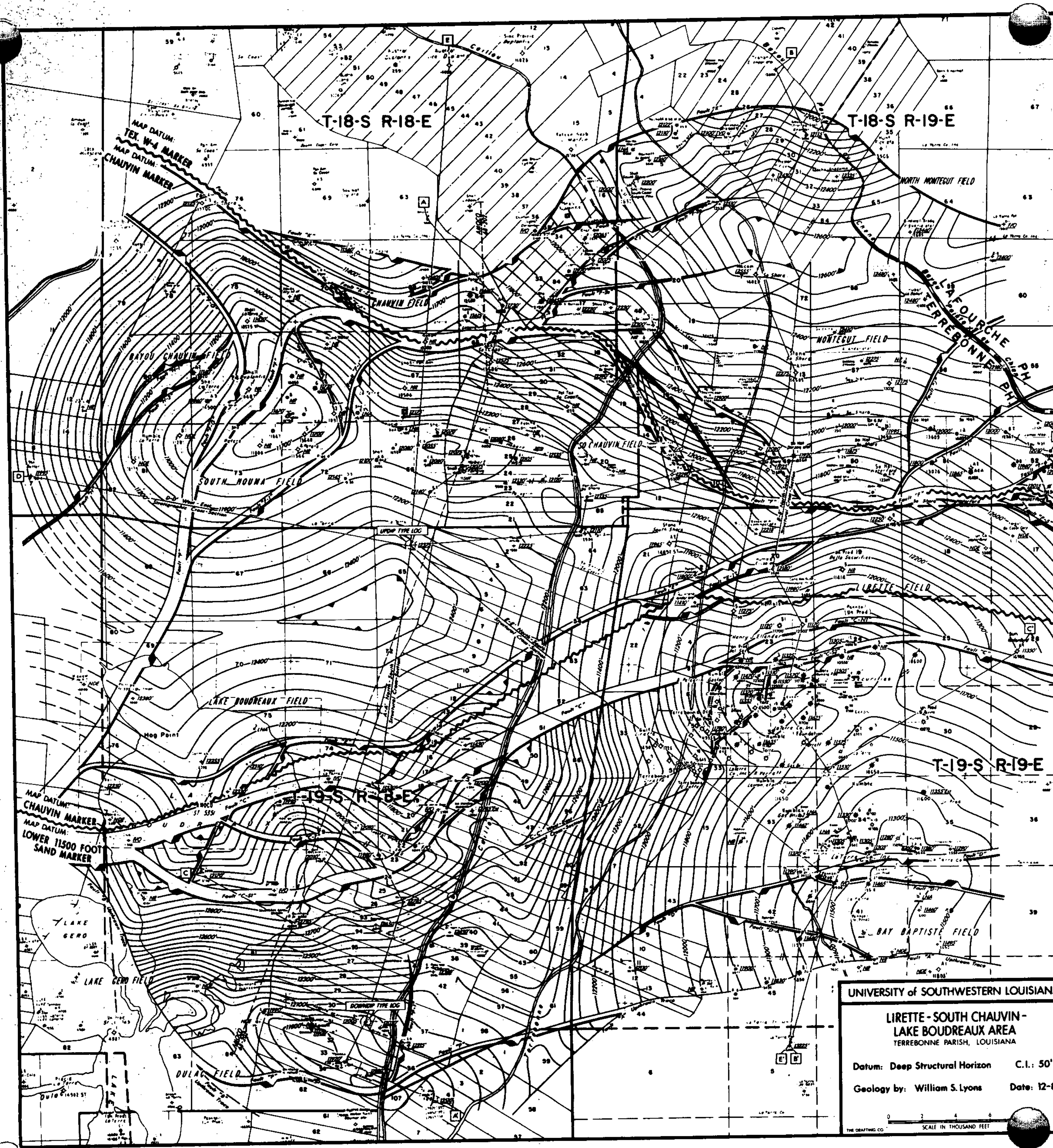
PLATE 2. South Chauvin - Lake Boudreaux, north - south seismic line.



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MAP DATUM: CHAUVIN MARKER
MAP DATUM: LOWER 11500 FOOT SAND MARKER
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
NORTH MONTEGUT FIELD
MONTEGUT FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
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LAFOURCHE PH
TERREBONNE PH
Hog Point
UPDIP TYPE LOG
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UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
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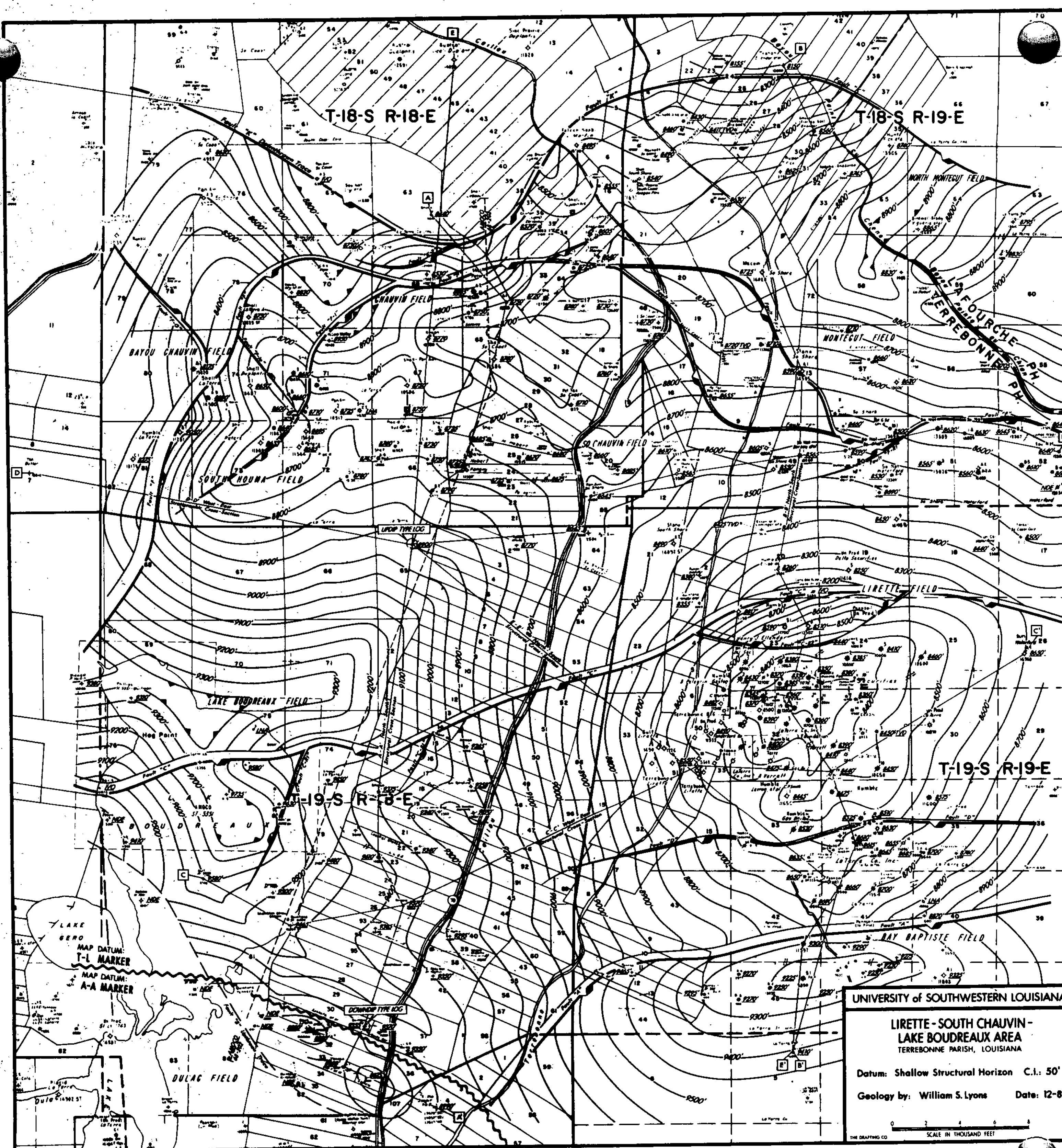
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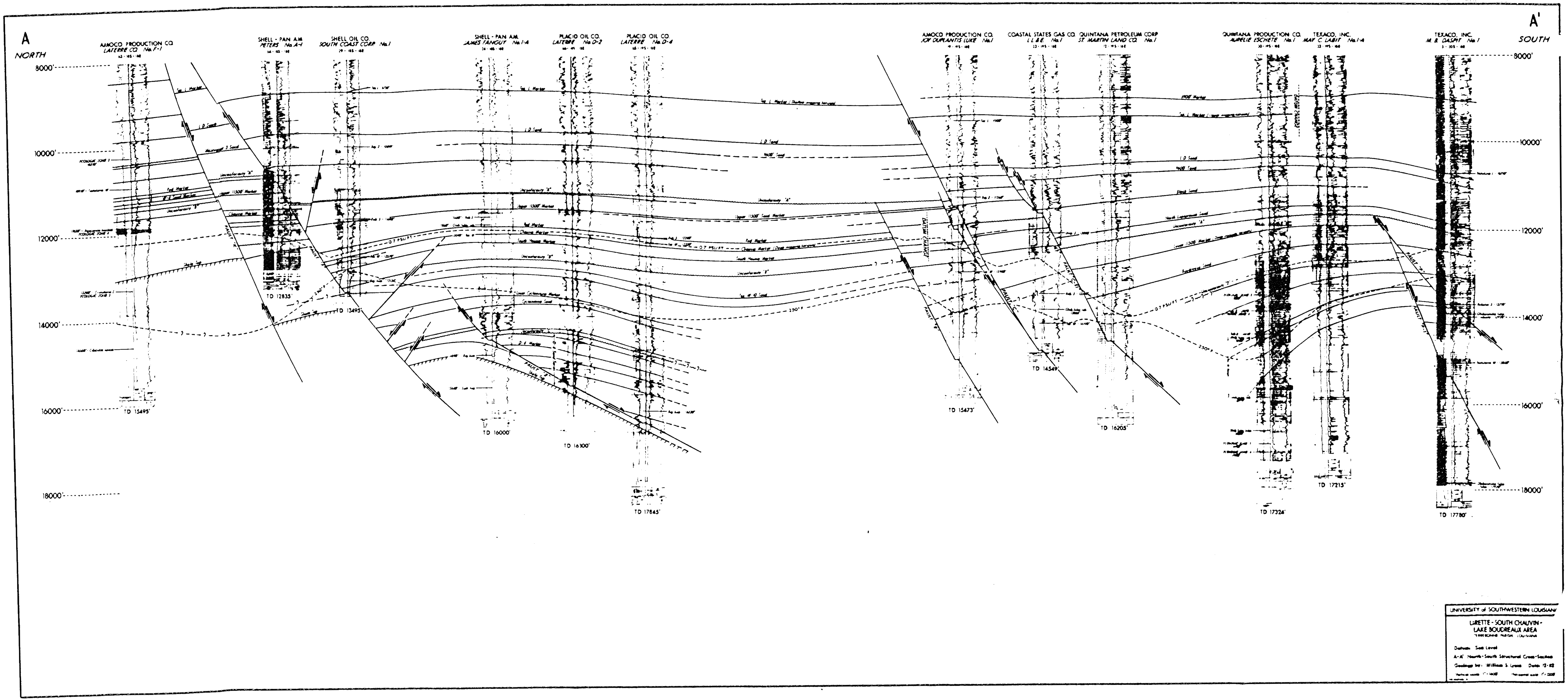
Fault "A"

3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PETERS No. A-1
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SOUTH COAST CORP. No. 1
SHELL - PAN AM.
JAMES FANGUY No. 1-A
PLACID OIL CO.
LATERRE No. D-2
PLACID OIL CO.
LATERRE No. D-4
AMOCO PRODUCTION CO.
JOY DUPLANTIS LUKE No. 1
COASTAL STATES GAS CO.
L.L. & E. No. 1
QUINTANA PETROLEUM CORP.
ST. MARTIN LAND CO. No. 1
QUINTANA PRODUCTION CO.
AURELIE ESCHETE No. 1
TEXACO, INC.
MAY C. LABIT No. 1-A
TEXACO, INC.
M. B. DASPIT No. 1
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10000'
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14000'
16000'
18000'
TD 15495'
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TD 17215'
TD 17780'
UNIVERSITY of SOUTHWESTERN LOUISIANA
LARETTE - SOUTH CHAUVIN -
LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
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Geology by: William S. Lyons Date: 12-82

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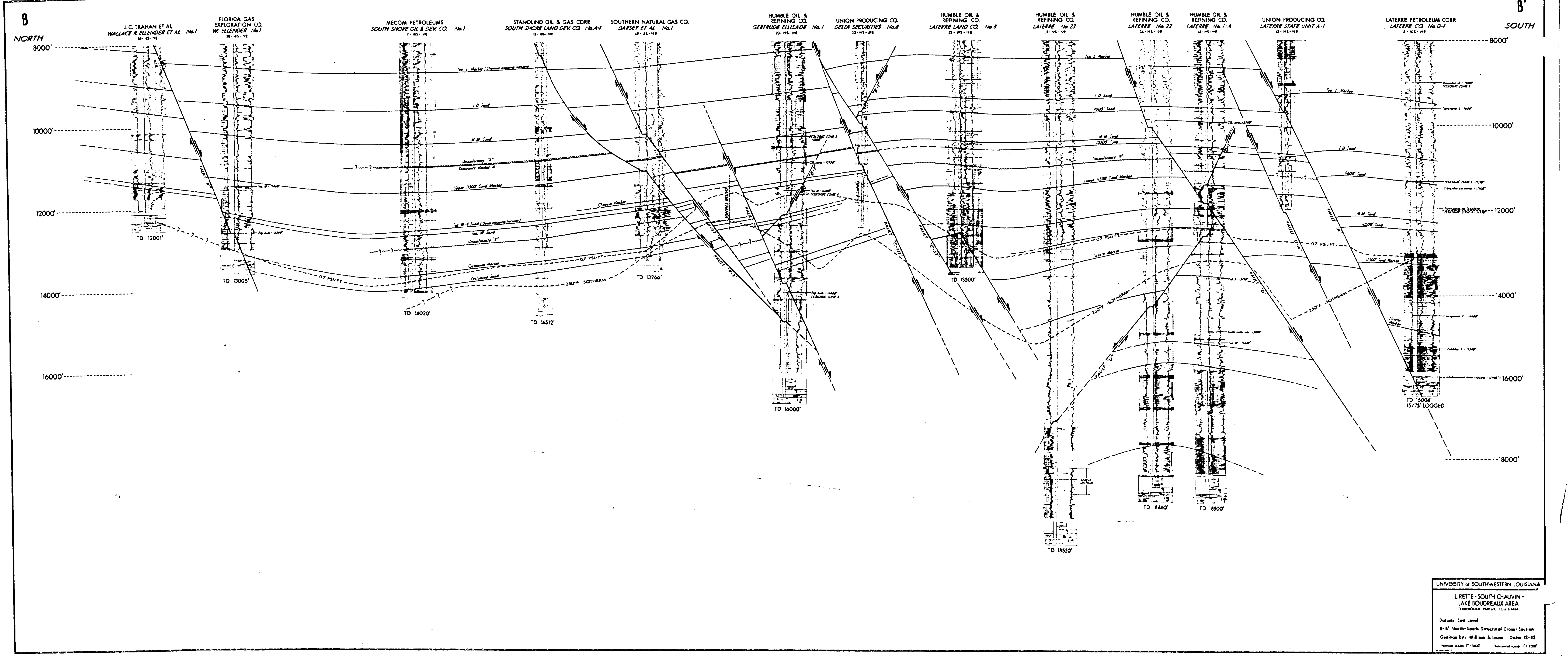
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MECOM PETROLEUMS
SOUTH SHORE OIL & DEV. CO. No. 1
STANOLIND OIL & GAS CORP.
SOUTH SHORE LAND DEV. CO. No. A-1
SOUTHERN NATURAL GAS CO.
DARSEY ET AL No. 1
HUMBLE OIL & REFINING CO.
GERTRUDE ELLISADE No. 1
UNION PRODUCING CO.
DELTA SECURITIES No. 8
HUMBLE OIL & REFINING CO.
LATERRE LAND CO. No. 8
HUMBLE OIL & REFINING CO.
LATERRE No. 23
HUMBLE OIL & REFINING CO.
LATERRE No. 22
HUMBLE OIL & REFINING CO.
LATERRE No. 1-A
UNION PRODUCING CO.
LATERRE STATE UNIT A-1
LATERRE PETROLEUM CORP.
LATERRE CO. No. D-1
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TD 18460'
TD 18500'
TD 16004'
15775' LOGGED
L D Sand
M M Sand
9600' Sand
Unconformity "A"
Upper 11500' Sand Marker
Cibicides Marker
Cyclammina Marker
Cyclammina Sand
0.7 PSI/FT
250°F ISOTHERM
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN -
LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
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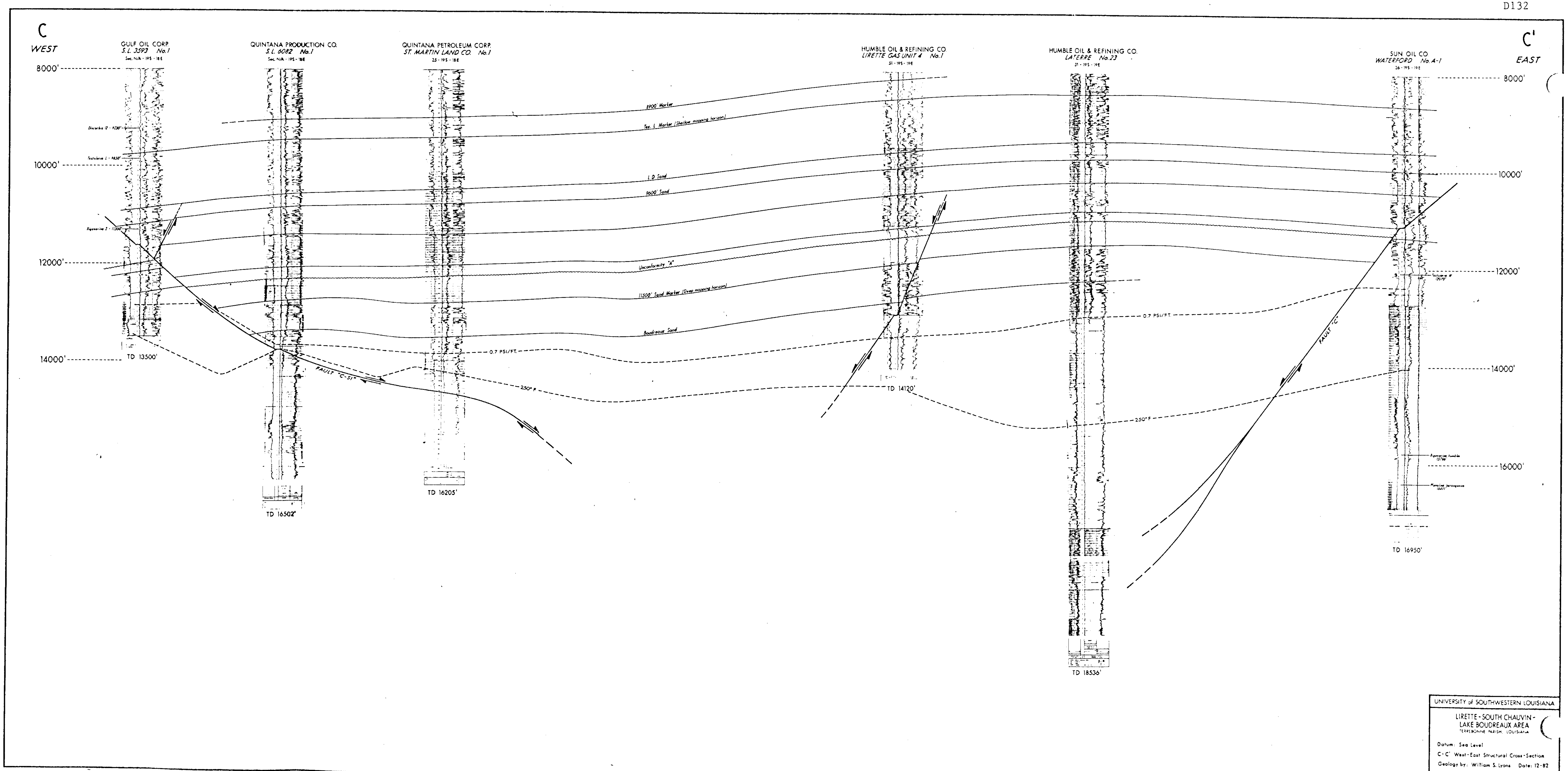
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ST. MARTIN LAND CO. No. 1
HUMBLE OIL & REFINING CO.
LIRETTE GAS UNIT 4 No. 1
HUMBLE OIL & REFINING CO.
LATERRE No. 23
SUN OIL CO.
WATERFORD No. A-1
8000'
10000'
12000'
14000'
16000'
8900' Marker
Tex. L Marker (Shallow mapping horizon)
L D Sand
9600' Sand
Unconformity "A"
11500' Sand Marker (Deep mapping horizon)
Boudreaux Sand
0.7 PSI/FT.
250° F
FAULT "C-51"
FAULT "C"
TD 13500'
TD 16502'
TD 16205'
TD 14120'
TD 18536'
TD 16950'
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
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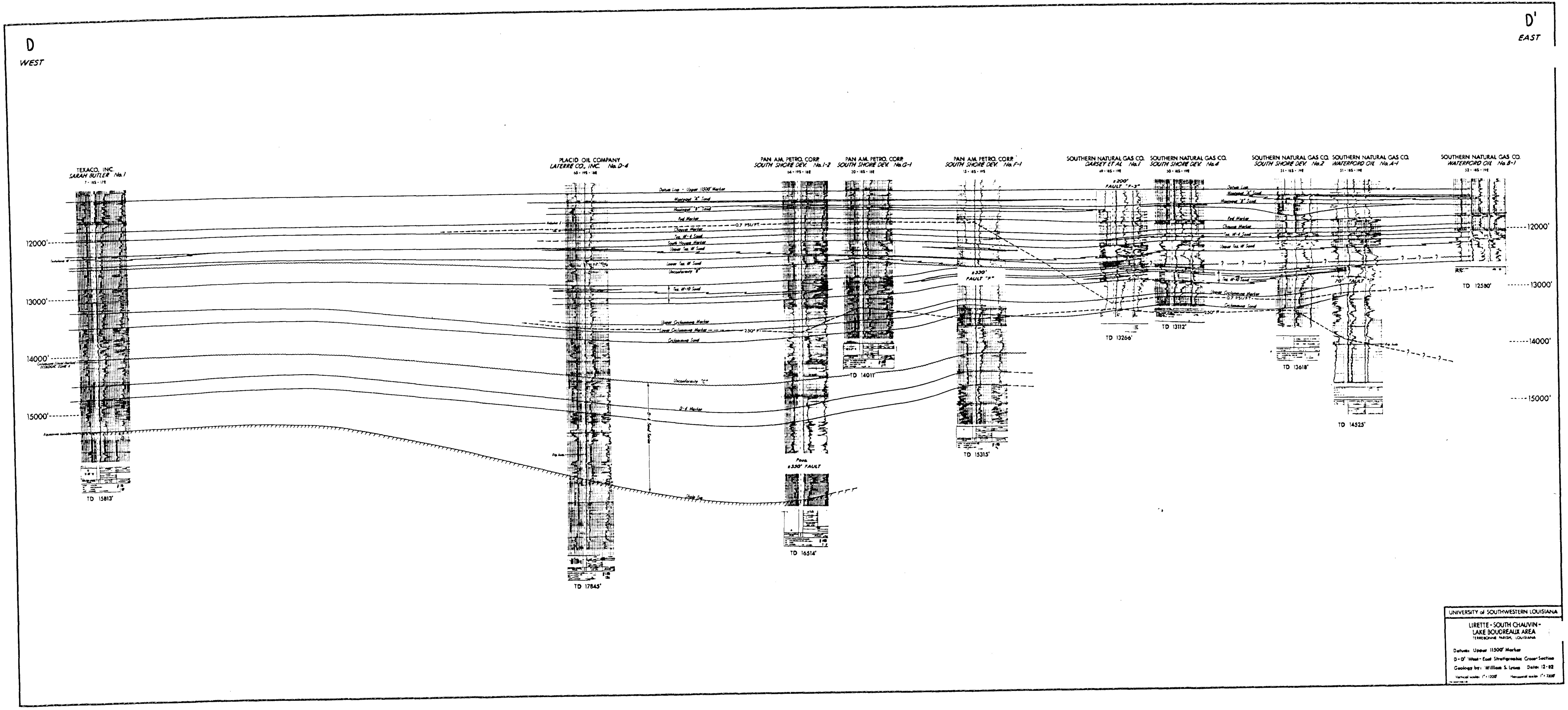
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PLACID OIL COMPANY
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PAN AM. PETRO. CORP.
SOUTH SHORE DEV. No. I-2
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SOUTH SHORE DEV. No. G-1
TD 14011'
PAN AM. PETRO. CORP.
SOUTH SHORE DEV. No. F-1
TD 15315'
SOUTHERN NATURAL GAS CO.
DARSEY ET AL No. 1
TD 13266'
SOUTHERN NATURAL GAS CO.
SOUTH SHORE DEV. No. 4
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WATERFORD OIL No. B-1
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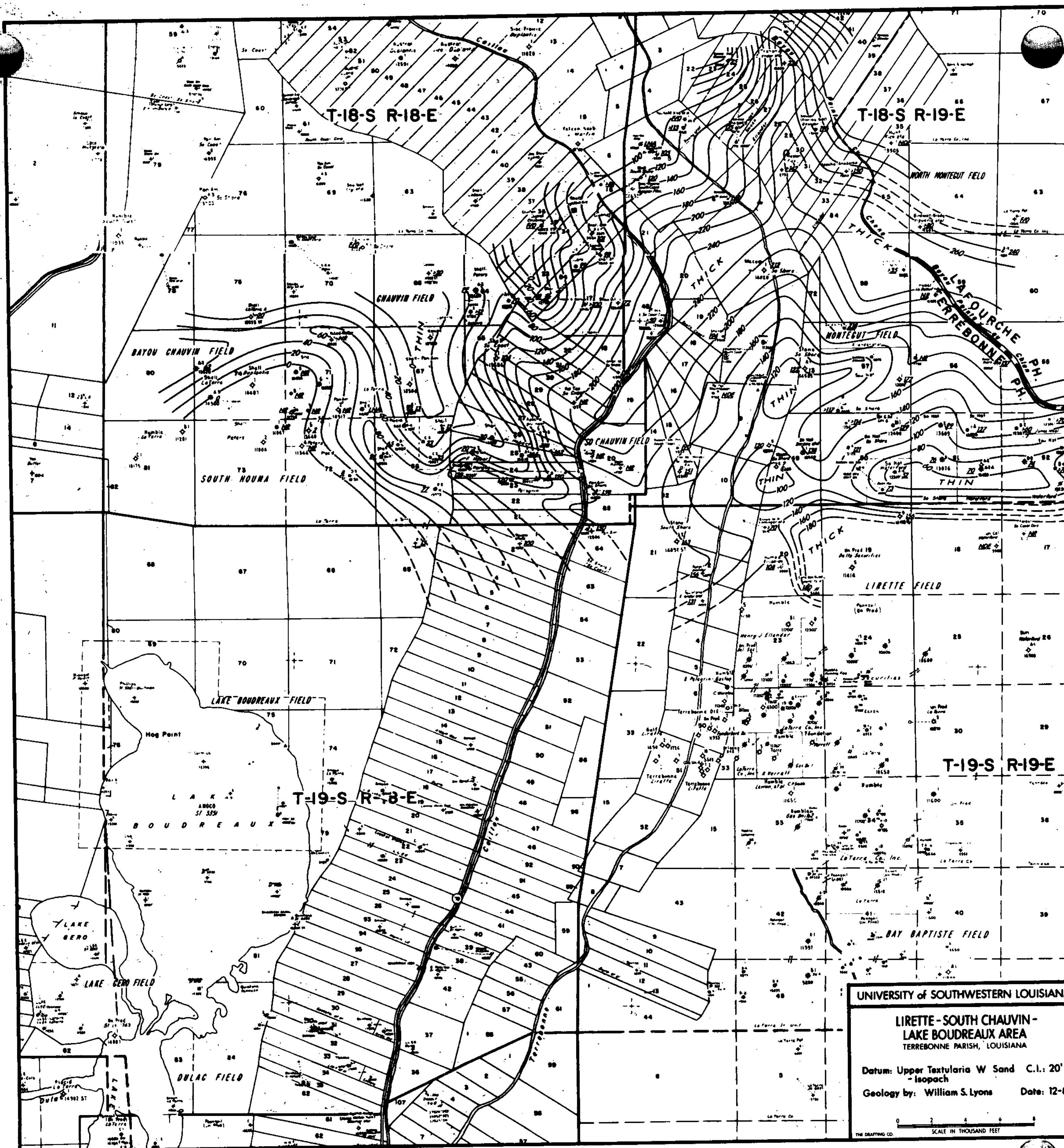
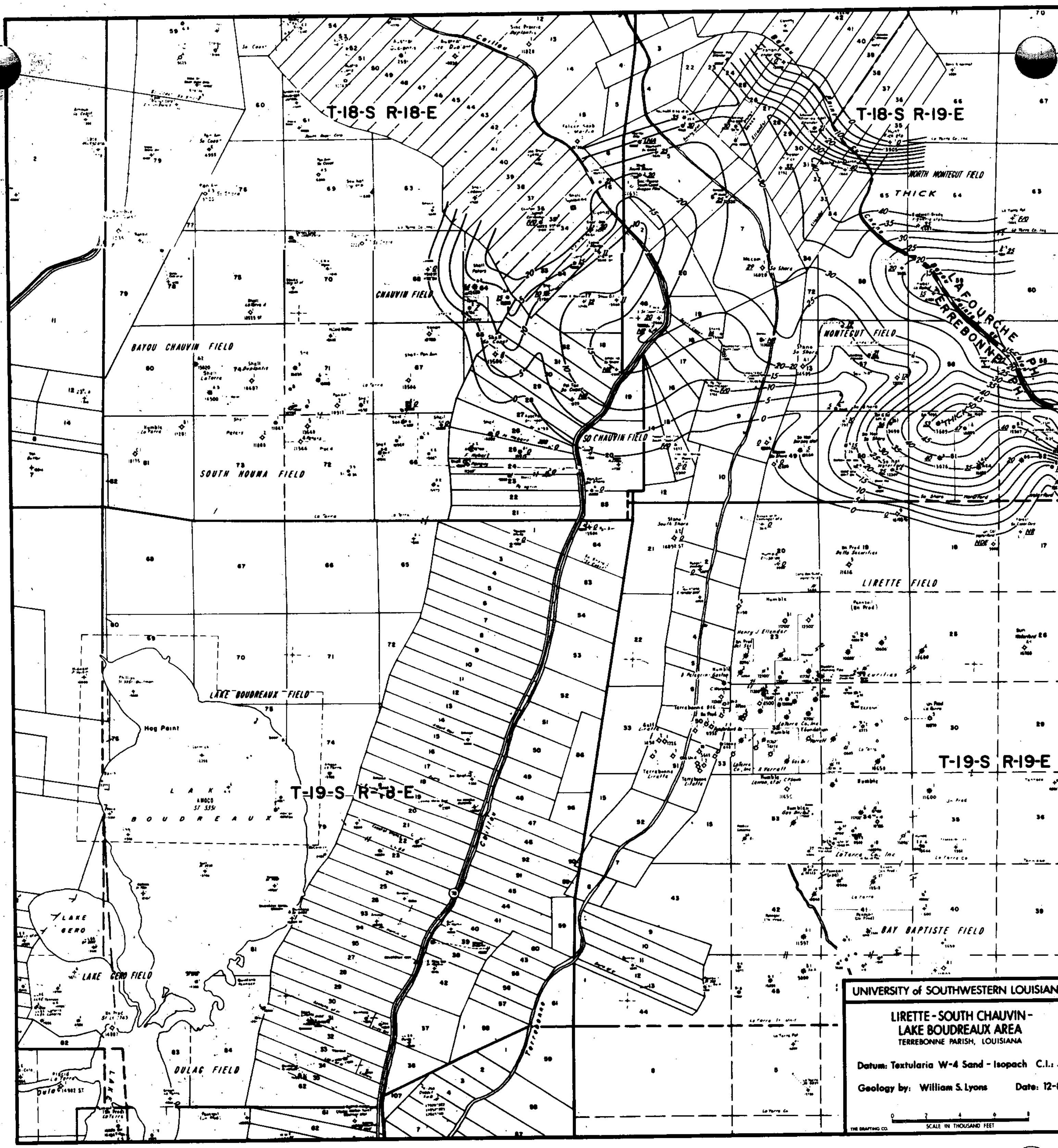
12000'
13000'
14000'
15000'
Unconformity "C"
D-4 Marker
Upper Cyclammina Marker
Lower Cyclammina Marker
Cyclammina Sand
FAULT "F"
±350' FAULT
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN -
LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Upper 11500' Marker
D - D' West - East Stratigraphic Cross-Section
Geology by: William S. Lyons Date: 12-82
Vertical scale: 1" = 1200' Horizontal scale: 1" = 3200'


T-18-S R-18-E
T-18-S R-19-E
T-19-S R-18-E
T-19-S R-19-E
NORTH MONTEGUT FIELD
MONTEGUT FIELD
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
BAY BAPTISTE FIELD
LAKE GERO FIELD
DULAC FIELD
LAFOURCHE PH.
TERREBONNE PH.
THICK
THIN
Hog Point
LAKE BOUDREAUX
LAKE GERO
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Upper Textularia W Sand - Isopach
C.I.: 20'
Geology by: William S. Lyons
Date: 12-
SCALE IN THOUSAND FEET
THE DRAFTING CO.



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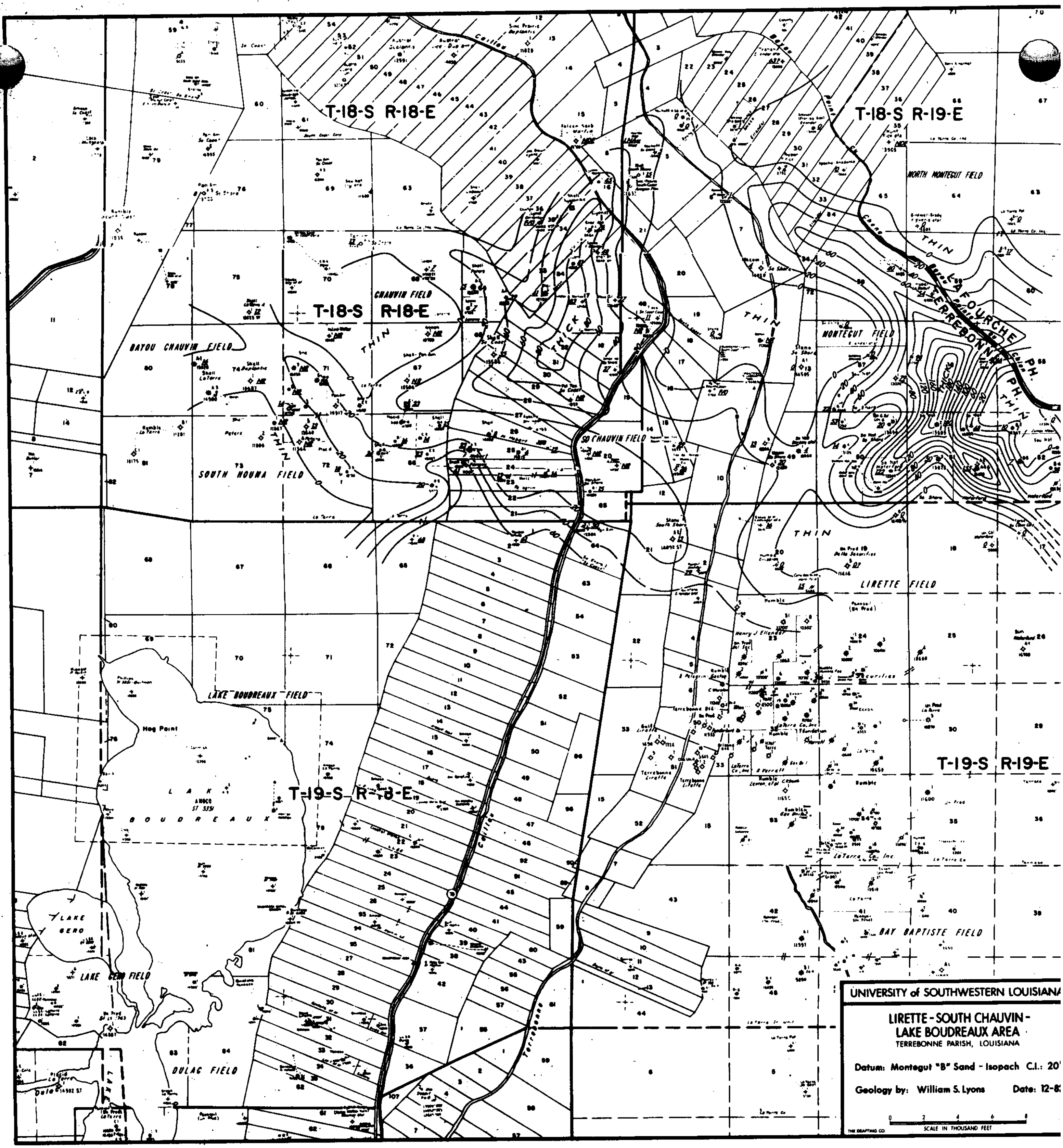
NORTH MONTEGUT FIELD
THICK
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
MONTEGUT FIELD
LAFOURCHE
TERREBONNE
SO CHAUVIN FIELD
SOUTH HOUMA FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
Hog Point
L A K E
B O U D R E A U X
LAKE GERO
LAKE GERO FIELD
DULAC FIELD
BAY BAPTISTE FIELD
UNIVERSITY of SOUTHWESTERN LOUISIAN
LIRETTE - SOUTH CHAUVIN -
LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Textularia W-4 Sand - Isopach C.I.:
Geology by: William S. Lyons
Date: 12-
0 2 4 6 8
SCALE IN THOUSAND FEET
THE DRAFTING CO.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NORTH MONTEGUT FIELD
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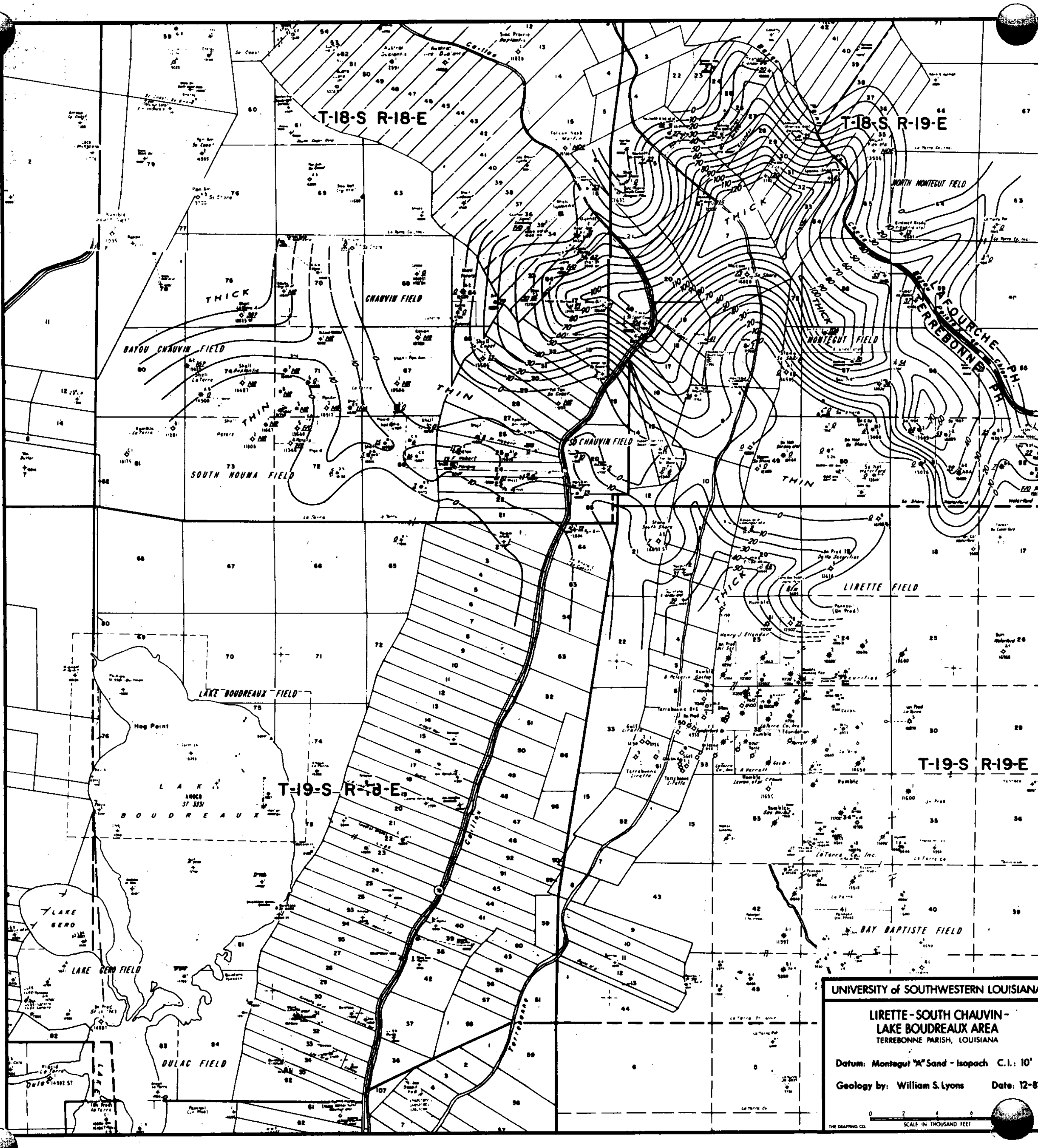
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
BAY BAPTISTE FIELD
LAKE GERO FIELD
DULAC FIELD
LAFOURCHE PH.
TERREBONNE PH.
THIN
THICK
Hog Point
LAKE BOUDREAUX
LAKE GERO
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Montegut "B" Sand - Isopach
Geology by: William S. Lyons
SCALE IN THOUSAND FEET


UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Montegut "A" Sand - Isopach C.I.: 10'
Geology by: William S. Lyons
SCALE IN THOUSAND FEET
T-18-S R-18-E
T-18-S R-19-E
T-19-S R-18-E
T-19-S R-19-E
NORTH MONTEGUT FIELD
MONTEGUT FIELD
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
LAKE GERO FIELD
BAY BAPTISTE FIELD
DULAC FIELD
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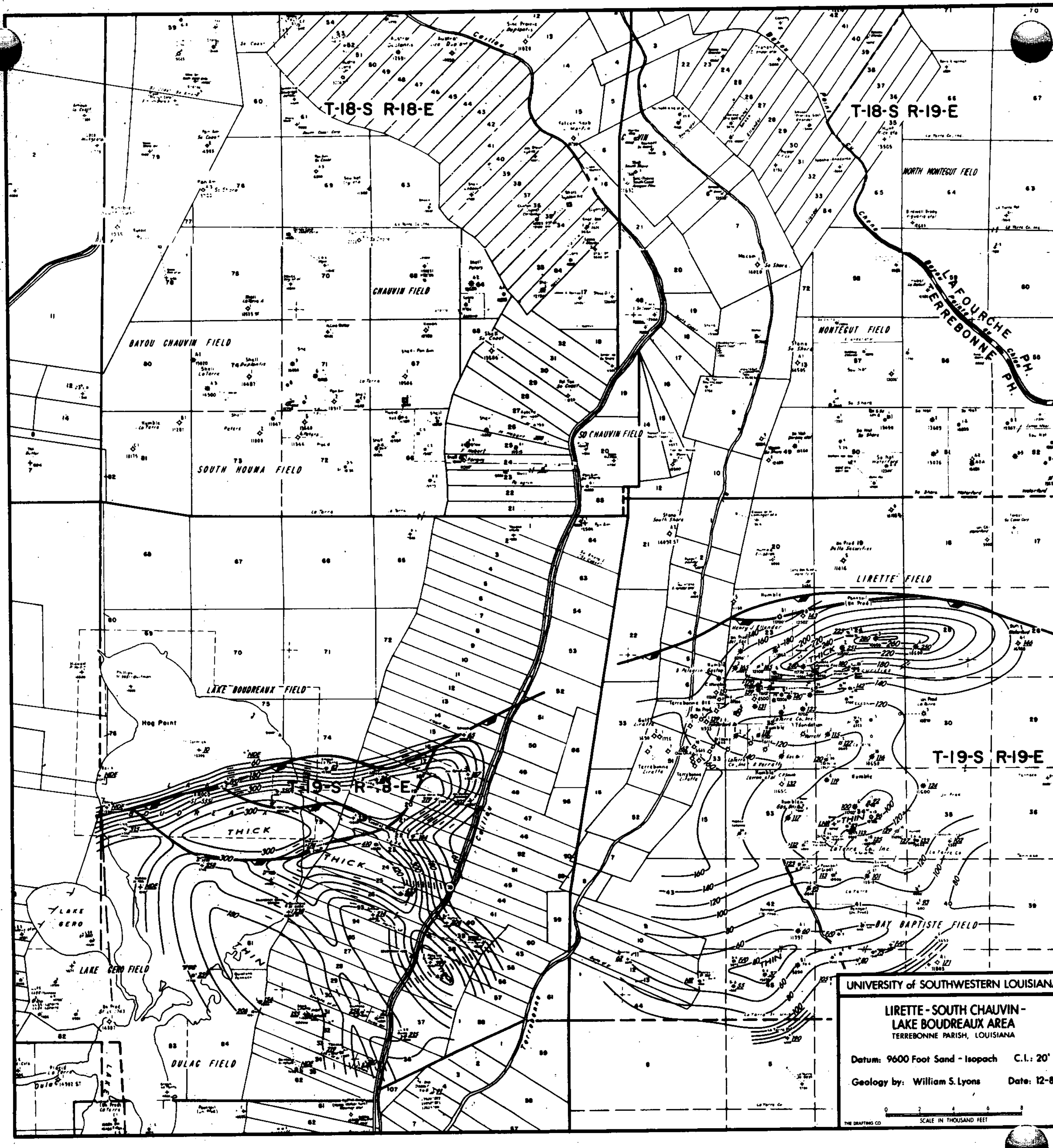
TERREBONNE PH.
THICK
THIN
Hog Point
LAKE BOUDREAUX
LAKE GERO



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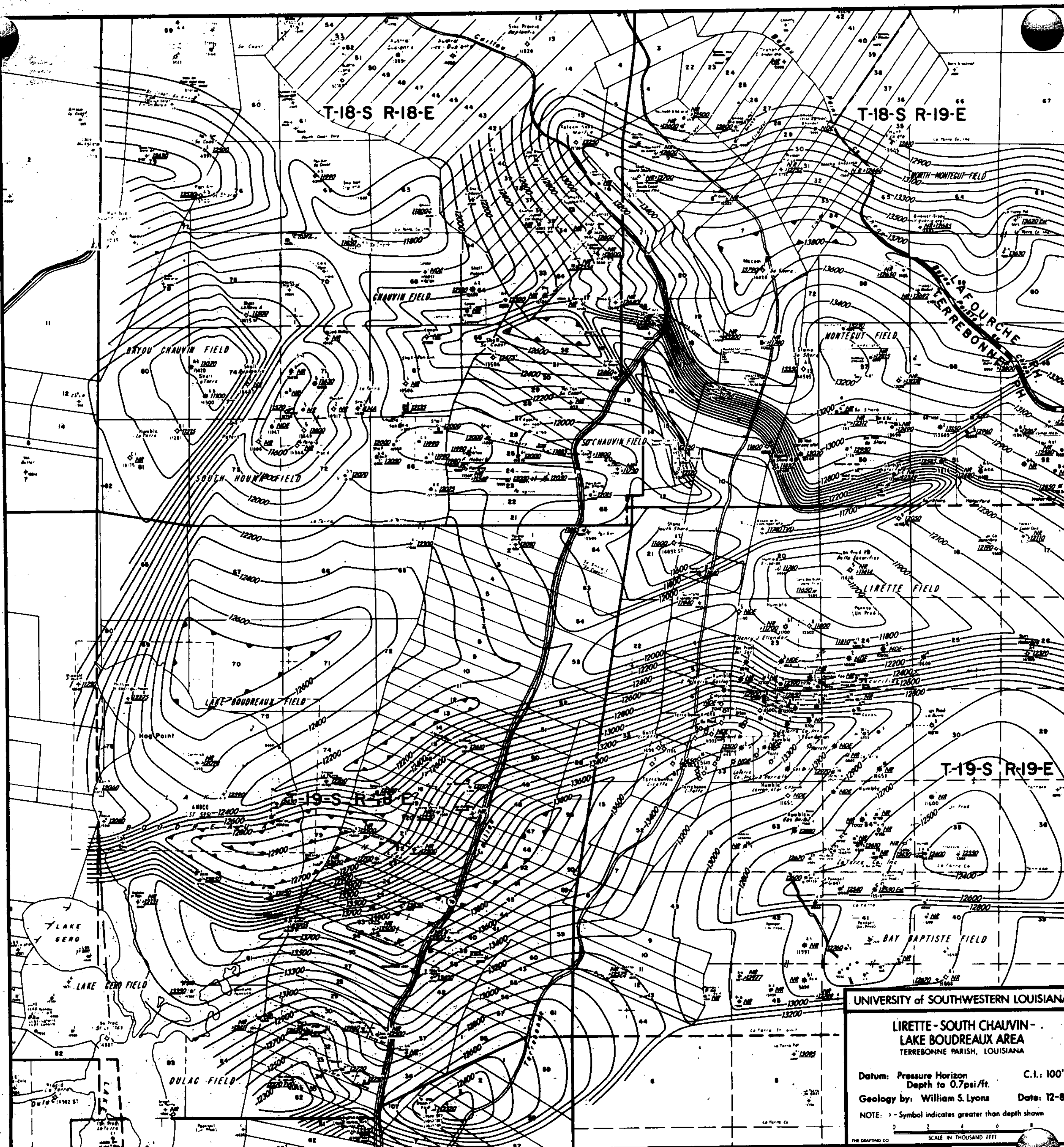
NORTH MONTEGUT FIELD
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
MONTEGUT FIELD
LAFOURCHE PH.
TERREBONNE PH.
LIRETTE FIELD
LAKE BOUDREAUX FIELD
Hog Point
THICK
THIN
LAKE GERO
LAKE GERO FIELD
DULAC FIELD
BAY BAPTISTE FIELD
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: 9600 Foot Sand - Isopach
Geology by: William S. Lyons
SCALE IN THOUSAND FEET



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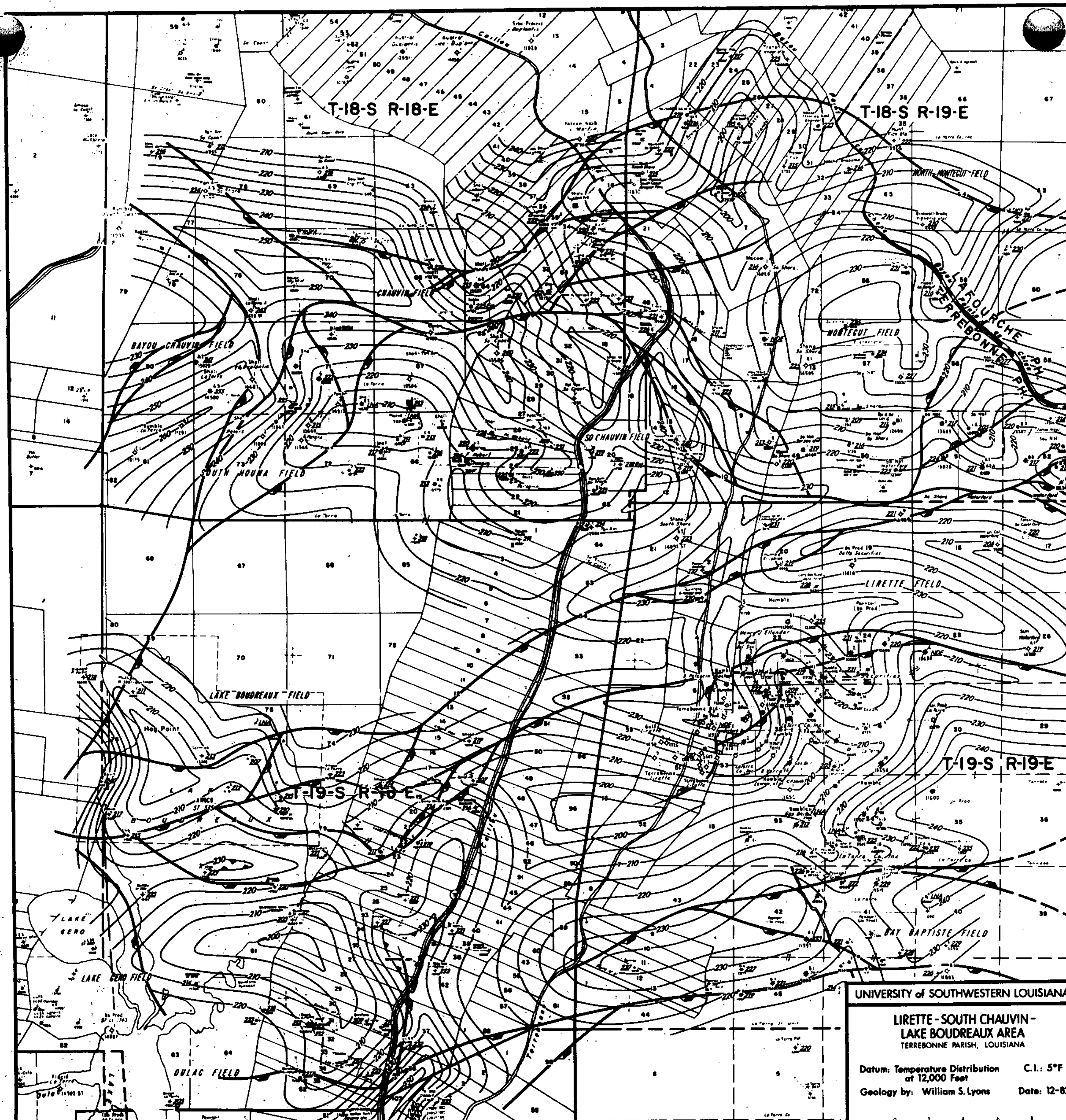
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO. CHAUVIN FIELD
NORTH MONTEGUT FIELD
MONTEGUT FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
Hog Point
LAKE GERO
LAKE GERO FIELD
DULAC FIELD
BAY BAPTISTE FIELD
LAFOURCHE
TERREBONNE
UNIVERSITY of SOUTHWESTERN LOUISIAN
LIRETTE - SOUTH CHAUVIN -
LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Pressure Horizon
Depth to 0.7psi/ft.
C.I.: 100'
Geology by: William S. Lyons
Date: 12-8
NOTE: > - Symbol indicates greater than depth shown
SCALE IN THOUSAND FEET
THE DRAFTING CO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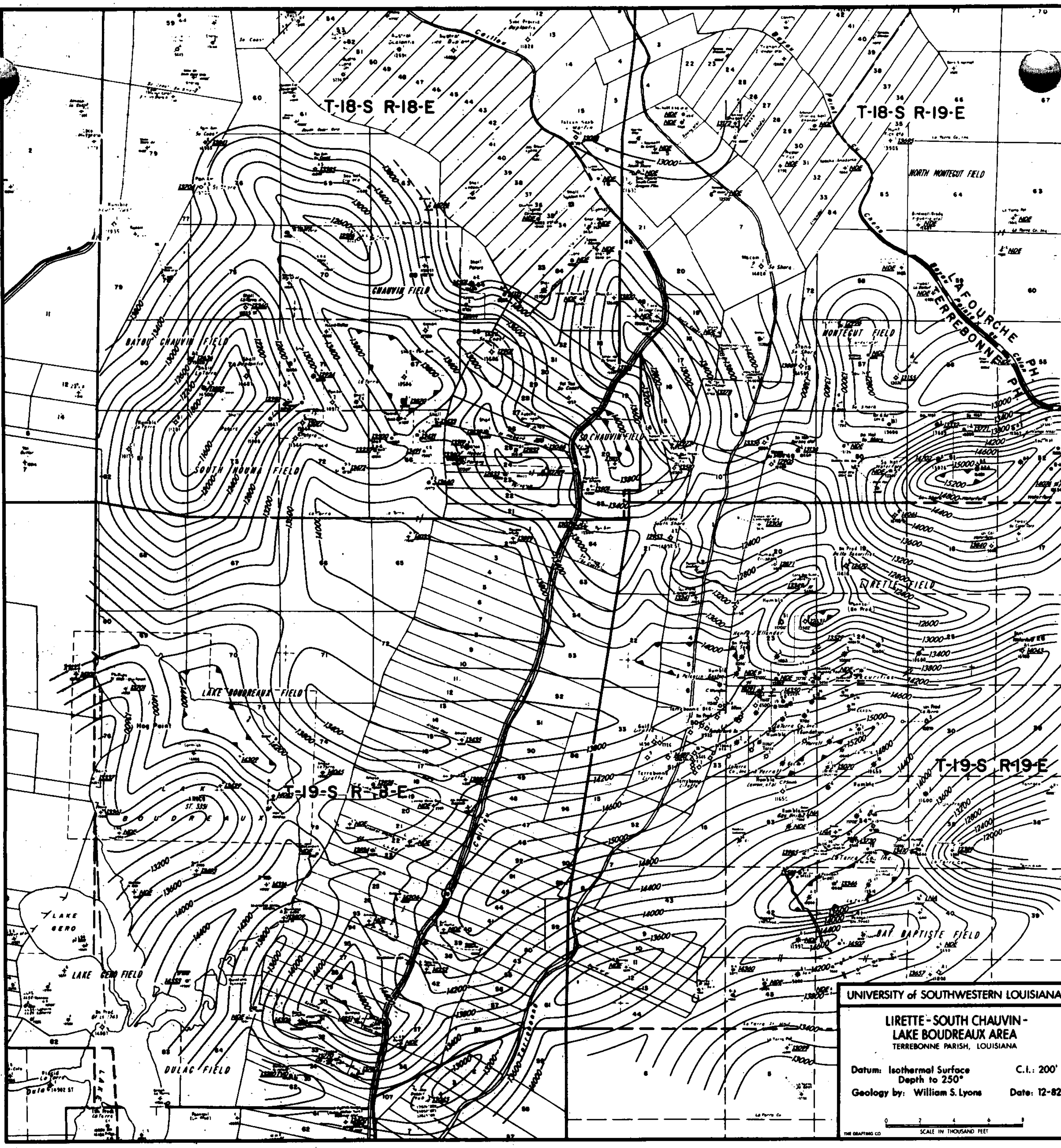
T-19-S R-19-E
CHAUVIN FIELD
BAYOU CHAUVIN FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
NORTH MONTEGUT FIELD
MONTEGUT FIELD
LIRETTE FIELD
LAKE BOUDREAUX FIELD
BAY BAPTISTE FIELD
LAKE GERO FIELD
DULAC FIELD
LAKE GERO
LAFOURCHE
TERREBONNE
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE - SOUTH CHAUVIN - LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Temperature Distribution at 12,000 Feet
C.I.: 5°F
Geology by: William S. Lyons
SCALE IN THOUSAND FEET


T-18-S R-18-E
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T-19-S R-19-E
NORTH MONTECUT FIELD
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BAYOU CHAUVIN FIELD
MONTECUT FIELD
SOUTH HOUMA FIELD
SO CHAUVIN FIELD
LAFOURCHE PH
TERREBONNE PH
LIRETTE FIELD
LAKE BOUDREAUX FIELD
BOUDREAUX
LAKE GERO
LAKE GERO FIELD
BAY BAPTISTE FIELD
DULAC FIELD
UNIVERSITY of SOUTHWESTERN LOUISIANA
LIRETTE-SOUTH CHAUVIN-
LAKE BOUDREAUX AREA
TERREBONNE PARISH, LOUISIANA
Datum: Isothermal Surface Depth to 250°
C.I.: 200'
Geology by: William S. Lyons
Date: 12-82
SCALE IN THOUSAND FEET