DOE/NV/10174

TECHNICAL SUPPORT FOR GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

ANNUAL REPORT

for the period

November 1, 1980 - October 31, 1981

D.G. Bebout, Z. Bassiouni, D.R. Carver, C.G. Groat, R.H. Pilger, Jr., and F.M. Wrighton

March 31, 1982

Work Performed Under Contract No. DE-AC08-81NV10174

LOUISIANA GEOLOGICAL SURVEY
LOUISIANA STATE UNIVERSITY
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SUMMARY

The research conducted at Louisiana State University (LSU) on the geopressured-geothermal project has been assembled here under a single contract and includes a broad spectrum of activities. Research functions and organizations responsible for their completion include Program Management (Louisiana Geological Survey), Resource Assessment (Louisiana Geological Survey), Site-Specific Studies (Department of Geology), Rock Mechanics and Subsidence Modeling (Department of Civil Engineering), Reservoir Analysis and Simulation (Department of Petroleum Engineering), Systems Analysis and Scientific Support (Department of Chemical Engineering), Information Systems (Energy Programs Office), and Environmental Monitoring (Louisiana Geological Survey). Significant accomplishments have been achieved in each of these functions.

The Program Management Function was responsible for all coordination, budgeting, and reporting for all functions. The Fifth Conference on Geopressured-Geothermal Energy was convened in Baton Rouge, and the papers from the Conference were published in the Transactions.

The Resource Assessment Function completed the assessment of the solution-gas resource; the total in-place solution-methane resource of 371 TCF was estimated to be present in the Wilcox, Frio, and Miocene sandstones of onshore Louisiana. The Bayou Hebert Prospect, considered by many as one of the most favorable sites for the location of a designed test well, was studied in detail. Thick sandstones do occur within the geopressured zone, but it was determined that water salinities are excessive according to present standards.

The Site-Specific Function was responsible for conducting detailed studies of prospective areas using seismic data where present. The geological

investigation of the Southeast Pecan Island Prospect has been completed and is reported on here. A new prospect located at the northeastern side of the area was delineated as very favorable and is recommended here as a future potential prospect because of the presence of thick sandstone units in a large fault block and low formation-water salinity.

The Rock Mechanics and Subsidence Modeling Function focused activity primarily on the Parcperdue test-well site. Detailed computer modeling has indicated that, upon complete drawdown of the prospective reservoir, subsidence at the surface will be approximately 0.004 feet.

The Reservoir Analysis and Simulation Function was responsible for conducting reservoir engineering studies utilizing data from the designed test wells; because none of the wells in Louisiana were producing within the contract period, this activity was not feasible. However, because of the difficulty in determining salinity from well logs, research in this function centered on developing a method of analysis which will produce results closer to those from water analyses.

The Annual Report on the Systems Analysis and Scientific Support was not available at the time of this publication and will be submitted by the Principal Investigator to DOE at a later date.

The Information Systems Function set up an Information Center for Geopressured-Geothermal (ICGG) research utilizing resources and data available from research in Louisiana. A computerized data base was developed which incorporates results of resource assessment and test-well activities. The computer capabilities of the group are also being used to store and manipulate environmental monitoring data from the designed test wells.

The Environmental Monitoring Function was responsible for designing and conducting all monitoring of environmental impact resulting from production from the three geopressured-geothermal designed test wells in Louisiana. This activity is continuing on the three wells.

INTRODUCTION - PROGRAM MANAGEMENT

With the beginning of this funding period, November 1, 1980, the Louisiana Geological Survey assumed the program management role for all research conducted at Louisiana State University (LSU) on the Geopressured-Geothermal Project. Prior to this, the Department of Petroleum Engineering and, then, the Energy Programs Office performed this function. The Louisiana Geological Survey, although a state agency operating through the Department of Natural Resources, is located on the LSU campus and, through years of cooperative research with the University, has become an official research institute of LSU. It is through this organizational structure that the Survey has managed the geopressured-geothermal project at LSU.

For the first time, all research functions of the geopressured-geothermal project were organized under a single contract. LSU continued to act as the lead research organization in Louisiana and assumed the responsibility for insuring that information gained from the geopressured-geothermal project is collected, analyzed, and preserved for use by others in the future. With the completion of three test wells in Louisiana, the DOE/Dow No. 1 Sweezy, DOE/Magma Gulf No. 1 Amoco Fee, and DOE/TF&S No. 1 Gladys McCall, large volumes of data are being collected by the subcontractors and are being stored by the Louisiana Geological Survey.

The objectives put forward in the proposal for this funding period are as follows:

1) to coordinate ongoing and new projects funded by the geopressured-geothermal programs,

2) to provide technical advice for the drilling and testing of the wells included in the DOE four-well and Wells-of-Opportunity programs in Louisiana,

3) to act as a repository for all data obtained from the geopressured-geothermal test wells drilled in Louisiana,

4) and to manage and supervise a comprehensive environmental monitoring program for each designed test well in Louisiana

The LSU geopressured-geothermal project is subdivided into the following eight functions, with principal investigators as indicated:

	FUNCTION	PRINCIPAL INVESTIGATOR	DEPARTMENT
I	Program Management	Don G. Bebout	Louisiana Geological Survey
II	Resource Assessment and Coordination of Geologic Studies	Don G. Bebout	Louisiana Geological Survey
III	Site-Specific Studies - geophysics, diagenesis, geochemistry	Rex H. Pilger, Jr.	Department of Geology
IV	Rock Mechanics and Subsidence Modeling	Dale R. Carver	Department of Civil Engineering
V	Reservoir Analysis and Simulation	Zaki Bassiouni	Department of Petroleum Engineering
VI	Systems Analysis and Scientific Support	Adrain E. Johnson, Jr.	Department of Chemical Engineering
VII	Information System	Fred M. Wrighton	Energy Programs Office
VIII	Environmental Monitoring	Charles G. Groat	Louisiana Geological Survey

RESOURCE ASSESSMENT

D. G. Bebout, D. R. Gutierrez, R. P. McCulloh,
M. A. Pino, and N. Y. Salem

IN-PLACE METHANE RESOURCE ASSESSMENT

D. G. Bebout, D. R. Gutierrez, and N. Y. Salem

Introduction

The rationale developed earlier and used in interpreting the various data bases were reported in the DOE final report for "Technical Support for Geo-pressured-Geothermal Well Activities in Louisiana" (August 31, 1981) by Fred M. Wrighton, Don G. Bebout, Dale R. Carver, Charles G. Groat, and Adrain E. Johnson, Jr., (Contract No. DE-AS05-78ET27160). Because the concepts presented in the previous report are so important in developing an assessment evaluation program, most of the text and illustrations are repeated for the convenience of the reader. However, the assessment techniques and calculations are new.

Estimates of the in-place methane resource in the geopressured zone of the U.S. Gulf Coast (Fig. 1) have varied widely from less than 1000 TCF to 49,000 TCF. The most recent assessment was made by Gregory, Dodge, Posey, and Morton (1981) who arrived at a total of 690 TCF for onshore Texas. Well logs from deep oil and gas wells comprise the data base used in all of the assessment studies; the interpretation of these logs varies greatly. In this study of the resource in Louisiana, it was found that the methods used and the results obtained compare favorably with those of Gregory and others for Texas. The Wilcox, Frio, and Miocene were included in this survey (Fig. 2).

One of the prime objectives in constructing the regional cross sections (Figs. 3 to 12) across the south Louisiana Gulf Coast was to aid in assessing the total solution-methane resource in place. The cross sections were deemed necessary not only because they provide point sources of information from key wells, but also because they provide considerably more insight into the significance of each well through logical correlations with others on the section. At the same time as the sections were being prepared, many detailed studies of smaller areas were conducted at LSU and other universities and private organizations throughout the Gulf Coast. Data from these detailed studies were also considered and played a role in determining the size of the resource. Obviously, it is essential that reasonable values be used for all of the parameters which affect the size of the resource. Also, in the areas of insufficient data it is necessary to make reasonable assumptions which are in accord with the general geological principles of structural and depositional processes.

The total area under consideration in south Louisiana includes more than 18,000 mi^2 (Fig. 1). The geopressured formations within this area (Fig. 13) are the Wilcox (1692 mi^2), Frio (5200 mi^2), and Miocene (11,514 mi^2). The parameters considered in this assessment are pressure, sandstone volume, porosity, temperature, and salinity (Table I.)

Sandstone Volume

The location of major sandstone accumulations in the various Tertiary formations depends upon the paleoclimate and location of major river systems which were responsible for delivering the sand and mud to the ancient coastline to be deposited in river deltas or barrier-bar systems. Through geologic time, these rivers systems and sites of accumulations shifted (Fig. 14).

TABLE I. Parameters used in assessing the solution-methane resource.

	Parish	(%) Porosity	($Mile^3$) Bulk Volume	($Mile^3$) Pore Volume	SCF/bbl (CH_4) Solubility	$x10^9$ Pore Volume (bbls)	$x10^{12}$ SCF (CH_4) In-Place
WILCOX	TOTAL	16.5	160	26	58		40.2
FRIO	Acadia	23	50.20	11.5	61	301.50	18.39
	Ascension	27	4.23	1.1	35	28.84	1.01
	Calcasieu	27	120.50	32.5	36.5	852.06	31.10
	Cameron	25	65.24	16.3	54	427.34	23.08
	Iberia	23	0.40	0.1	--	2.62	---
	Iberville	22	26.53	5.8	46	152.06	6.99
	Jefferson	25	62.75	15.7	46	411.61	18.93
	Lafayette	25	30.63	7.6	57	199.25	11.36
	Livingston	26	2.00	0.5	39.5	13.11	0.52
	St. Landry	25	3.75	0.9	33.5	23.59	0.79
	St. Martin	25	30.84	7.7	48	201.87	9.69
	Vermilion	18	19.00	3.4	81	89.14	7.22
	TOTAL	24.8	416	103			129.08
MIOCENE	Assumption	20	10.5	2.1	59	55.05	3.2
	Cameron	25	74.5	18.6	41.5	487.60	20.2
	Iberia	20	39.4	7.9	42	207.10	8.7
	Jefferson	21	28.4	6.0	41	157.30	6.4
	Lafourche	23	74.8	17.2	46	450.90	20.7
	Plaquemines	24	136.7	32.8	47	859.85	40.4
	St. Bernard	25	48.3	12.0	25	314.58	7.9
	St. Charles	25	23.5	5.9	42	154.67	6.5
	St. James	27	3.1	0.8	34.5	20.97	0.7
	St John the Baptist	25	8.7	2.2	32	57.67	1.8
	St. Mary	20	114.7	22.9	56	600.32	33.6
	Terrebonne	20	101.6	20.3	56	532.16	29.8
	Vermilion	18	82.2	14.8	58	387.98	22.5
	TOTAL	21.9	746.4	163.5			202.4

The first buried sediments to be deposited gulfward of the older, buried Lower Cretaceous shelf margin (Fig. 1) became the oldest growth-faulted and geopressured sandstones and shales in that area. The stability of the Lower Cretaceous carbonate shelf landward of the shelf edge prevented growth faulting there. Gulfward of the Lower Cretaceous shelf edge, prograding deltaic and shoreline sands and muds were deposited on soft, unstable basinal mud (Fig. 15), and growth faulting was initiated. The formations to reach this position onshore are the Tuscaloosa, Wilcox, Vicksburg/Frio, and Fleming (Fig. 2). In Texas, the oldest known geopressured section consists of Tertiary Wilcox sandstones and shales; in Louisiana, the Upper Cretaceous Tuscaloosa section is geopressured.

The initial constraint on reservoir size is imposed by the various depositional models as understood from the study of modern areas. Superimposed upon the depositional models are the numerous contemporaneous (growth) faults which are assumed to be barriers to lateral fluid flow. The major growth-fault systems in the Gulf Coast (Fig. 16) are complex and result in the subdivision of sandstone-prone areas into units generally averaging less than 50 mi^2 in area. Detailed study invariably results in the identification of many additional faults and further reduction in the size of the area of lateral continuity (Bebout, Weise, Gregory, and Edwards, 1979; McCulloh and Pino, 1981; Flournoy and Ferrell, 1980). There may be fluid flow across a fault if sandstones not genetically related are juxtaposed.

In general, sandstone units become thinner and less abundant with depth. Exceptions to this overall trend result from variations in sediment supply, climate, and subsidence rates during specific geologic times and consequent differences in the amount of progradation of sand units into the Gulf. Norwood and Holland (1974) illustrate the general changes in sandstone thickness and occurrence for the offshore Pleistocene (Fig. 19). Norwood and Holland show thick sandstones and thin shales in the hydropressured zone, interbedded sandstone and shale in the transition zone, and thick shales and thin sandstones in the geopressured zone. This general trend is substantiated by the trends shown on the regional cross sections across south Louisiana (Figs. 4 to 12) and Texas (Gregory and others, 1980). These cross sections also show important exceptions where thick sandstone units occur deep in the geopressured zone in Section C, Well 9 (Fig. 6), and Section D, Wells 11 and 12 (Fig. 7). Although the thick sandstone units in the geopressured zone do not conform to the general trend, they are not at all rare; however, it is important to emphasize that thick geopressured sandstones are the exception to the regional model and do not occur everywhere.

The sandstone volume (reservoir bulk volume) was obtained from the net-sandstone maps (Figs. 17 and 18) by planimetering each contour. The area thus obtained was multiplied by the contour value in order to obtain the volume. It should be pointed out that this figure is a minimum because many wells did not penetrate the entire formation and no additional sandstone was added to account for the remainder of the section. In the case of the Wilcox, an assumption of 500 ft of net sandstone was made because of the lack of wells extending to the base.

Pressure

The top of geopressure occurs just beneath the massive sandstones, as shown by Norwood and Holland (Fig. 19) and discussed in the previous section. The top is picked more precisely at the distinct break to a lower resistivity in the shale section, aided by the point at which drilling muds heavier than 13 ppg were used (Figs. 20 to 22). The depth to the top of geopressure (Fig. 23) depends upon the amount of porous sandstone present in the section.

Gregory and others (1980) describe this phenomenon along the upper Texas Gulf Coast where the top of geopressure is deeper than -10,000 ft along the Wilcox sandstone trend, between -8000 to -10,000 ft downdip where Wilcox prodelta and shelf shales predominate, and again deeper than -10,000 ft along the Frio sandstone trend. This relationship of pressure to the amount of sandstone within each formation continues to the east into Louisiana, but is not so well defined because of the large number of salt domes which interrupt the pattern.

In general, the depth to the top of geopressure is shallower along the lower Texas Gulf Coast and deeper to the northeast into Louisiana; for example, the top cf geopressure ranges in depth from -7000 to 12,000 ft along the lower Texas Gulf Goast and from -9000 to greater than -18,000 ft in Louisiana.

The pressure for each well in a parish was determined at a depth between the top and bottom of the formation according to the pressure/mud-weight formula:

$$P = 0.052 \times D \times p$$

Where P is the pressure in $lb/in.^2$,

D is the depth in feet to the middle of the formation,

and p is the mud density (weight) in lb/gal.

The pressures for the wells in a parish were calculated, and the average for all these wells was used. Shale-resistivity plots (Figs. 20 to 22) from well logs combined with mud weights were used to identify the top of geopressure.

Temperature

Bottom-hole temperatures recorded on well logs make possible the prediction of subsurface temperature trends with depth in Texas and Louisiana. The temperatures have been recorded on the regional cross sections (Figs. 4 to 12) and interpolated to 200°F and 300°F. The 200°F isotherm occurs near the top of geopressure and generally ranges in depth from -10,000 to -12,000 ft. However, the 200°F isotherm occurs as shallow as -8000 ft in the Frio and Wilcox formations. The 300°F isotherm occurs between -13,000 and -18,000 ft.

The geothermal gradient in the geopressured zone of the Miocene and Frio decreases from greater than 2.5°F/100 ft along the lower Texas Gulf Coast, to 1.8 to 2.1°F/100 ft along the upper Texas Gulf Coast and west Louisiana, to 1.2 to 1.3°F/100 ft in east Louisiana; consequently, the 300°F isotherm occurs at -13,000 to -15,000 ft in Texas and west Louisiana, but at -15,000 to -18,000 ft in east Louisiana.

Temperature plots have been prepared for each parish (Figs. 24 to 27) using bottom-hole measurements corrected to equilibrium temperature. The temperature used for the assessment is the temperature at the average depth of the formation in the parish.

Salinity

In general, salinity increases with depth and is highest in the hydropressured zone, just above the geopressured zone. Here in the major hydrocarbon-producing zone, salinity is generally 100,000 ppm or greater. In the geopressured zone, the salinities are highly variable and range from more than 100,000 ppm to less than 20,000 ppm. Controls on the formation-fluid salinity are poorly known, but reservoir porosity and permeability, aquifer, size, nature and spacing of bounding growth faults, and fluid movement along the faults and out of overlying and underlying shale units during burial are probable contributing factors.

The salinity of the formation was calculated using the method developed by Silva and Bassiouni (1981). The average salinity of each parish was determined by addding all the salinity values of formation water of all sandstones within the parish and dividing by the number of wells in that parish.

Solubility of methane is a function of pressure and temperature and salinity of the formation water. In this report, methane solubilities were computed by the empirical equation of Blount, Price, Wenger, and Tarullo (1979). The equation is:

$$\log_e(CH_4) = 3.6003 + 1.1176 \times 10^{-3}\ T\log_e P + 0.10002\ Y$$
$$- .01634\ T = 1.6574 \times 10^{-5}\ T^2\ -0.2828 \times 10^{-3} TY$$
$$-0.01124\ Y\log_e P + 2.1262 \times 10^{-5}\ YT \log_e P$$

Where CH_4= methane solubility, SCF/bbl,

T = temperature, degrees, Kelvin

P = pressure, psi,

and Y = NaCl concentration, weight percent.

Price, Blount, MacGowan, and Wenger (1981) report that the original experimental data of Blount and others (1979) is in error by 10 %. However, this correction is very small compared to the much larger errors inherent in the other data which have gone into the final calculations and, therefore, has not been taken into account in this assessment.

Porosity-Permeability

Porosity decreases with depth uniformly and, in general, predictably. Loucks, Dodge, and Galloway (1979) showed this trend very clearly in the lower Tertiary by using many diamond-core analyses from the Texas Gulf Coast (Fig. 28). A similar trend in Louisiana is displayed using diamond-core analyses from Core Laboratories data (Fig. 29). However, it is important to note that there are wide variations in porosity at any depth because of differences in original composition of the sand, burial history of the sediment, and formation-fluid composition and movement.

Porosity plots by parish (Figs. 30 to 32) are probably more meaningful for prospect evaluation. For example, in Cameron Parish (Fig. 30), site of the Gladys McCall test well, porosities ranging from 15 to 30% can be expected at the proposed reservoir depth. Similarly, in LaFourche Parish (Fig. 32), proposed site of another test well, the porosities at the projected reservoir depth will range between 20 and 25%. Porosity plots of this type are now available for all parishes in south Louisiana and have already been published for subdivisions comprising groups of counties in Texas (Gregory and others 1980).

Permeability plots (Fig. 33) using the same samples as those used for porosity show considerably more variation; consequently, permeability is more difficult to predict.

The average porosity for each parish was determined using the porosity/depth plot constructed for each parish. Data on this plot included core analyses from diamond and sidewall cores and from reservoir pressure tests. It is obvious from examining the spread of values shown on the plots that this number is extremely generalized. Porosity of many individual sandstones will diverge greatly from the value used here.

Assessment

Regional assessment of the volume and distribution of potential sandstone reservoirs from each formation was made from data from the 15 dip cross sections and 1 strike cross section. Reservoir bulk volume was determined by constructing a new sandstone isopach map. The contour lines of net sandstone were planimetered, and the units obtained were converted to acres. A plot of the contour values-vs-acres was used to determine the bulk volume in acre-feet, which then was converted to cubic miles.

The Wilcox corridor comprises an area of 1692 mi^2 (4382 km^2). The stratigraphic section extends from -11,000 ft to the deepest significant sandstone occurrence. For the estimate of the total volume of in-place methane dissolved in formation waters, an assumption of an optimistic average thickness of 500 ft of net sandstone was made. The fact that not enough wells penetrated to the base of the Wilcox made it difficult to obtain a realistic volume of the net sandstone. Based on the assumed value of 500 ft, the bulk volume of Wilcox sandstone was calculated to be 160 mi^3 (699 km^3), with an average porosity of 16%. The methane solubility value was estimated to be 58 SCF/bbl, based on the empirical equation of Blount and others (1979). The total in-place solution methane for the Wilcox corridor in Louisiana is calculated to be 40.2 TCF.

The areal extent of the Frio corridor is 5200 mi^2 (13,468 km^2). The total bulk volume of Frio sandstone below 8000 ft is estimated to be 416 mi^3 (1741 km^3). The total pore volume which is assumed to be filled with water with no net pay of hydrocarbon is estimated to 103 mi^3 (429 km^3 using an average porosity for the Frio corridor of 24%. Methane solubility values for the formation waters of the Frio corridor range from 33.5 SCF/bbl to 81 SCF/bbl. The total volume in place of solution methane in Frio reservoirs in Louisiana is 129 TCF.

The area extent of the Miocene corridor is 11,514 mi^2 (29,821 km^2). The lower Miocene extends over 6176 mi^2 (15,996 km^2) and contains a total bulk volume of 426 mi^3 (1782 km^3). The total pore volume which is assumed to be filled with water with no net pay of hydrocarbon is estimated to be 87.4 mi^3 (366 km^3), using average porosity of 20% for the lower Miocene. Methane solubility values for formation waters of the geopressured lower Miocene average 50 SCF/bbl. Therefore, the total in-place volume of methane for lower Miocene in Louisiana is 118.7 TCF (13,825 km^2). The areal extent of the middle Miocene corridor is 5338 mi^2. The pore volume is 76.4 mi^3 (319.7 km^3), using an average porosity of 24%. Methane solubility values for formation waters of geopressured middle Miocene average 38.8 SCF/bbl. The total in-place volume of methane is 83 TCF. A total volume of 201 TCF of in-place methane has been assessed for the total onshore Miocene.

Total in-place solution-methane resources of 371 TCF was estimated to be present in the Wilcox, Frio, and Miocene of onshore Louisiana. It is believed that this assessment is based on a reasonable interpretation of the data now available from the Louisana Gulf Coast; however, it is a minimum value because of the lack of wells which penetrate the entire section of each unit evaluated. The Louisiana resource estimate is compatible with that report for Texas of 690 TCF. Therefore, the total solution-methane resource of Texas and Louisiana is calculated to be aproximately 1000 TCF. Although considerably smaller than several earlier predictions, this resource is still sizable and worthy of further research and development.

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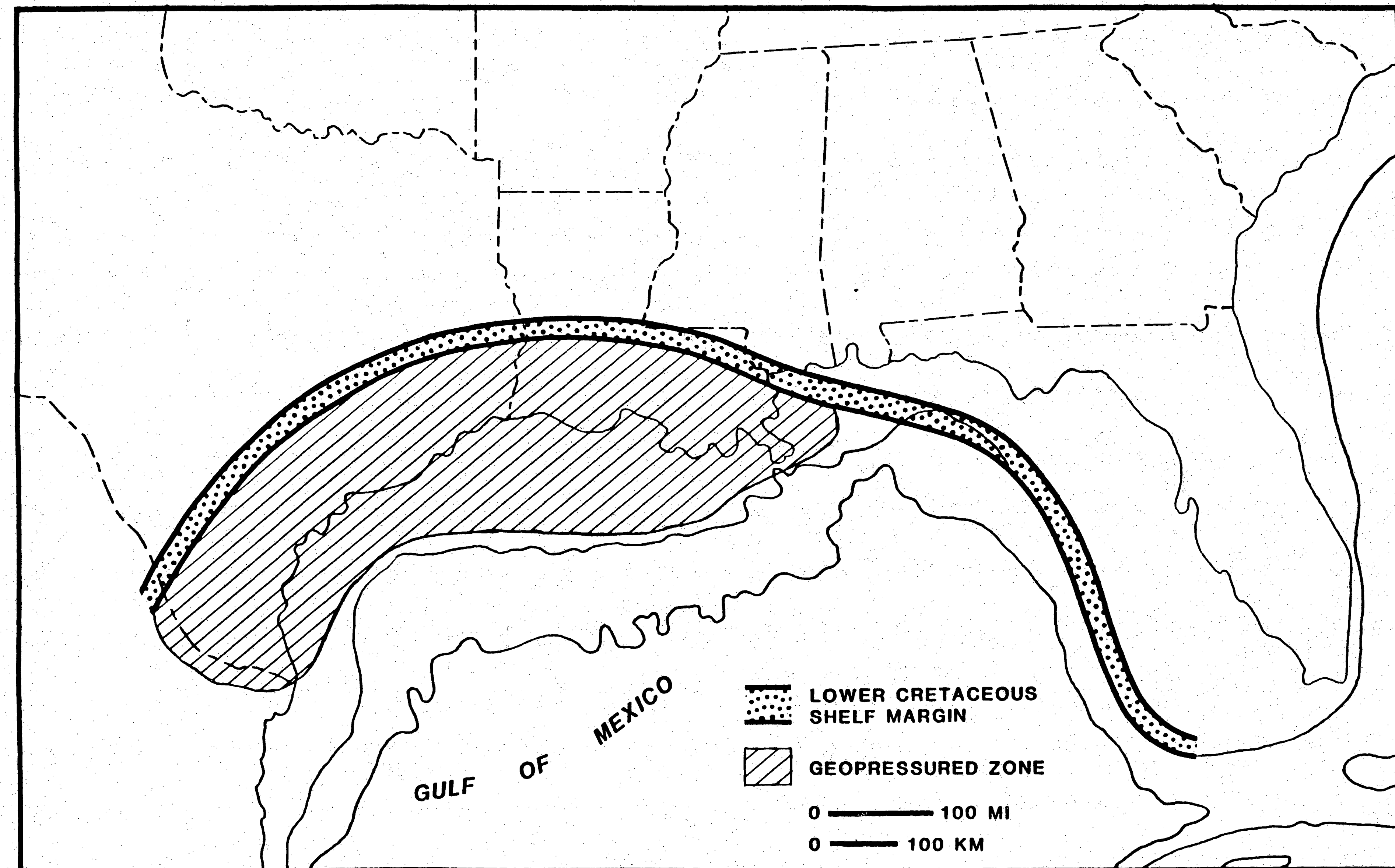

Figure 1. Geopressured zone along the Texas and Louisiana Gulf Coast.

SYSTEM	SERIES	GROUP/ FORMATION
QUATERNARY	RECENT PLEISTOCENE	UNDIFFERENTIATED HOUSTON
TERTIARY	PLIOCENE	GOLIAD
	MIOCENE	FLEMING
		ANAHUAC
	?——?	
	OLIGOCENE	FRIO
		VICKSBURG
	EOCENE	JACKSON
		CLAIBORNE
		WILCOX
		MIDWAY
CRETACEOUS	UPPER	NAVARRO
		TAYLOR
		AUSTIN
		TUSCALOOSA

Figure 2. Upper Cretaceous and Tertiary formations of the northern Gulf Coast.

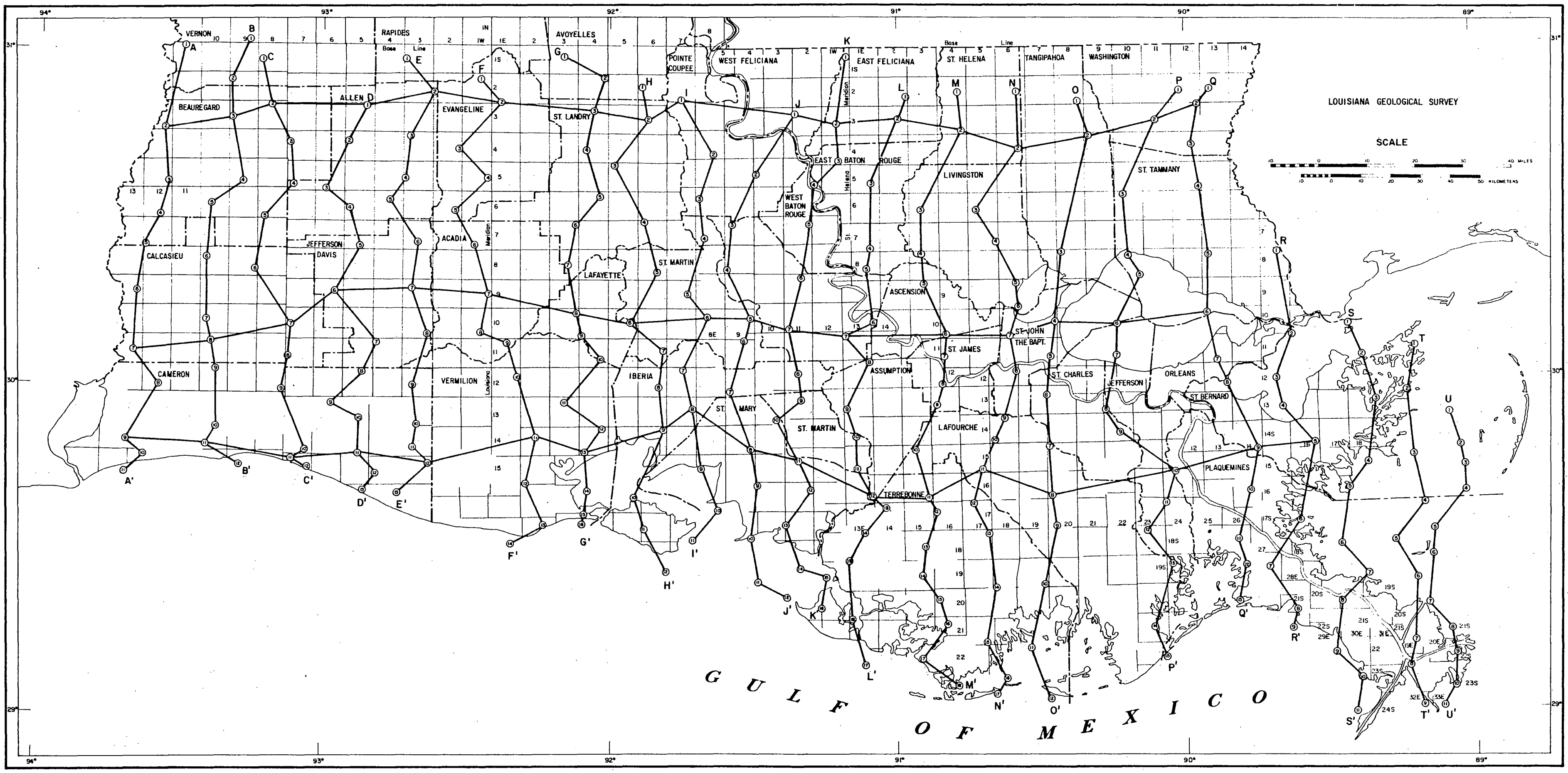

Figure 3. Location of regional dip and strike sections.

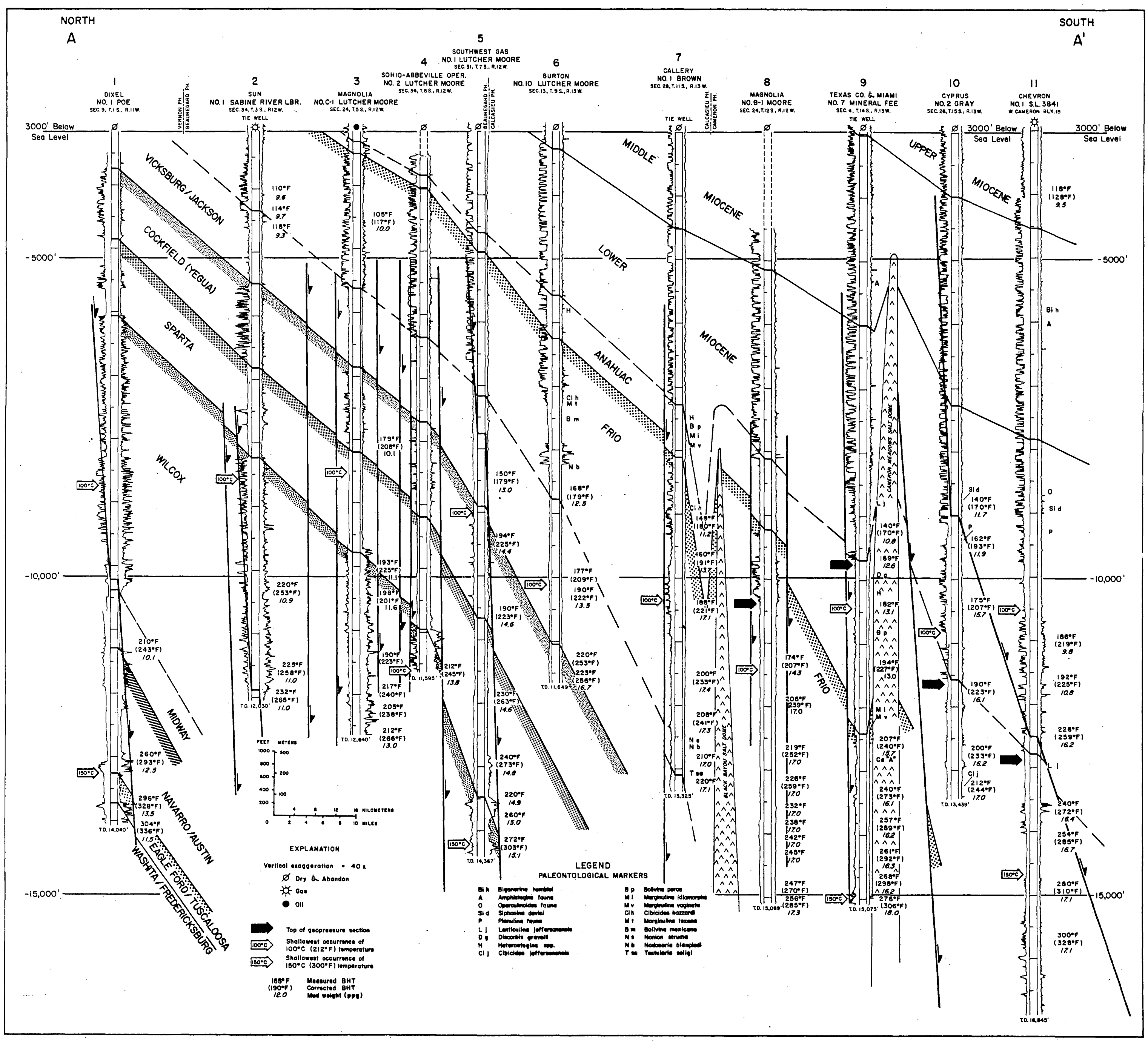

Figure 4. Dip section AA'.

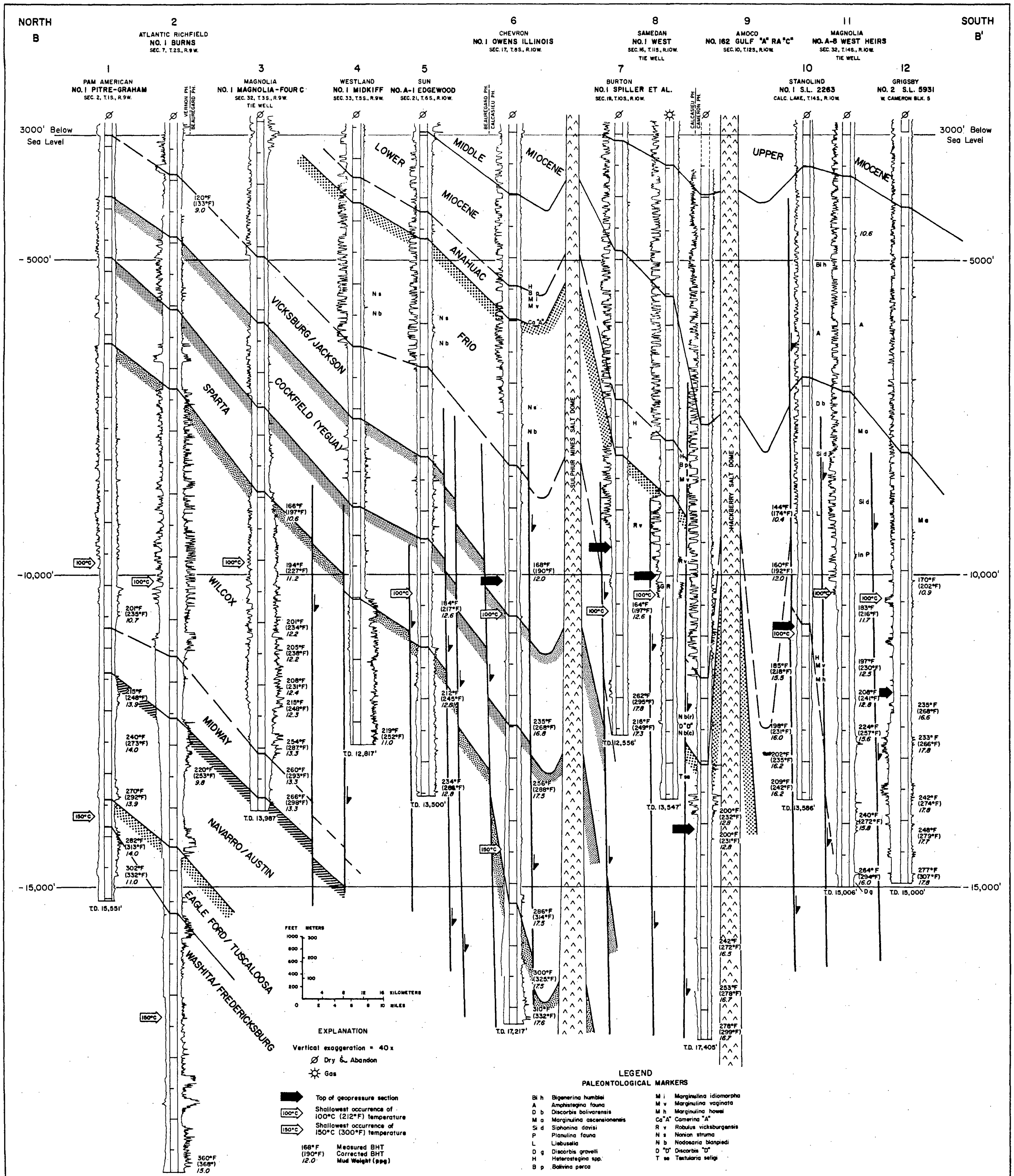

Figure 5. Dip section BB'.

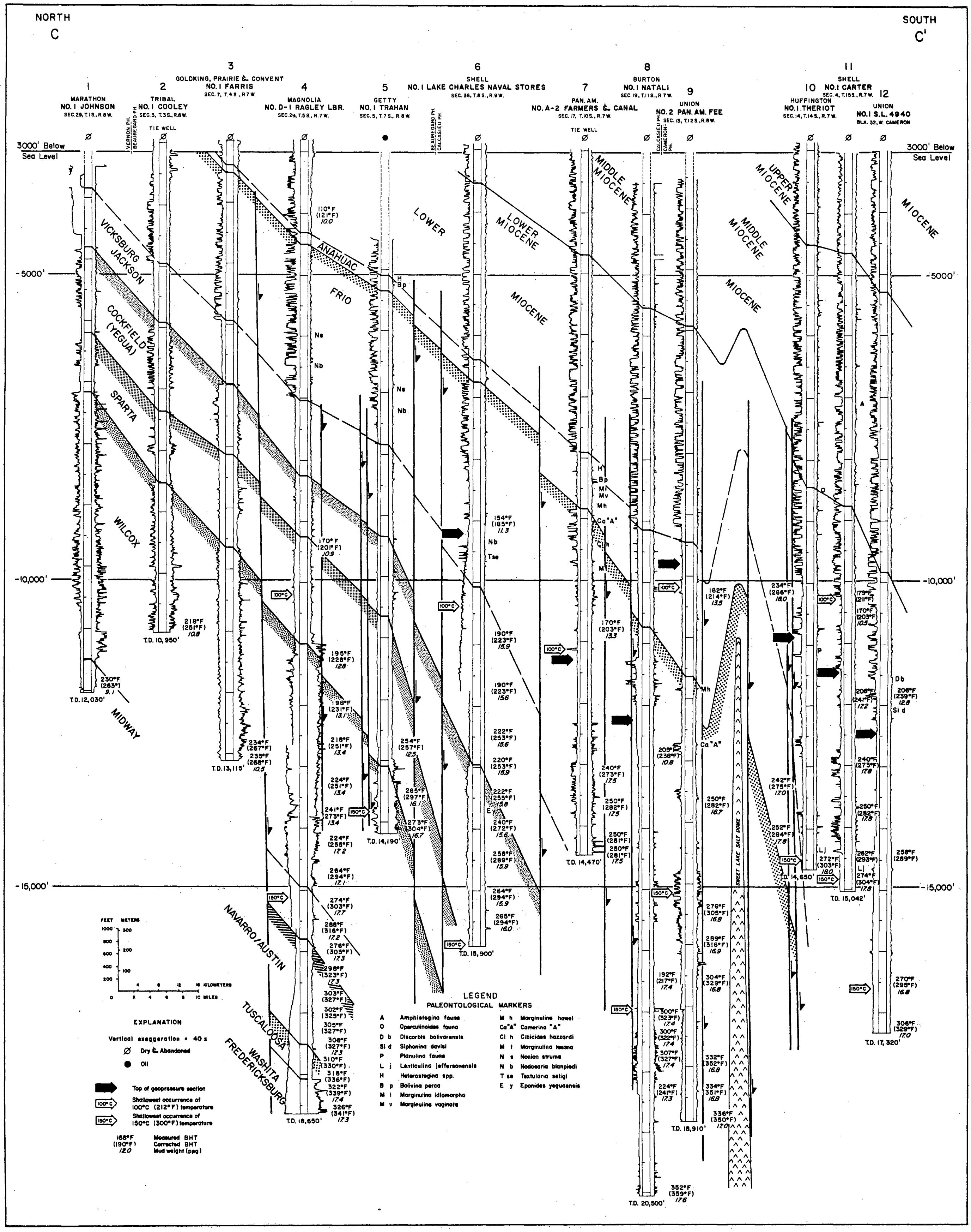

Figure 6. Dip section CC'.

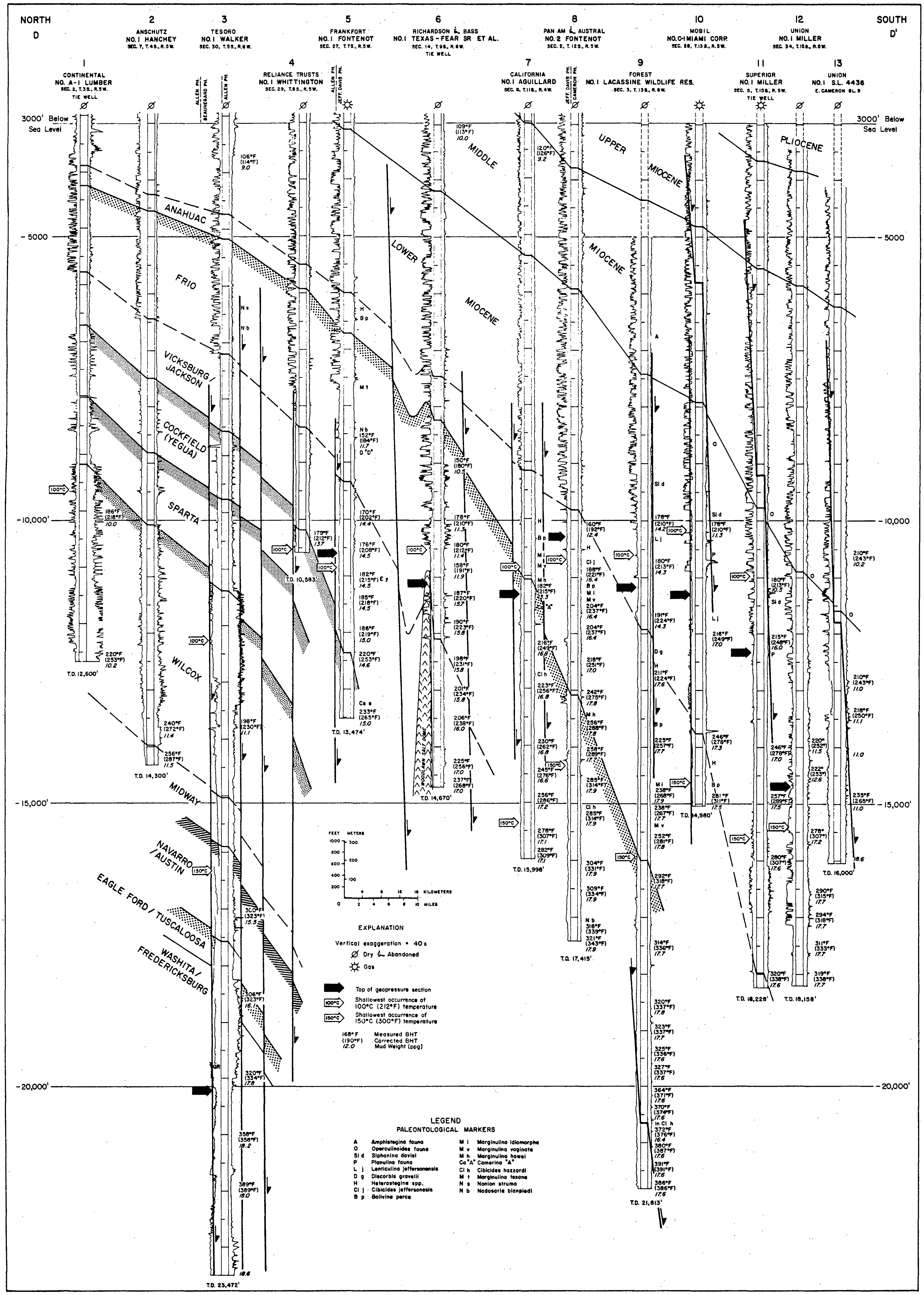

Figure 7. Dip section DD'.

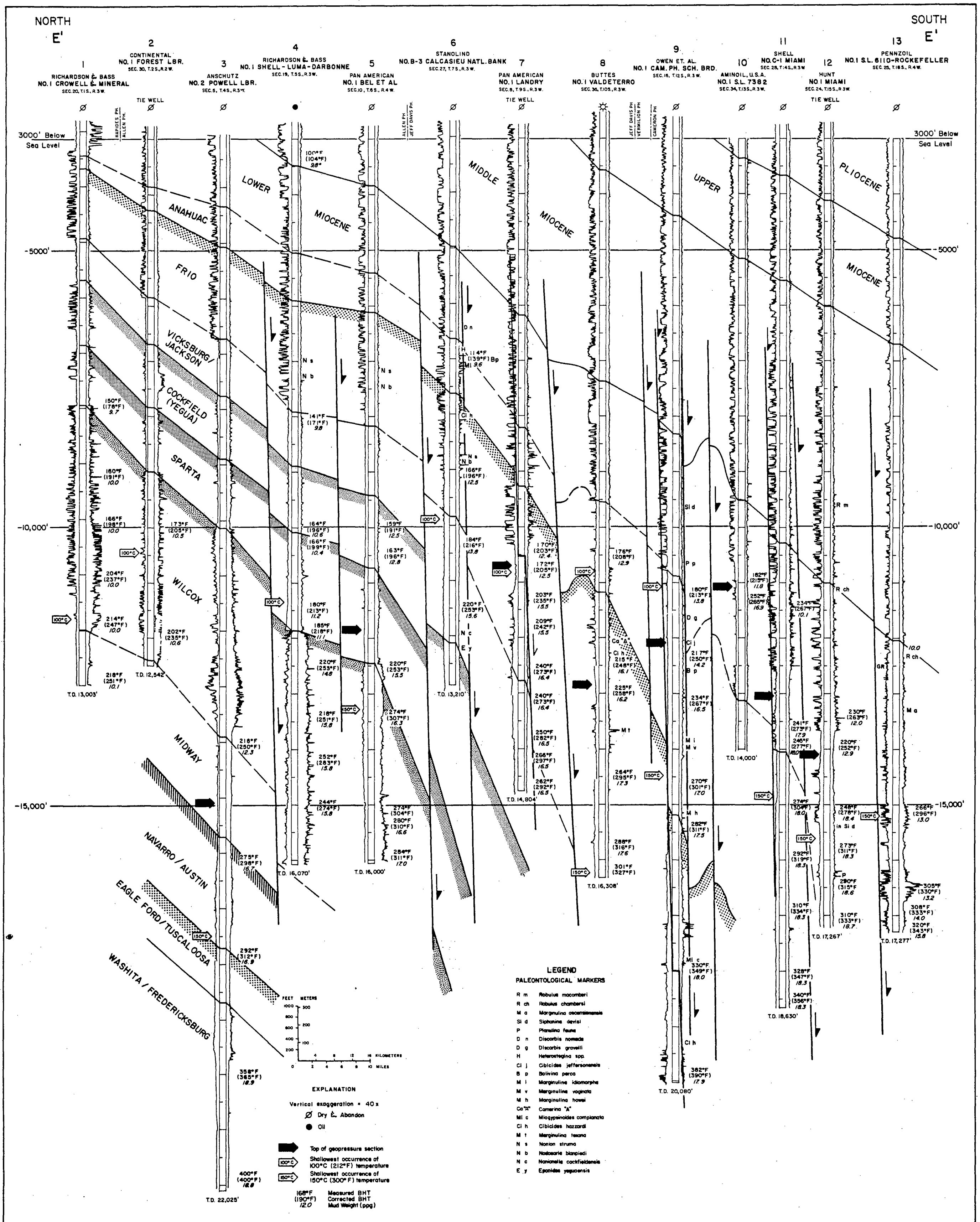

Figure 8. Dip section EE'.

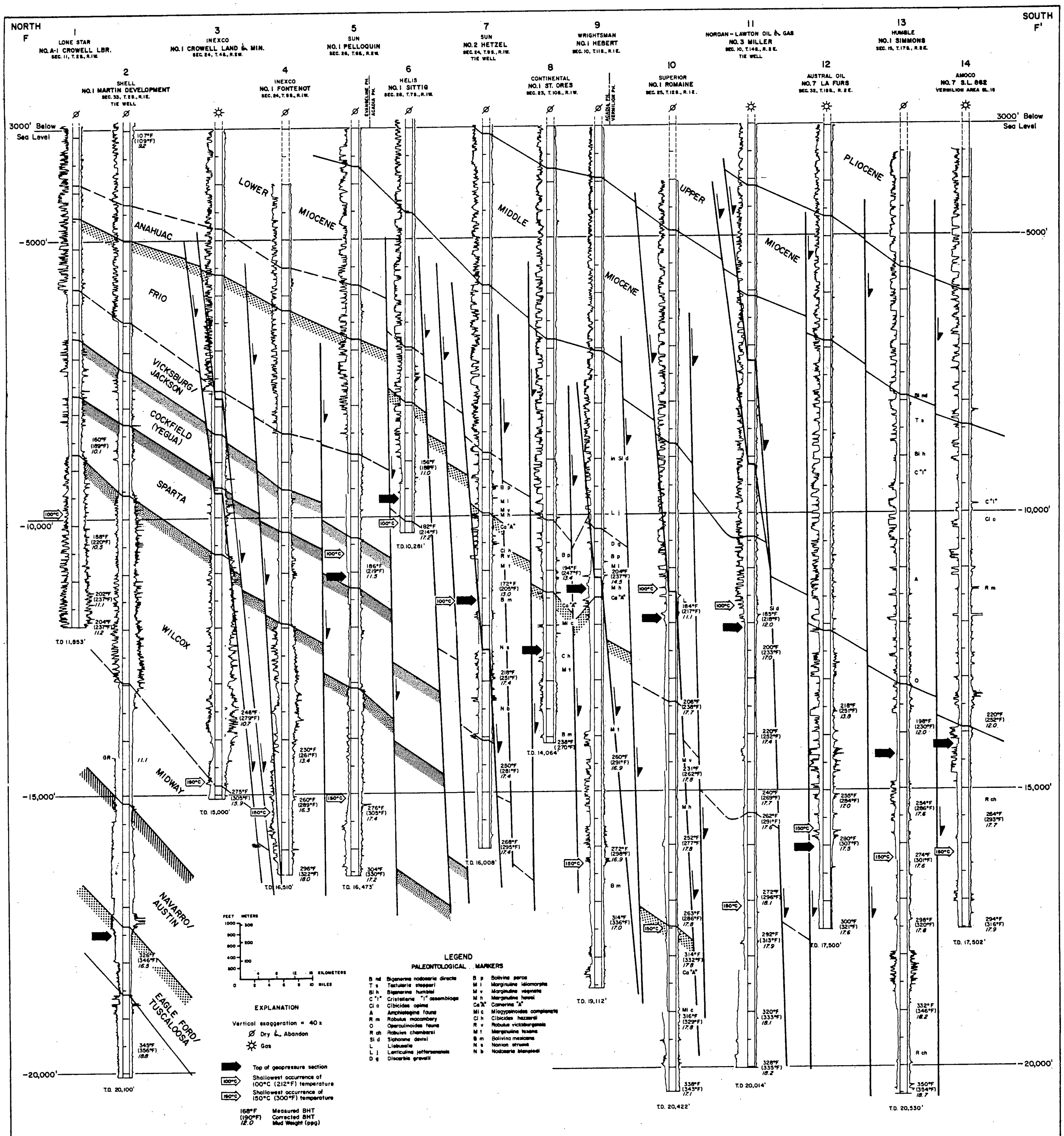

Figure 9. Dip section FF'.

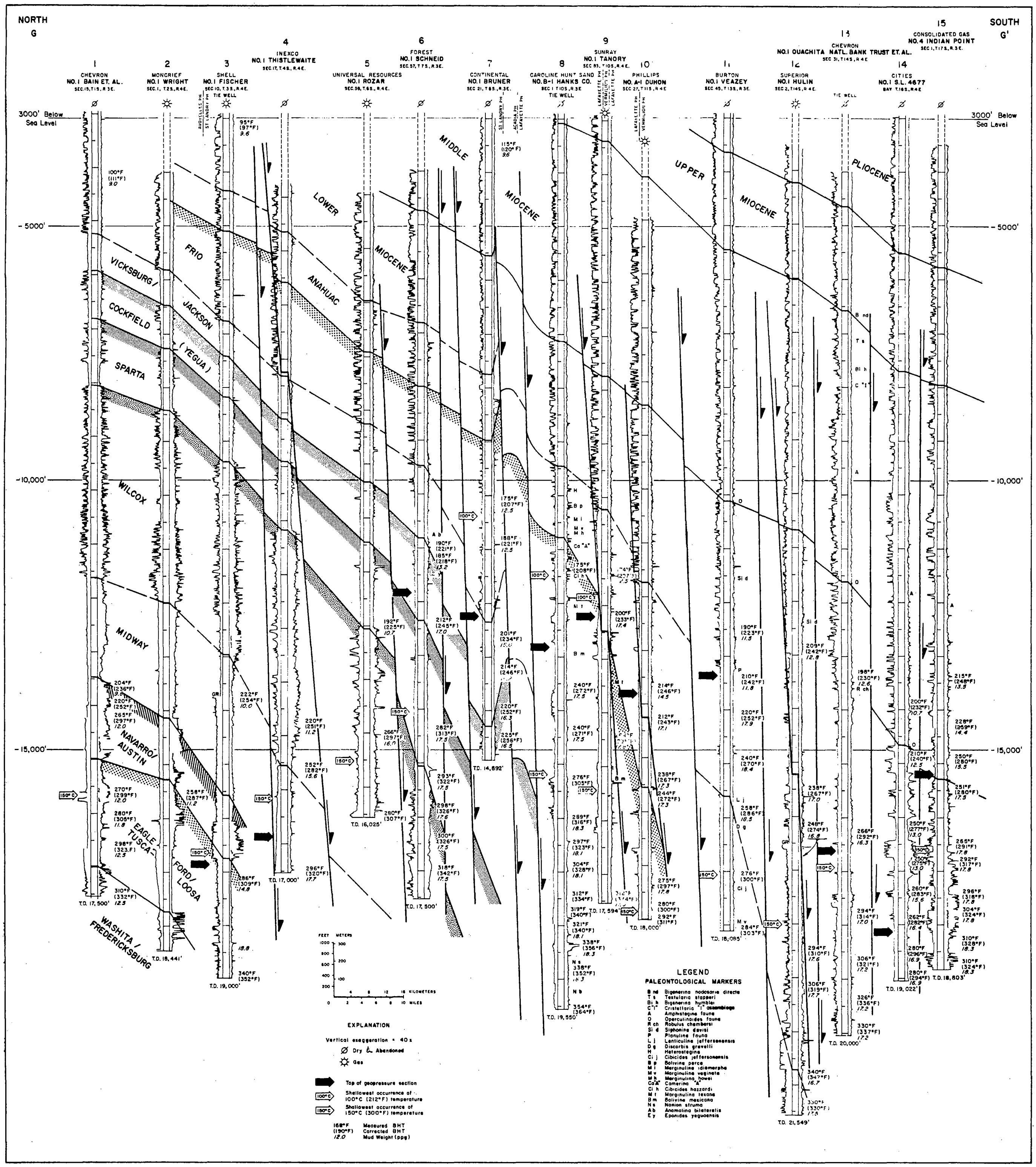

Figure 10. Dip section GG'.

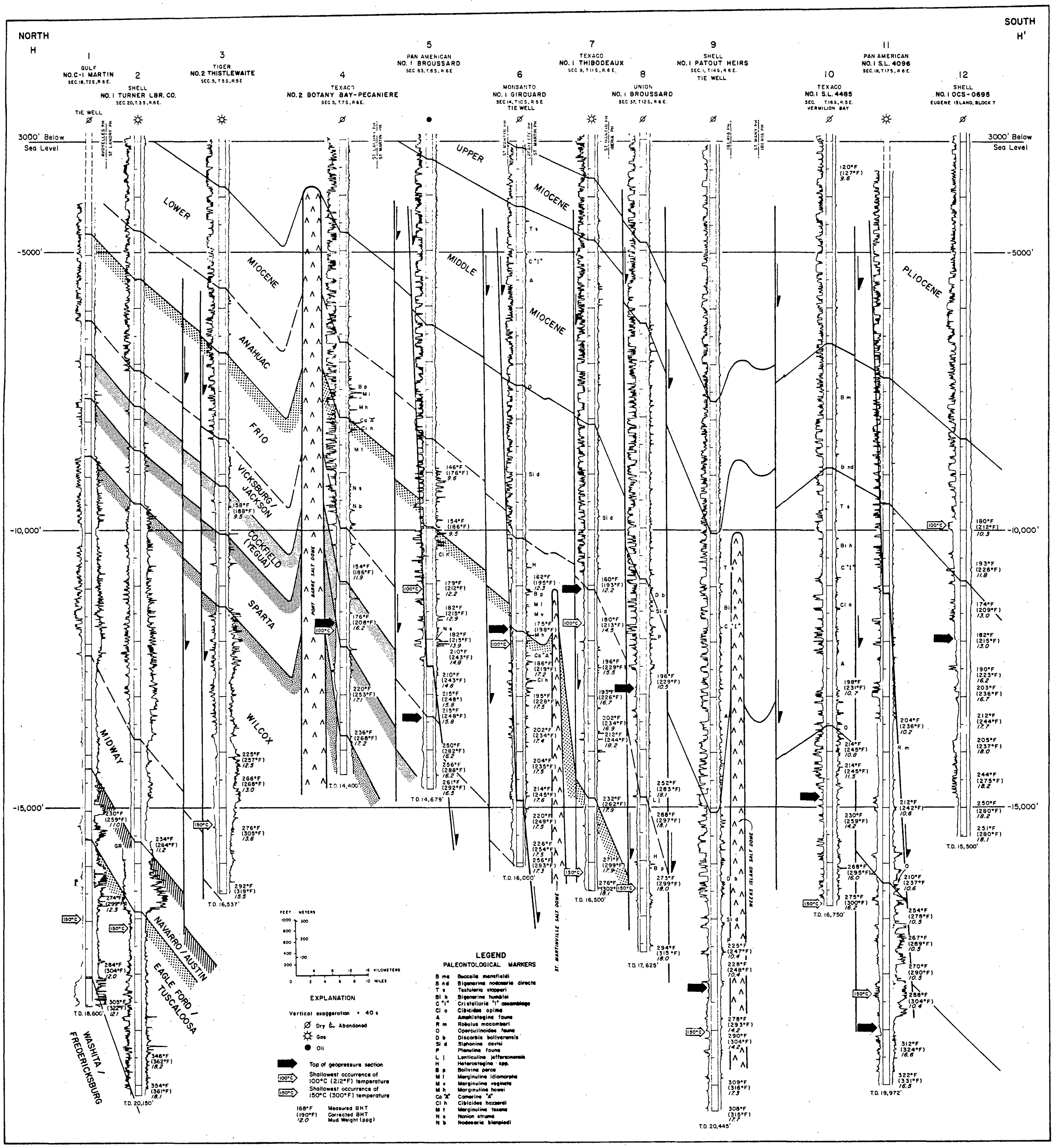

Figure 11. Dip section HH'.

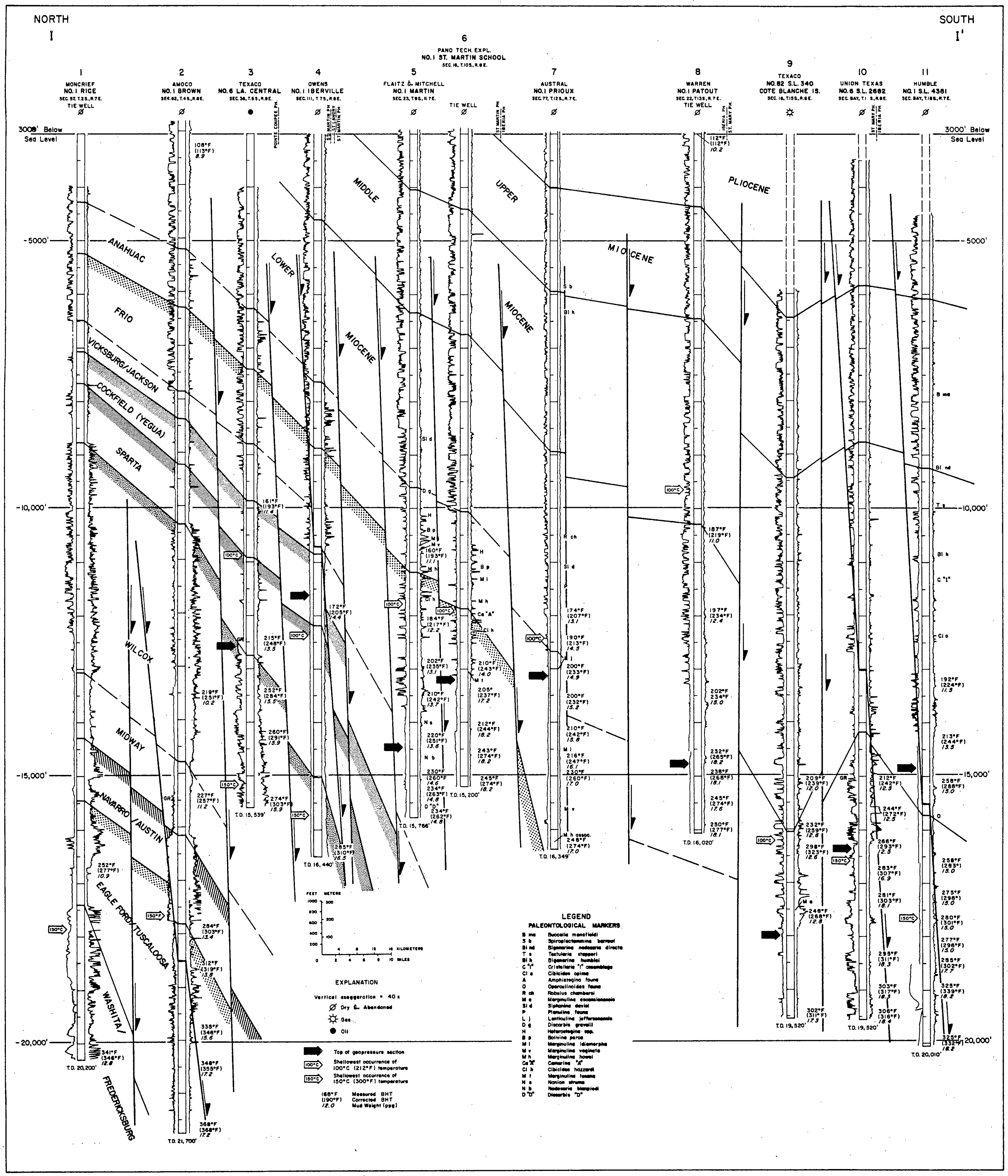

Figure 12. Dip section II'.

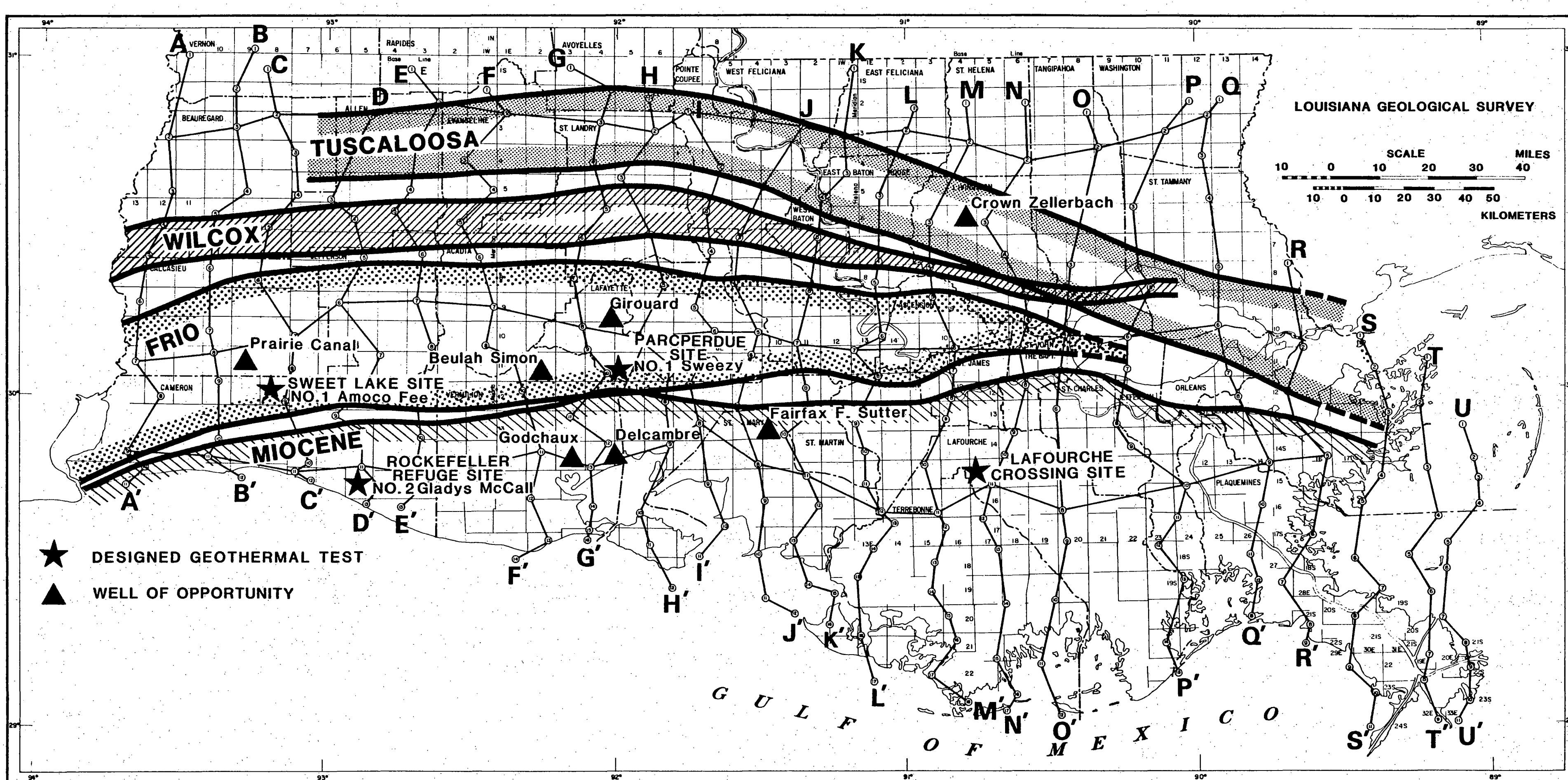

Figure 13. Geopressured-geothermal corridors, south Louisiana. Locations of the wells of opportunity and designed wells are also shown.

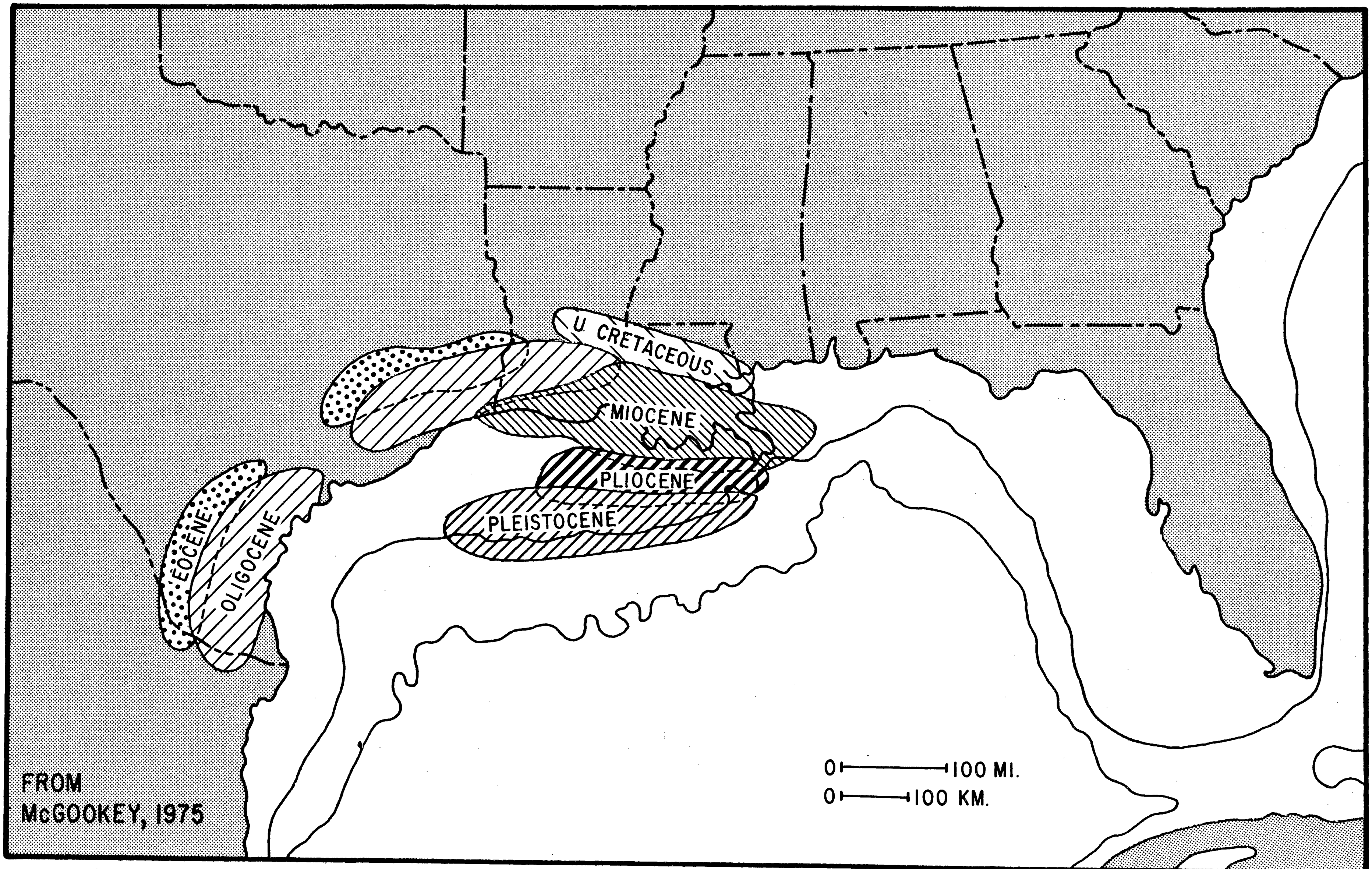

Figure 14. Major sediment depocenters during the Upper Cretaceous and Tertiary along the northern Gulf of Mexico.

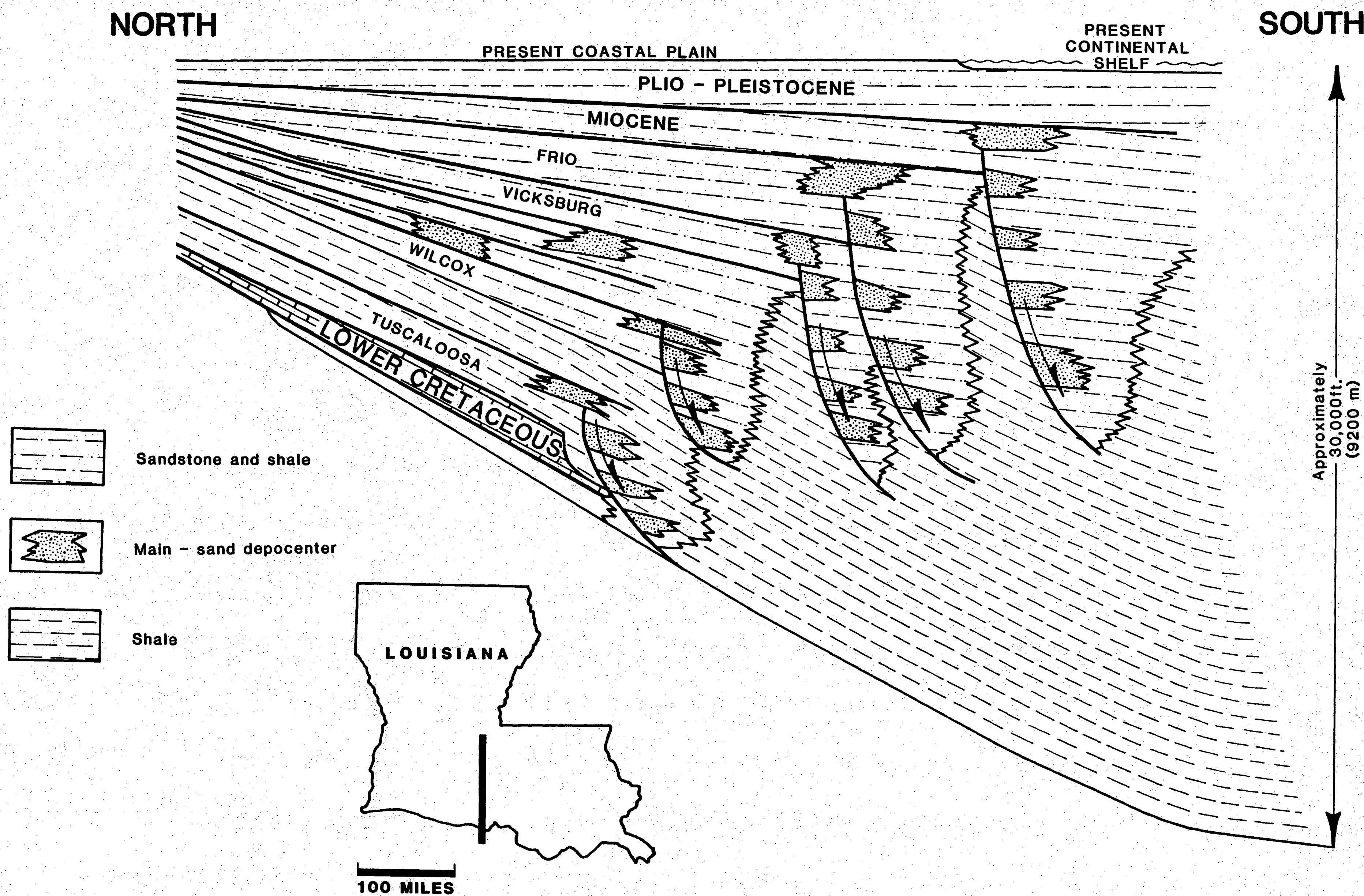

Figure 15. Diagrammatic cross sections across the geopressured zone of south Louisiana.

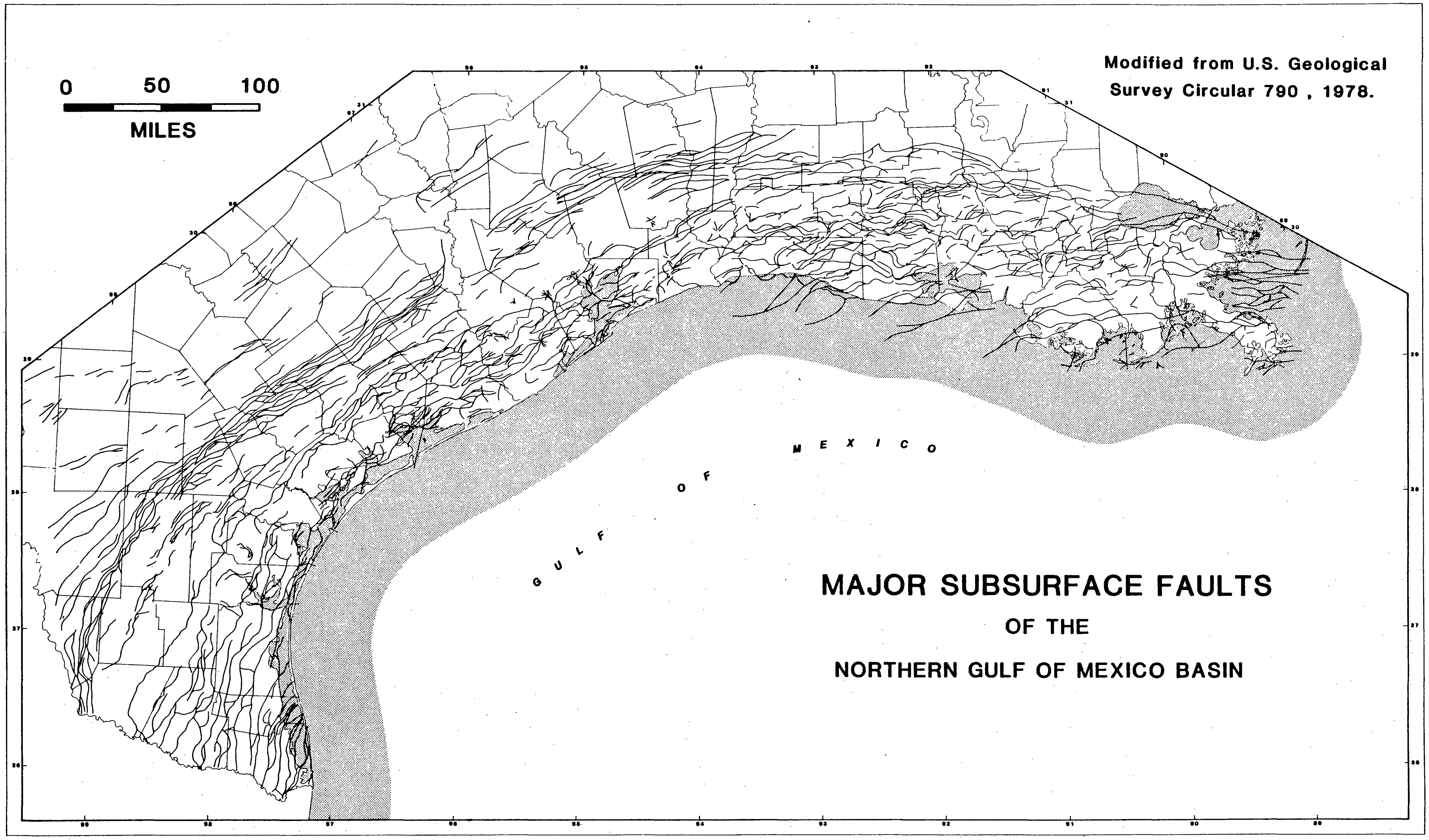

Figure 16. Major subsurface faults along the Texas and Louisiana Gulf Coast.

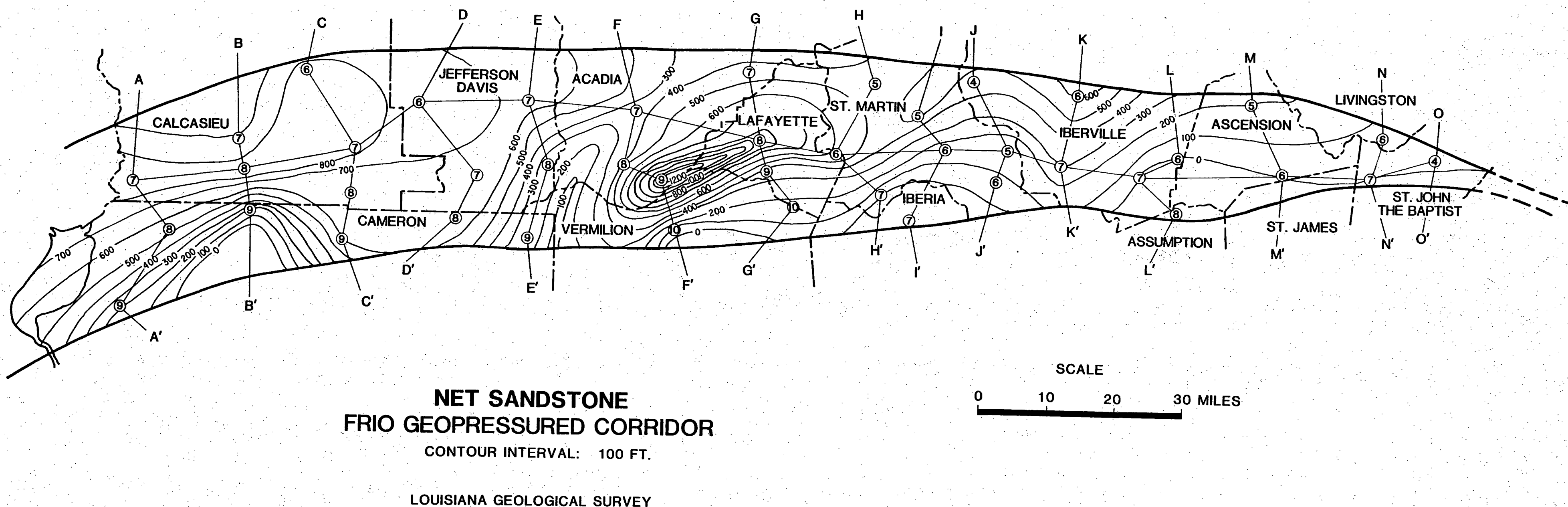

Figure 17. Net sandstone with the Frio geopressured corridor in Louisiana. (See Figure 13 for location of the corridor).

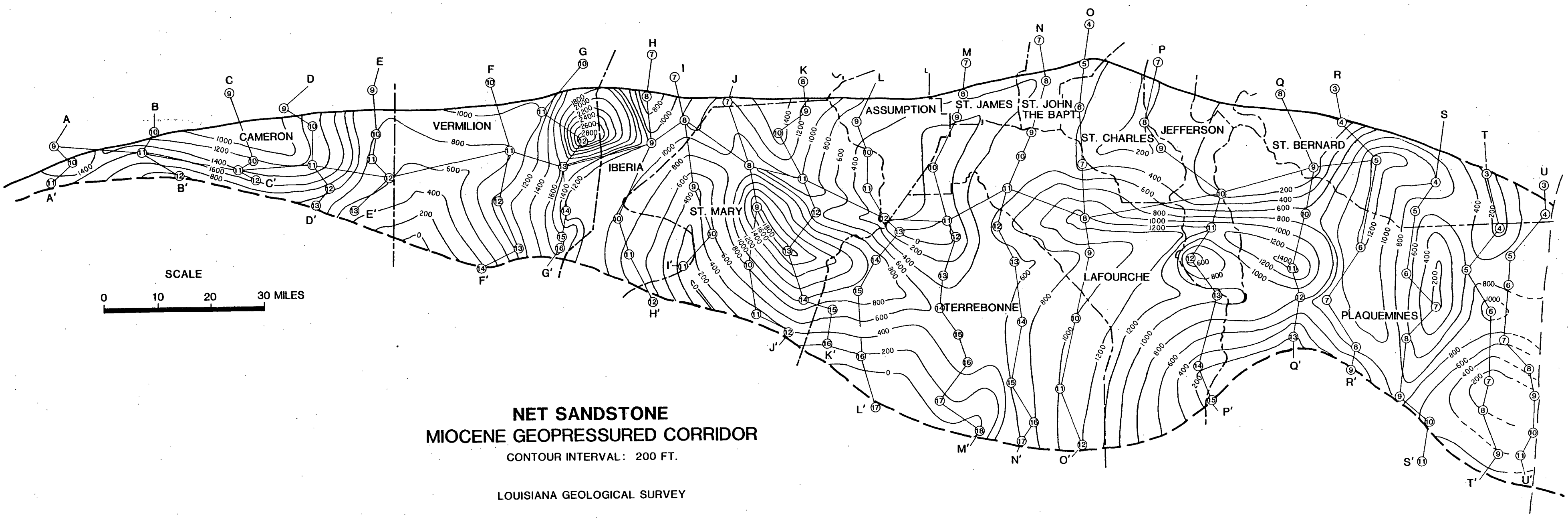

Figure 18. Net sandstone within the Miocene geopressured corridor in Louisiana. (See Figure 13 for location of the corridor).

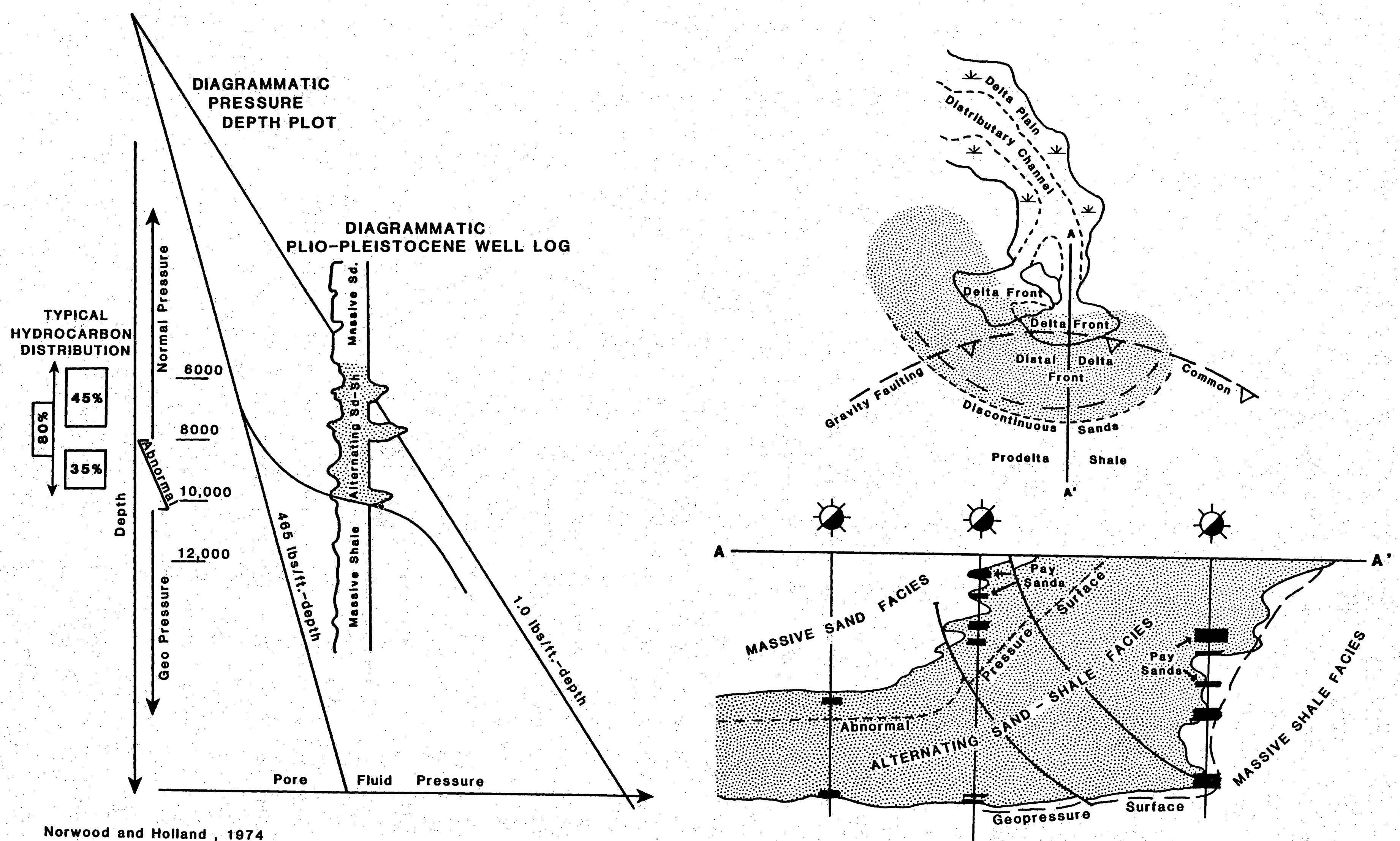

Figure 19. Relationship of sandstone thickness and geopressure in the Pleistocene of offshore Louisiana.

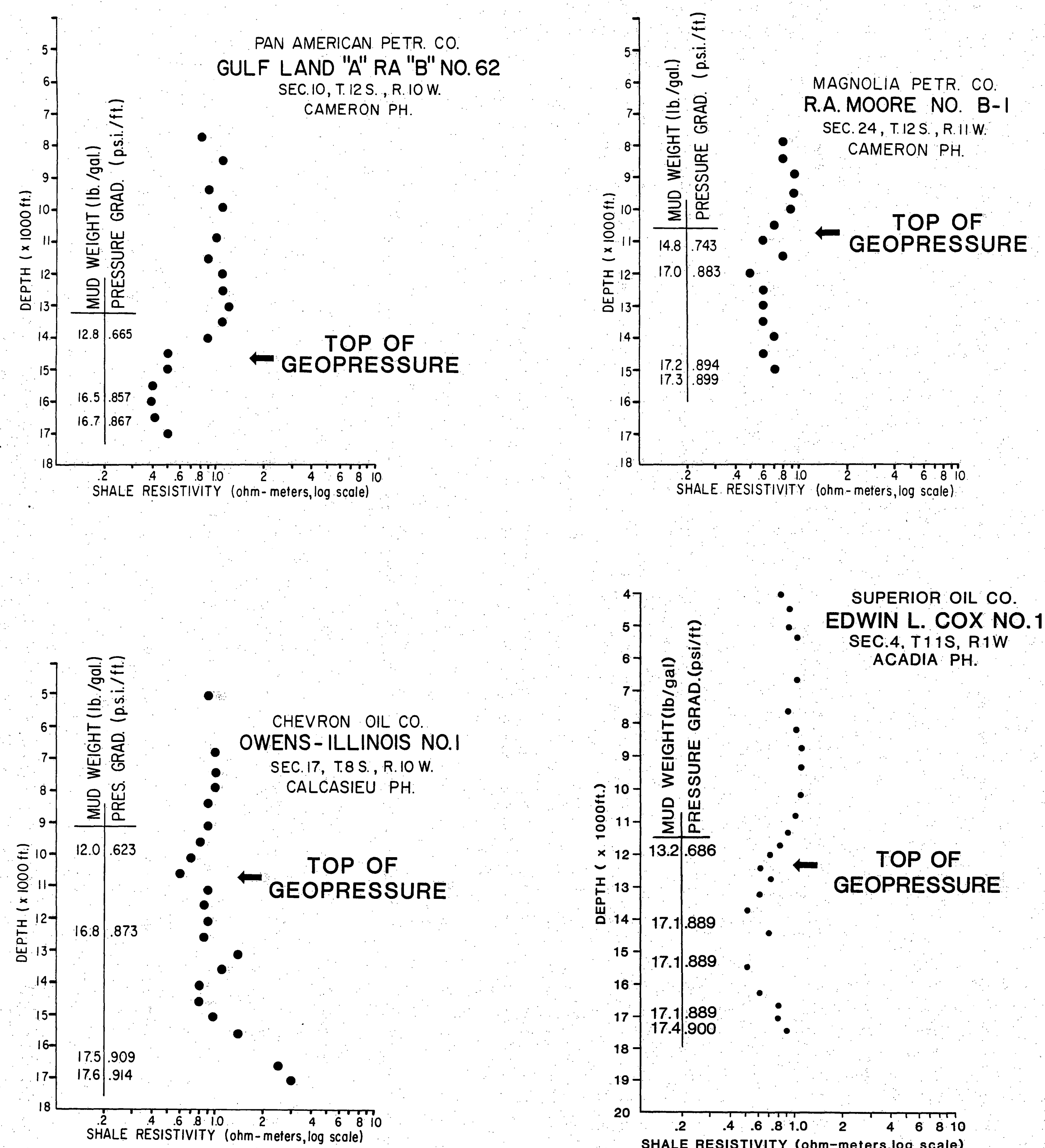

Figure 20. Shale-resistivity plots for Cameron, Calcasieu, and Acadia Parishes.

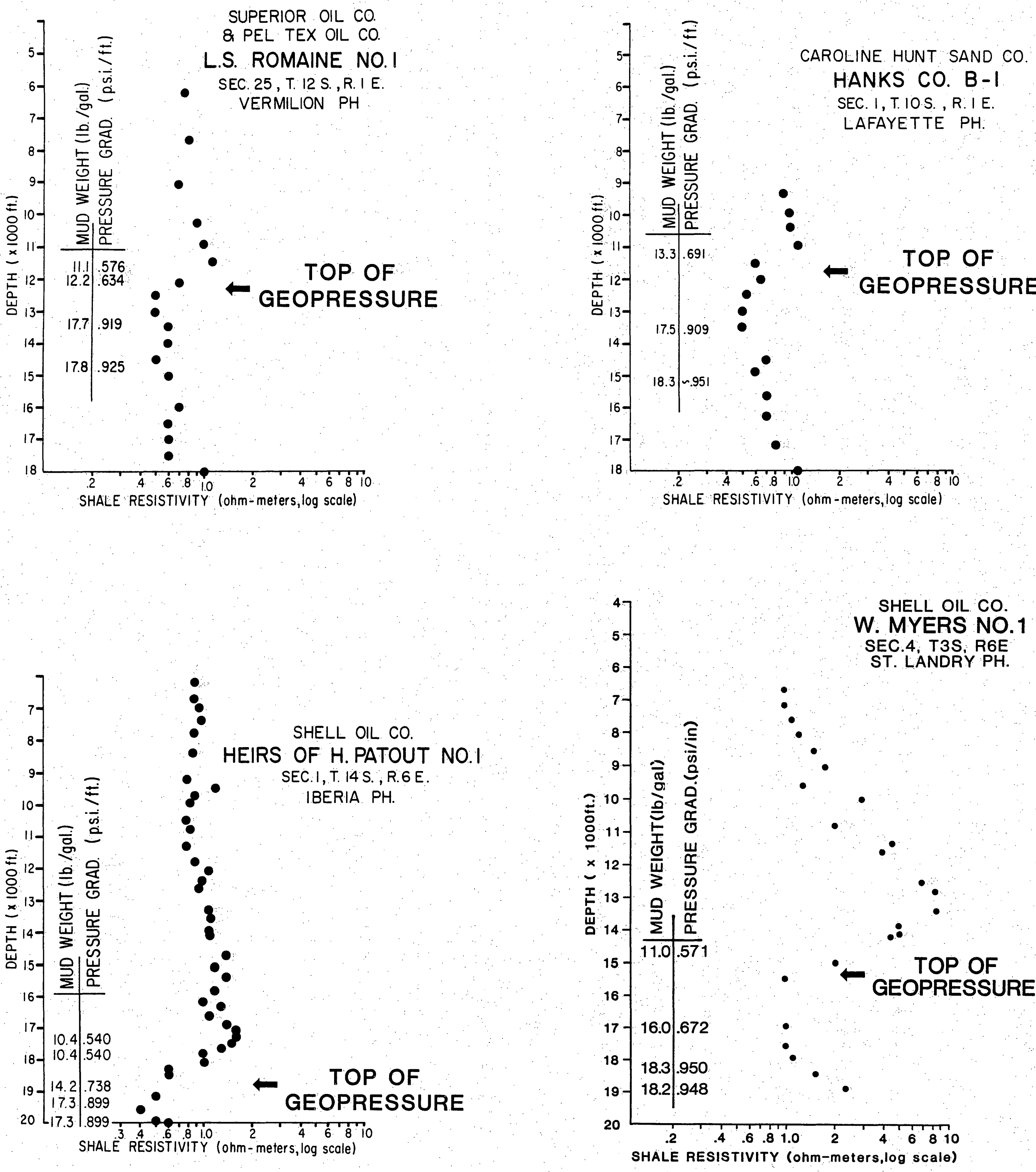

Figure 21. Shale-resistivity plots for Vermilion, Lafayette, Iberia, and St. Landry Parishes.

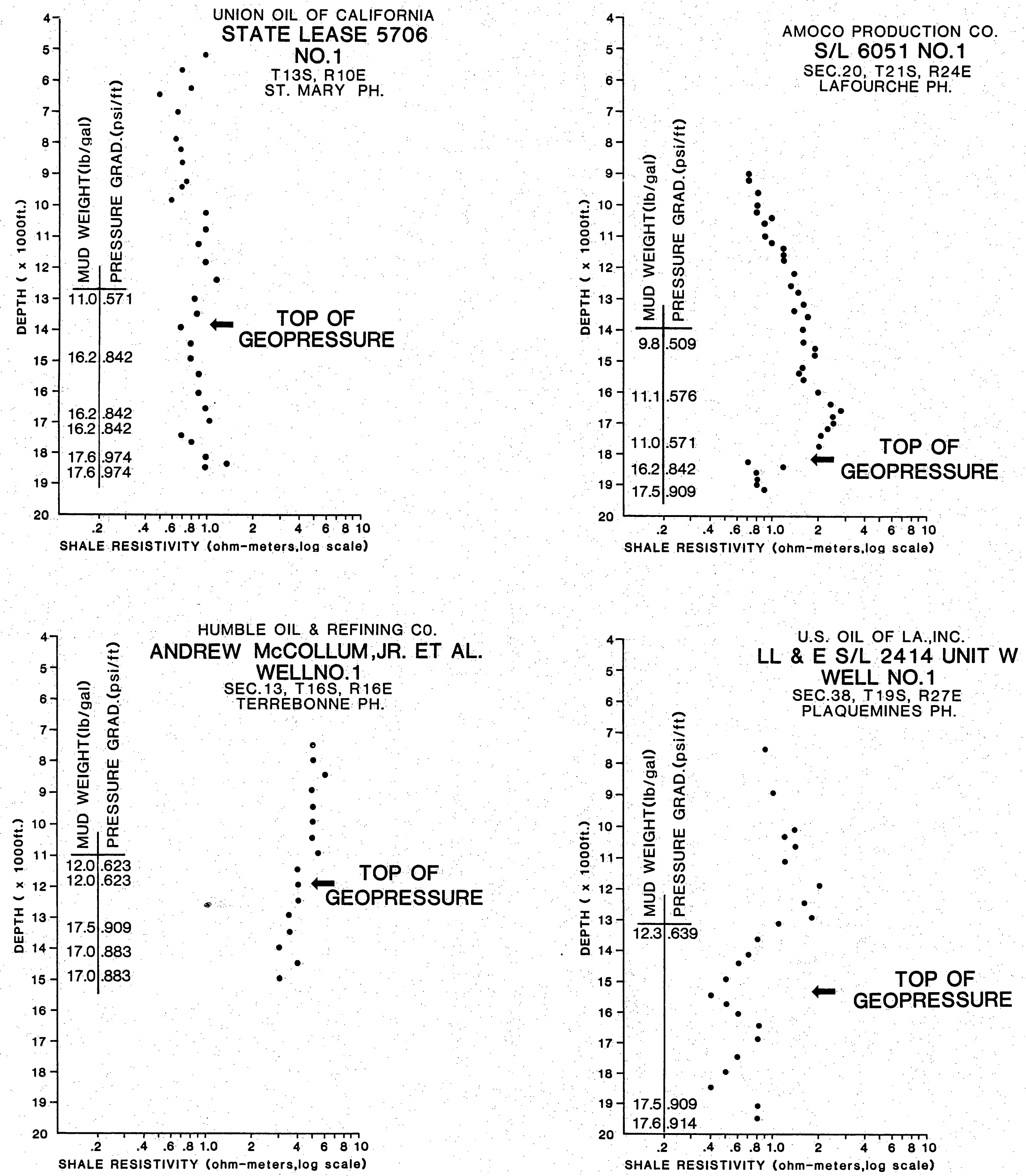

Figure 22. Shale-resistivity plots for St. Mary, LaFourche, Terrebonne, and, Plaquemines Parishes.

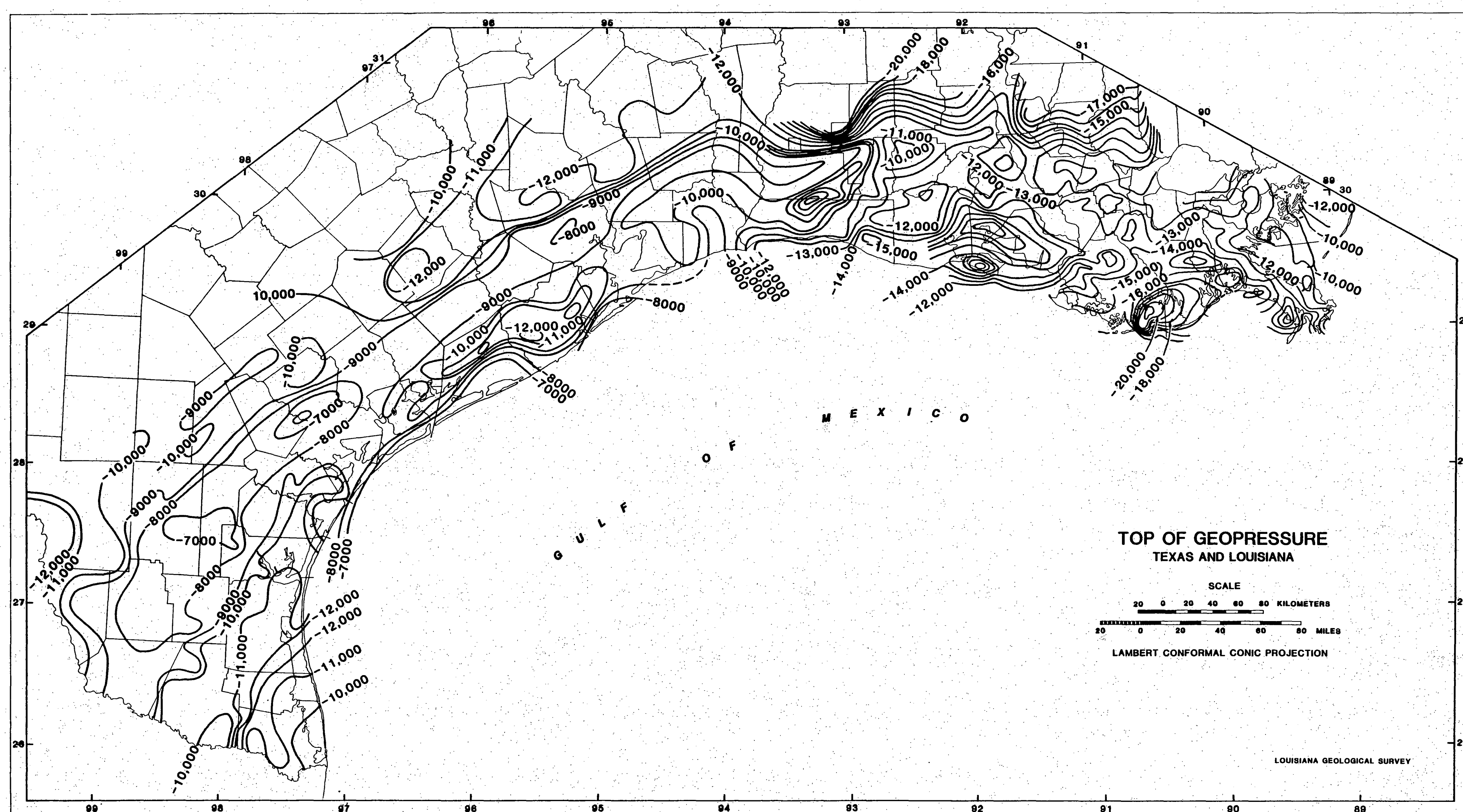

Figure 23. Top of geopressure along the Texas and Louisiana Gulf Coast.

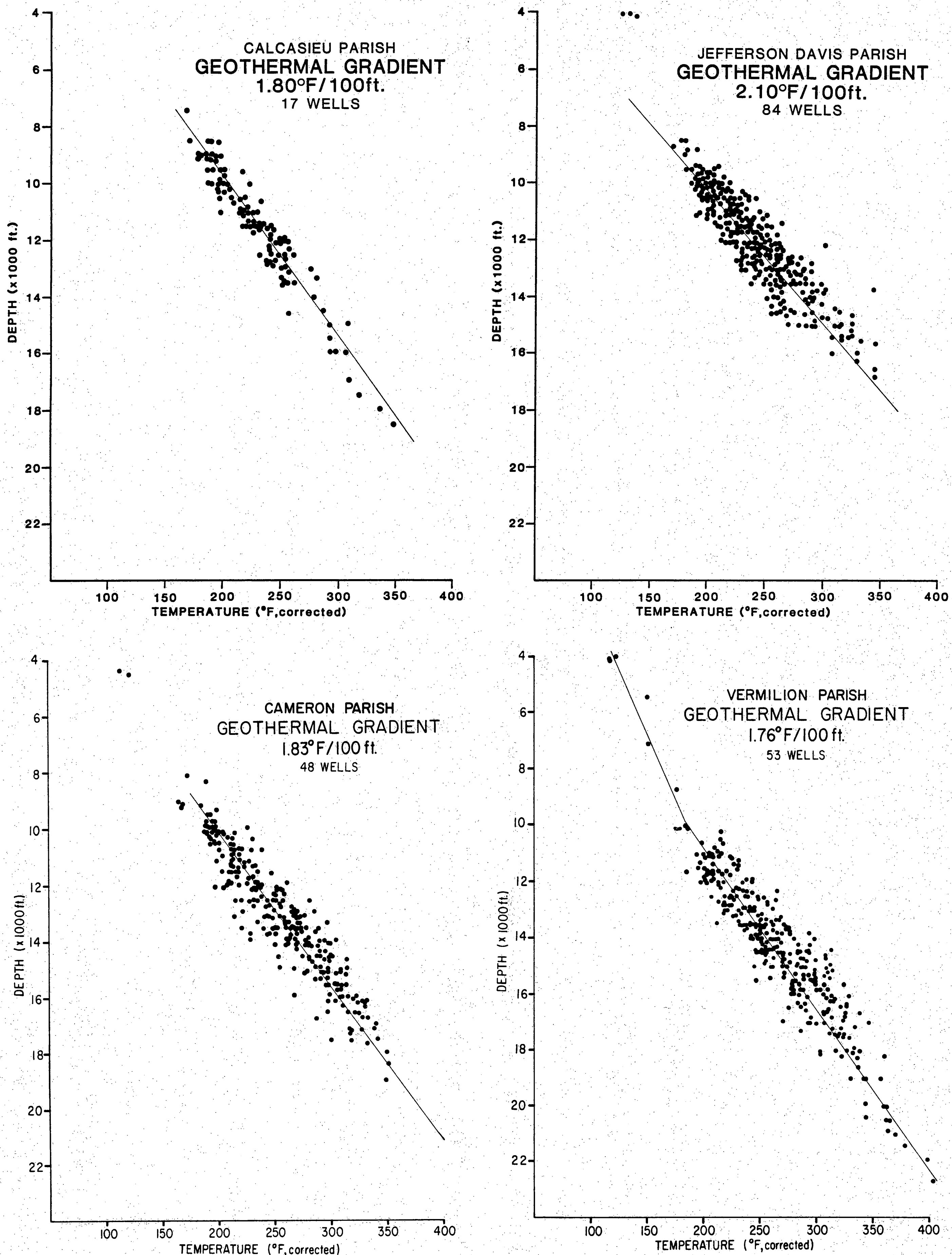

Figure 24. Temperature plots for Cameron, Calcasieu, Jefferson Davis, and Vermilion Parishes.

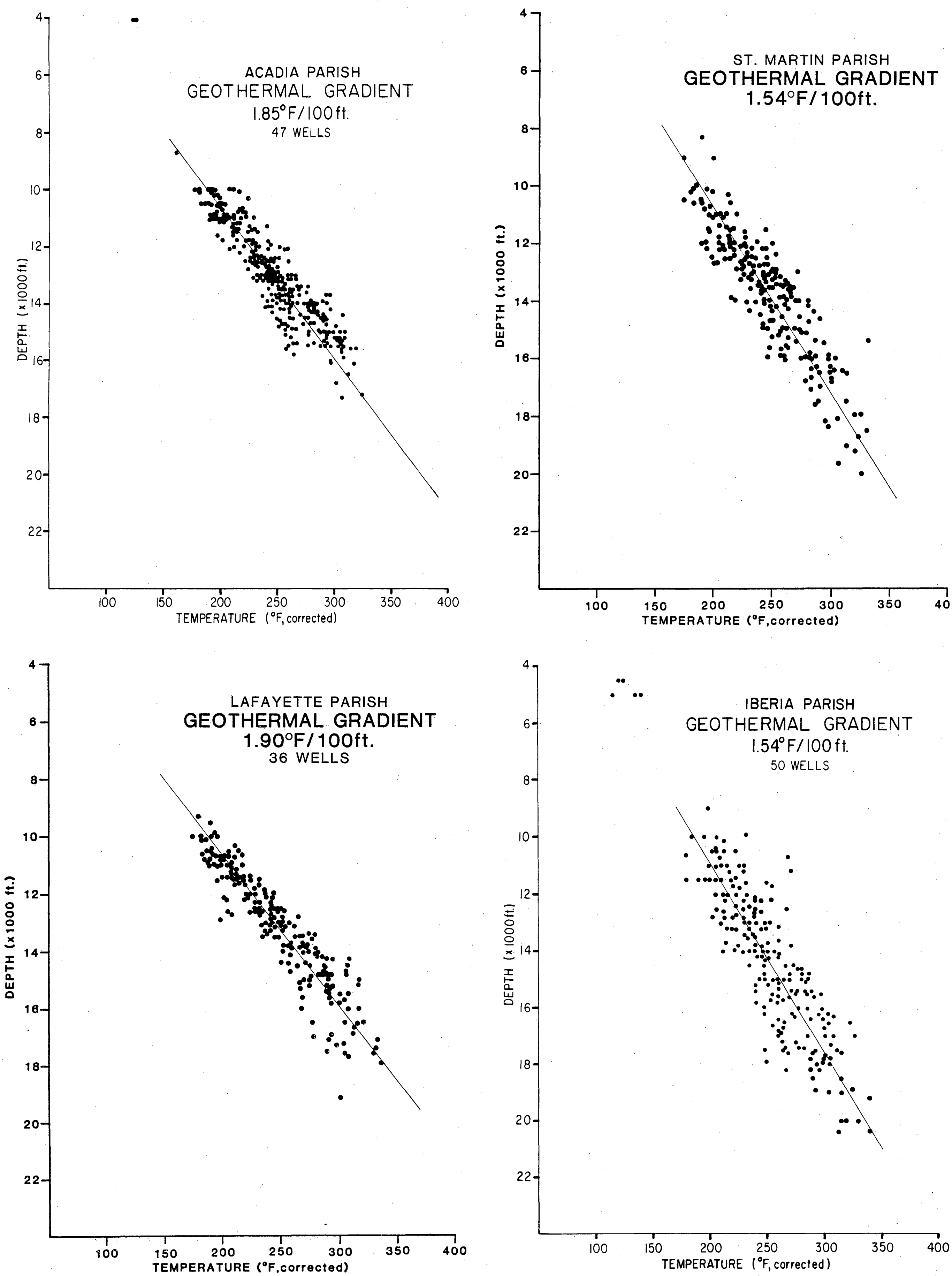

Figure 25. Temperature plots for Acadia, St. Martin, Lafayette, and Iberia Parishes.

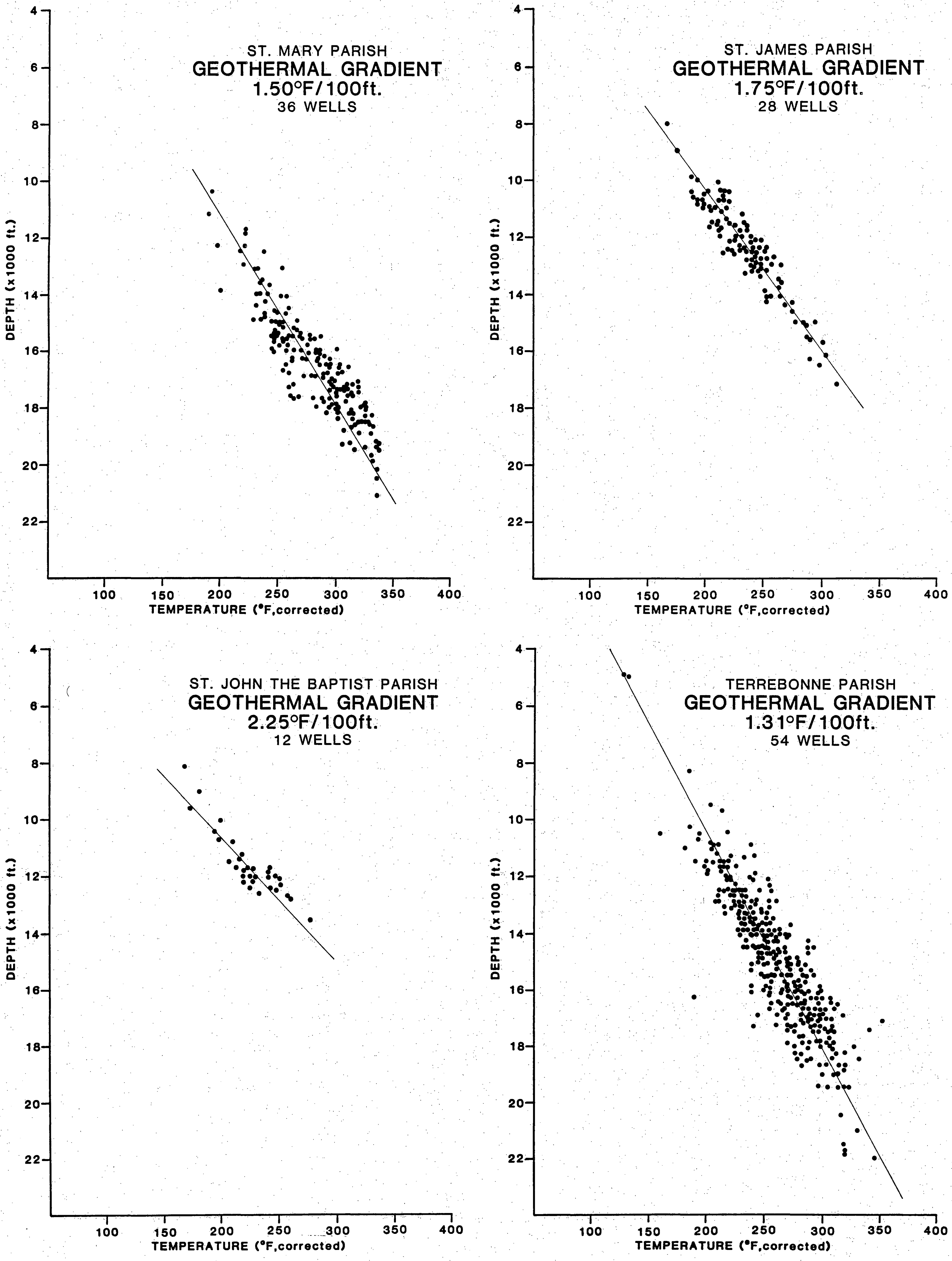

Figure 26. Temperature plots for St. Mary, St. James, St. John the Baptist, and Terrebonne Parishes.

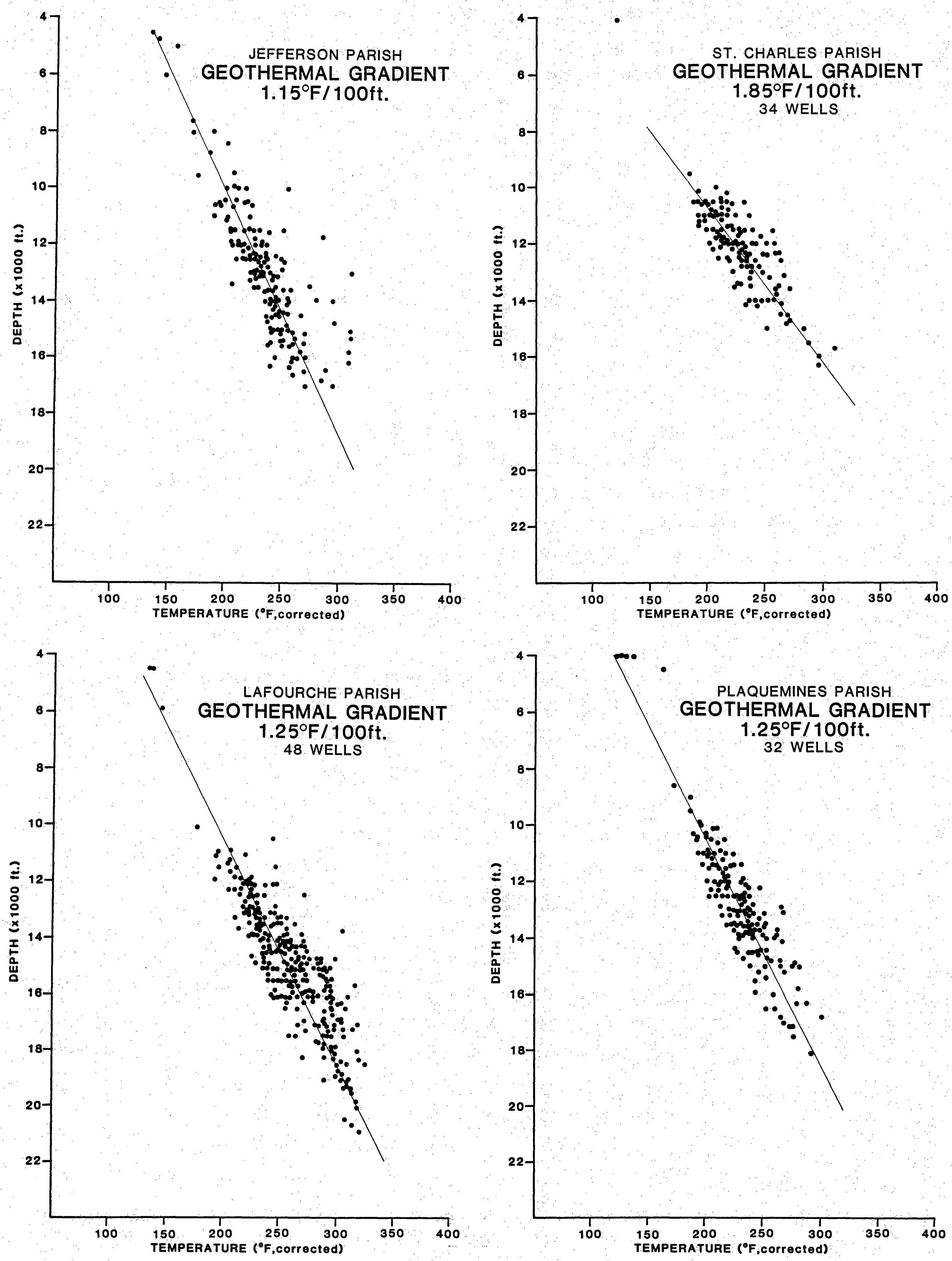

Figure 27. Temperature plots for Jefferson, St. Charles, LaFourche, and Plaquemines Parishes.

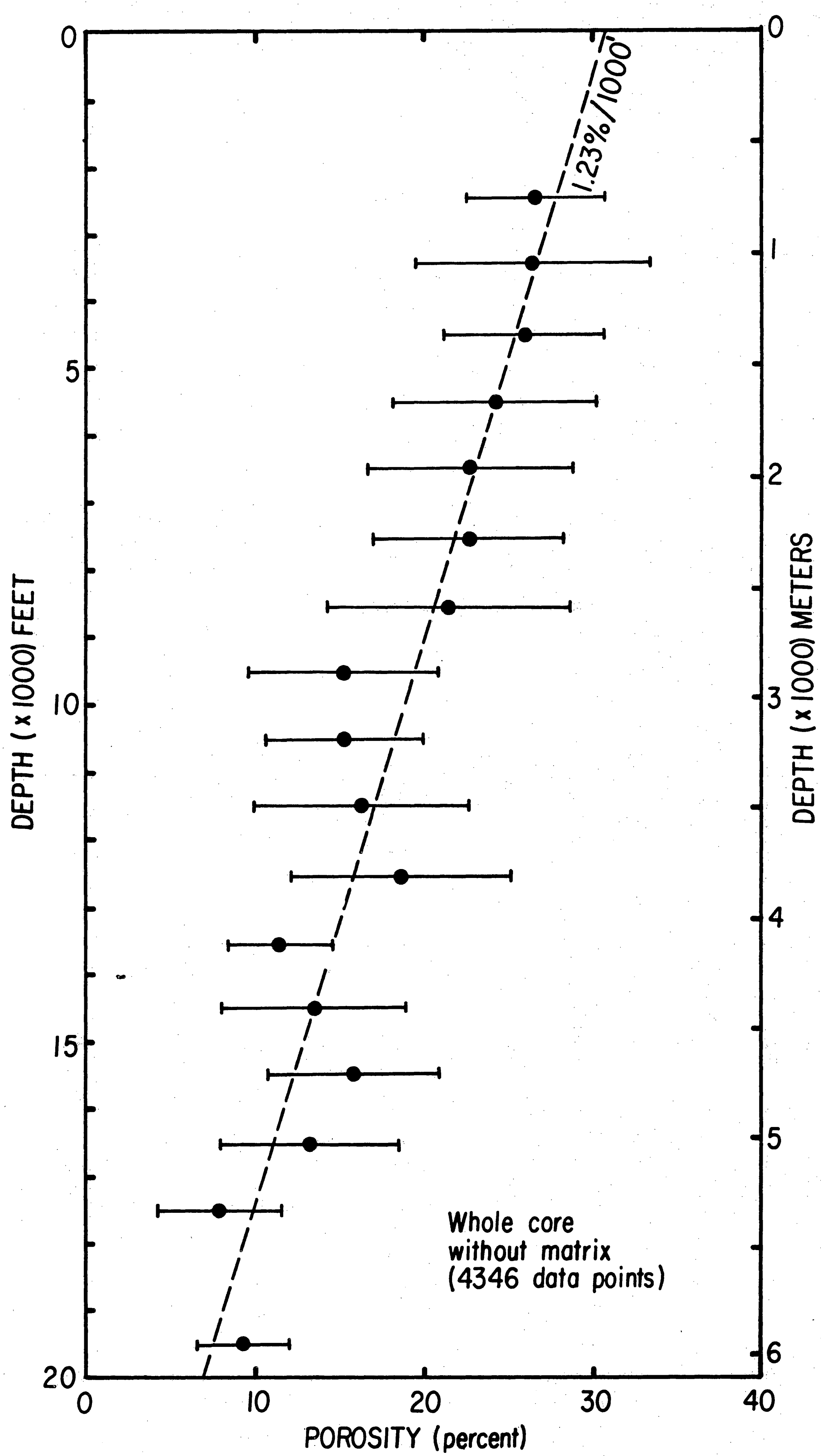

Figure 28. Porosity-depth from diamond-core analyses for the lower Tertiary of Texas (Loucks, Dodge, and Galloway, 1979).

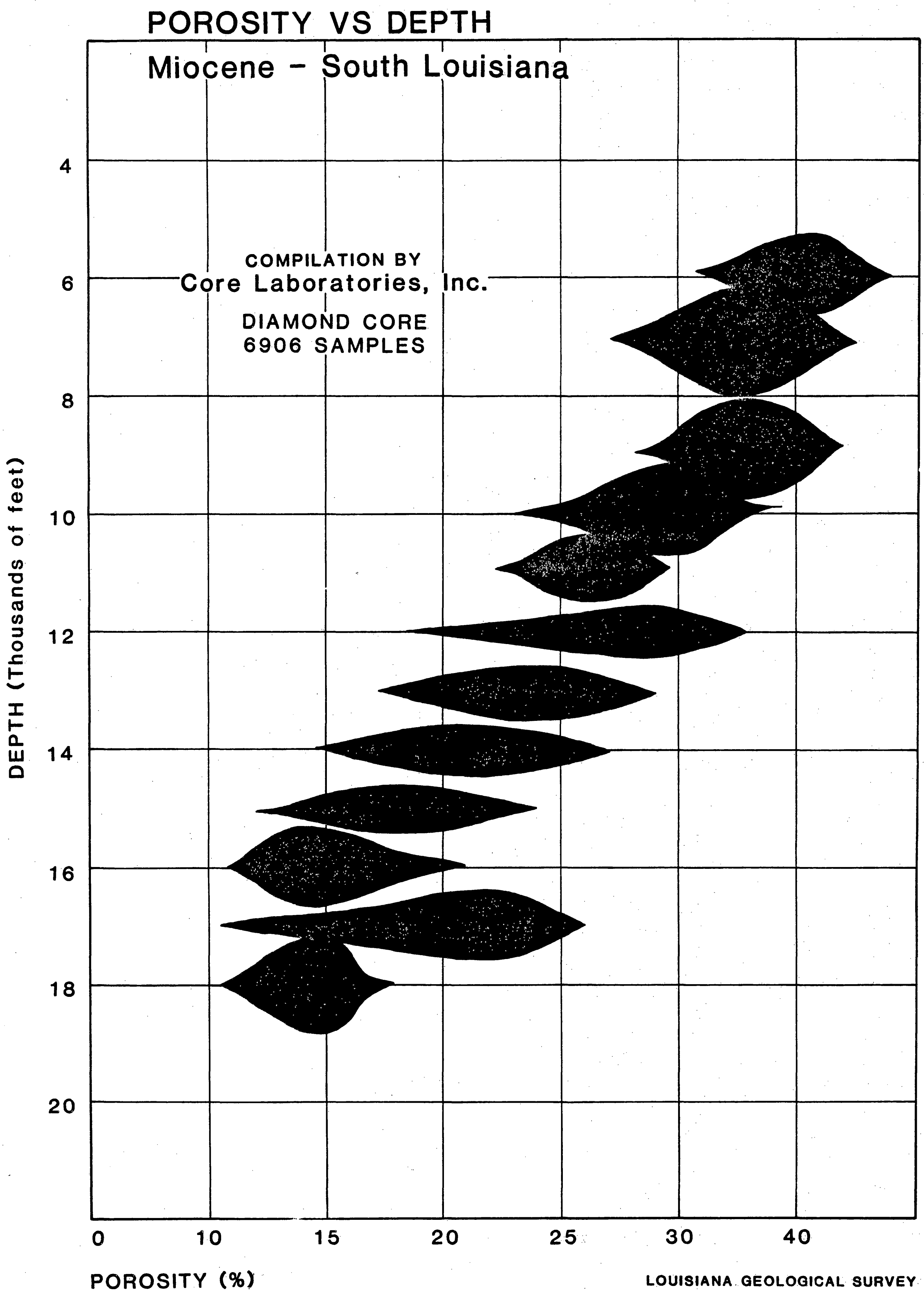

Figure 29. Porosity-depth from diamond-core analyses for Oligocene and Miocene sandstones of south Louisiana.

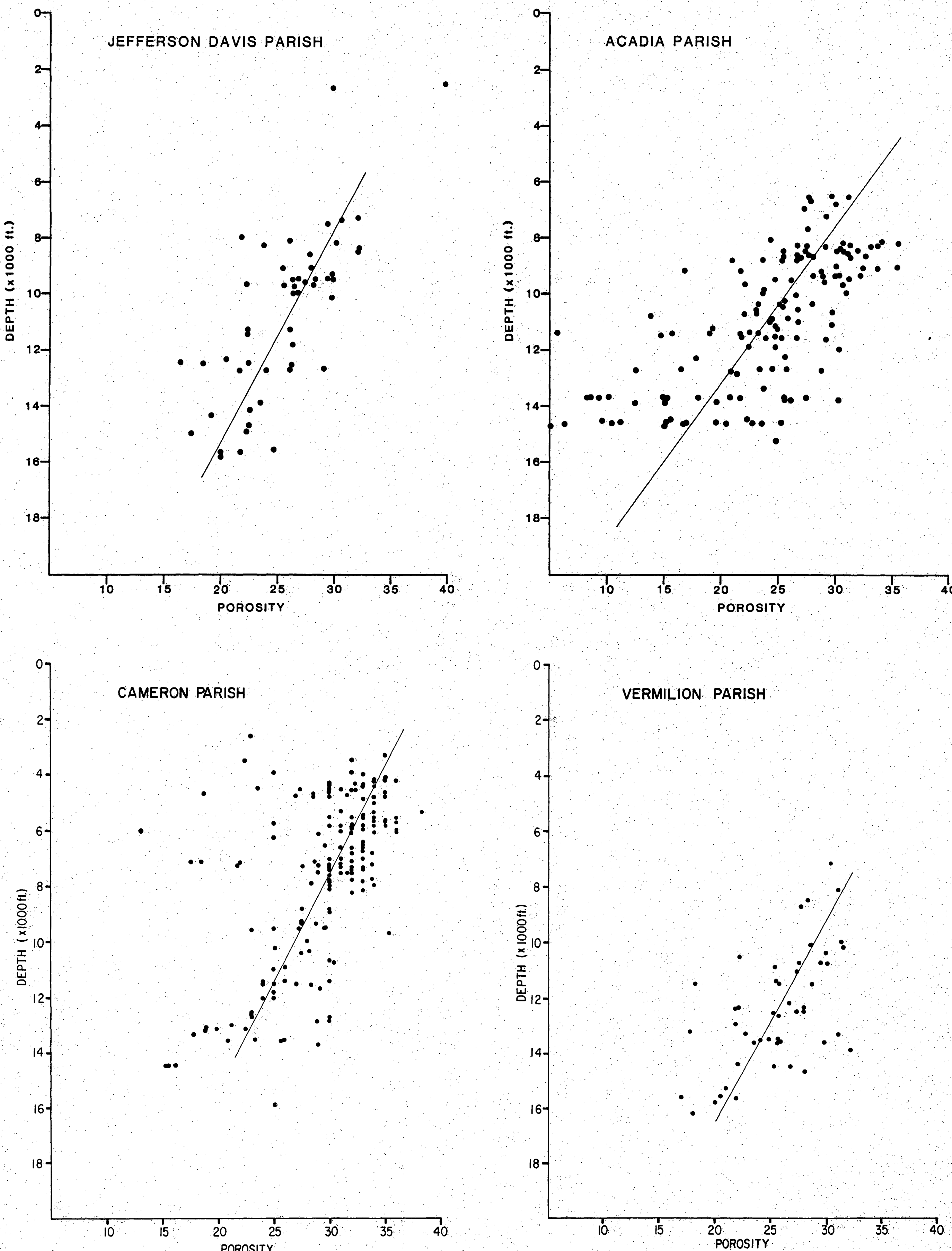

Figure 30. Porosity plots for Jefferson Davis, Acadia, Cameron, and Vermilion Parishes.

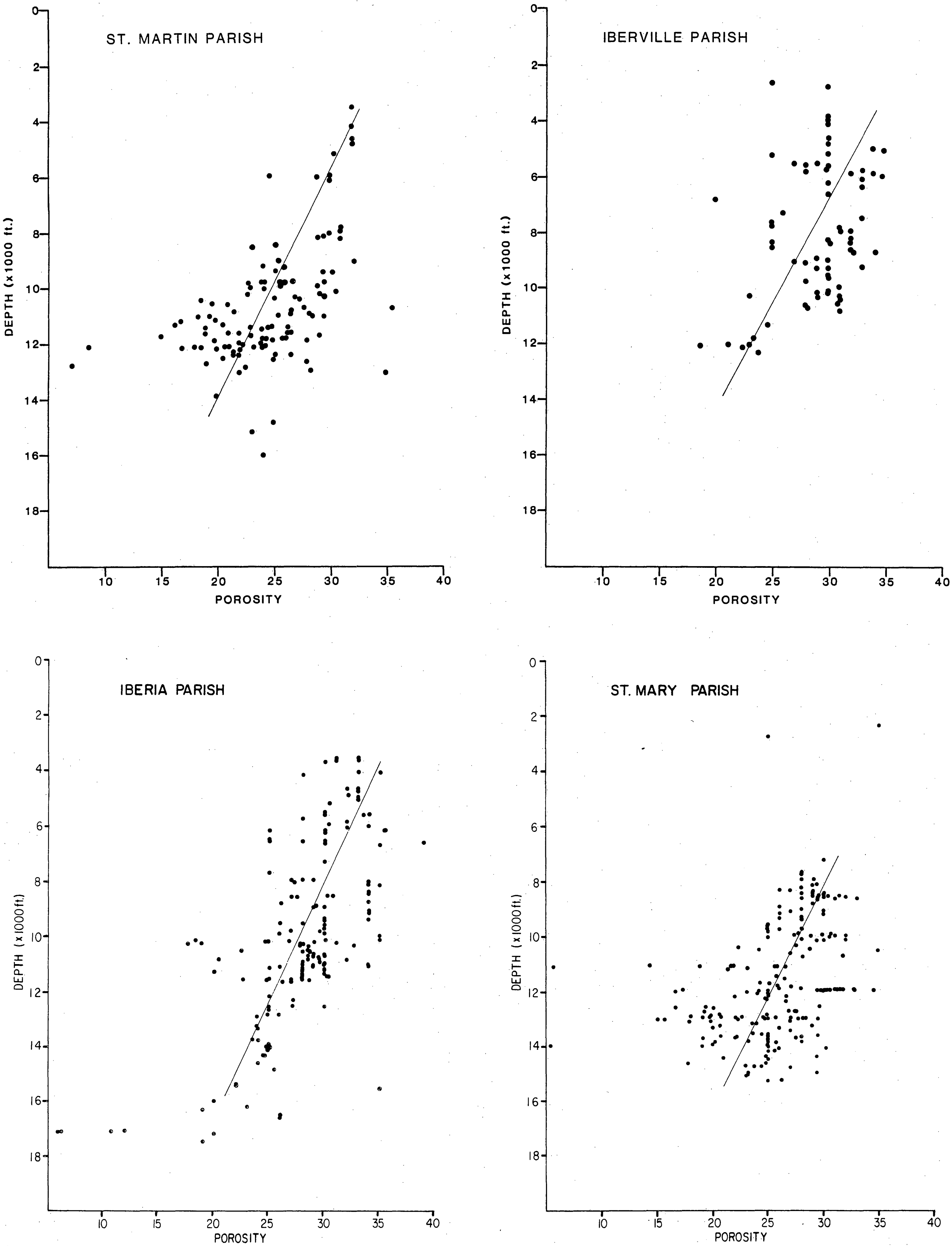

Figure 31. Porosity plots for St. Martin, Iberville, Iberia, and St. Mary Parishes.

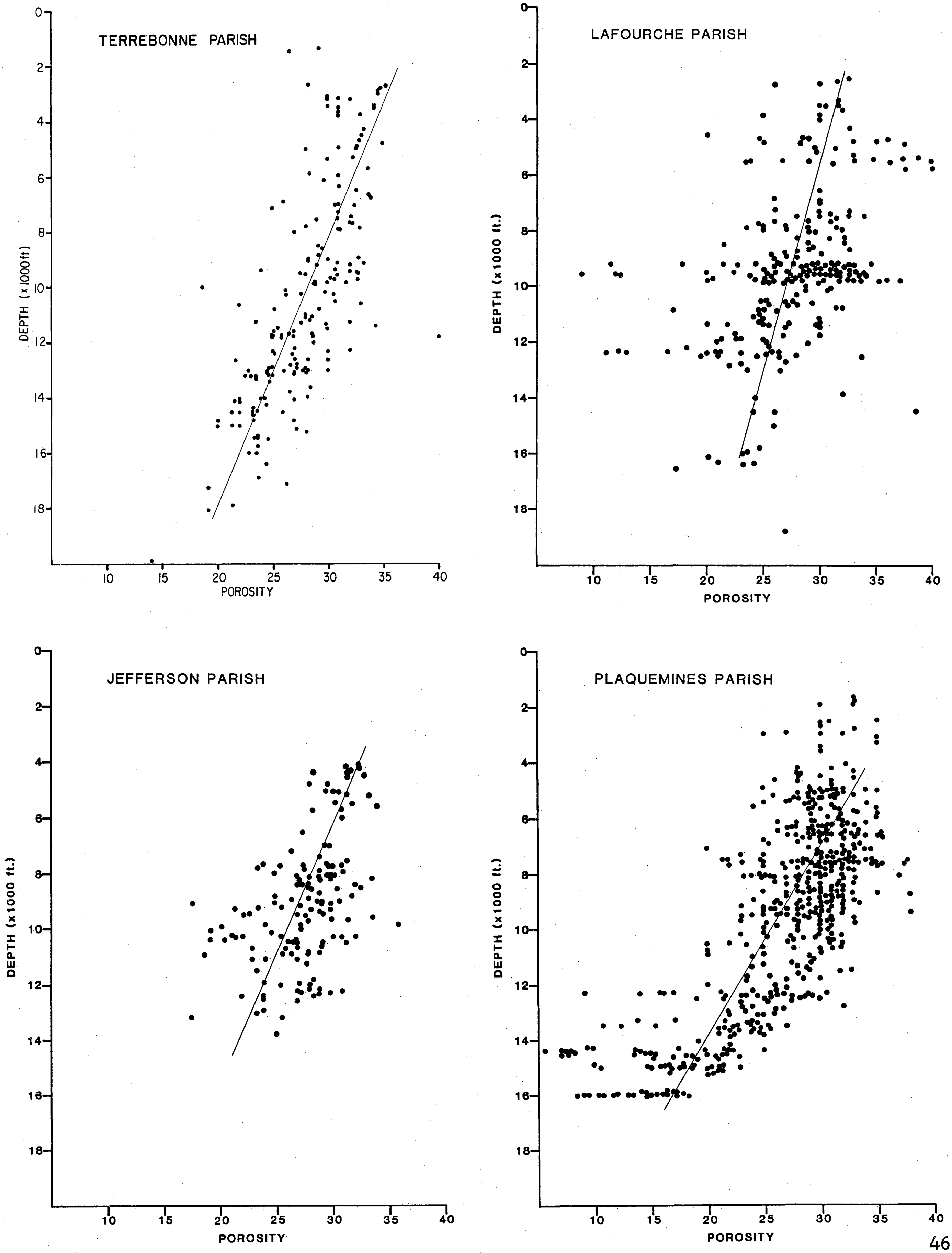

Figure 32. Porosity plots for Terrebonne, LaFourche, Jefferson, and Plaquemines Parishes.

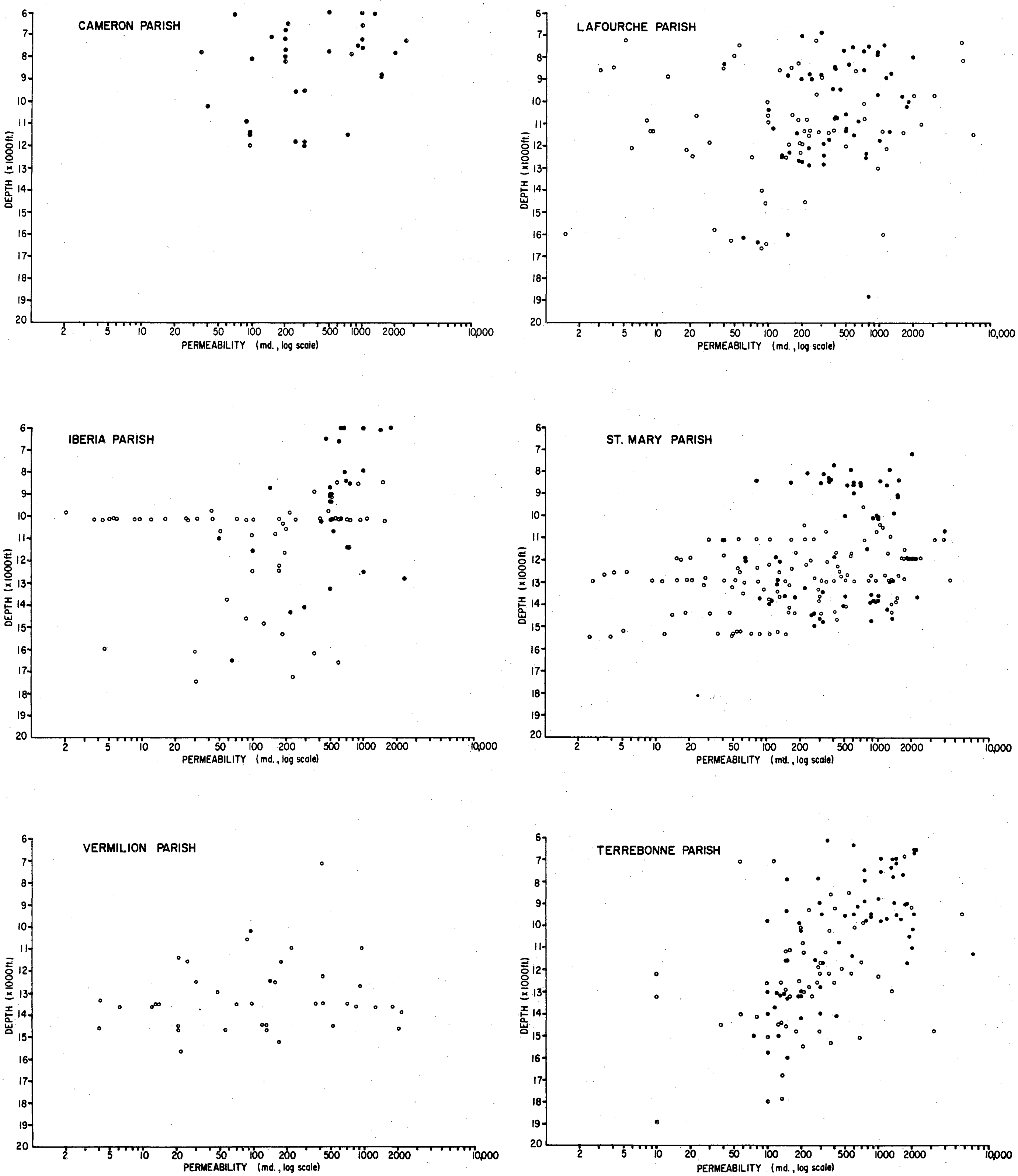

Figure 33. Permeability plots for Cameron, LaFourche, Iberia, St. Mary, Vermilion, and Terrebonne Parishes.

GEOPRESSURED-GEOTHERMAL RESOURCE POTENTIAL OF MIOCENE BAYOU HEBERT PROSPECT, VERMILION AND IBERIA PARISHES, LOUISIANA

R. P. McCulloh, M. A. Pino, and N. Y. Salem

Introduction

A study of the Bayou Hebert prospect by Bassiouni (1980) indicated moderate pressure gradient (0.80 psi/ft) and temperature (230°F at an average depth of 14,500 ft). However, the study also indicated good sandstone development along with favorable porosity (10-23%, x = 16%), permeability (15-220 md, x = 45 md), and salinity of 35,000 to 130,000 ppm (x - 87,000 ppm). Because salinity, permeability, and reservoir development have presented the greatest obstacles to prospect delineation in many other potential areas of the Texas and Louisiana Gulf Coast, the present study was begun to investigate in more detail the geology and salinity distribution of the Bayou Hebert prospect. Well logs used in this investigation are listed in the appendix. Structure maps used in this study were obtained from Geomap Company's structure map service of south Louisiana.

Geologic Setting

The fault block evaluated here for geopressured-geothermal potential lies immediately northwest of Vermilion Bay in southwestern Louisiana (Fig. 1). Three main boundary fault zones give the block a triangular shape (Fig. 2). Electric logs cross sections constructed for this study (Figs. 1, 3, 4, 5, and 6) show substantial thickening of the lower Miocene section across the growth faults which form the southern boundary of the prospect. The abundance of persistent marker beds recognizable by consistent and characteristic resistivity traces makes it possible to distinguish two mechanisms of thickening: (1) expansion on the downthrown sides of faults by the same units which lie on the upthrown sides and (2) addition of new units on the downthrown sides of faults. The second of these processes is the most significant, as a single one of the intervals added may be up to 2100 ft thick (Fig. 6).

The two dip sections indicate differential subsidence along the southern boundary fault zone; a 720-ft interval of section is added between two marker beds on C-C' with no equivalent on D-D', while D-D' shows 2100 ft of new section not represented on C-C' between a different pair of markers. Therefore, D-D' shows about 1400 ft of net subsidence downdip of the fault zone compared to C-C'. A corresponding deepening of the top of geopressure shows up as an embayment of contour lines around section D-D' downdip of the fault zone on Fig. 7. Both sections show an addition of 500 to 700 ft of new section between a third set of markers.

Faults show discernible growth only below and slightly above the top of geopressure (Figs. 3 to 6), a situation which Dickey, Shiram, and Paine (1968) attributed to mutual stimulation between growth faulting and abnormal pressured genesis. The maps of new sandstone thickness within intervals immediately above and below the top of geopressure show that deposition in these intervals was controlled mostly by faulting (Figs. 8 and 11). These maps also show a westward shift of the main sand depocenter on the downthrown side of the southern boundary fault zone. This depocenter migration reflects differential subsidence along the fault zone which might ultimately have been controlled by delta lobe switching.

Geopressured-Geothermal Resource Potential

The top of geopressure corresponds to the base of the main sandstone series of the Miocene, as described by Dickinson (1953) (Figs. 3 to 6), and lies at an average depth of 12,500 ft within the fault block (Figs. 3 to 7). Steeper geothermal gradients and deeper geopressures abut the block on all sides (Fig. 7).

Two intervals above 21,000 ft in the geopressured zone contain possible prospective sandstone units. One has a 500-ft massive sandstone unit indicated by the gamma ray log at a depth of 20,200 ft in the Superior #1 Hulin well (Fig. 6), but this is the only well which penetrated the interval; thus, the lateral extent of the sandstone is unknown. The other interval lies not far below the top of geopressure, where Swanson, Oetking, Osoba, and Hagens (1976) believed that "high pressure aquifers of large extent" would mainly occur because of fluid migration upward along faults into sealed sandstone. This interval has sandstone units thicker than 200 ft indicated by induction logs for many wells over most of the fault block, with thicker net sandstone developed in the eastern fourth of the fault block. The area underlain by shallow geopressured sandstone units is estimated at about 58 mi^2, so that the total reservoir volume is about 2.2 mi^3 if the units are in hydrologic communication and average only 200 ft thick.

Selected core analyses indicate that the average permeability of sandstone in the top of the geopressured zone in Bayou Hebert exceeds the 20-md minimum prescribed by Bebout, Loucks, Bosch, and Dorfman (1976). But the 300°F isotherm lies well below these sandstones at depths of 15,000 to 19,000 ft (Fig. 10). The 212°F isotherm lies nearer the top of geopressure (Figs. 7 and 9) and more nearly approximates the temperature within shallow geopressured reservoirs.

Salinity values calculated from wells by the method of Silva and Bassiouni (1981) range from about 30,000 to 350,000 ppm TDS within individual sandstone units as well as for the prospect as a whole. The values show erratic vertical and lateral distribution in both hydropressured and geopressured horizons and lack any consistent relationship with faults (Figs. 12 to 17). Shale resistivity, log-calculated porosity, and hydrostatic pressure show similar erratic vertical distribution, but do not consistently correlate with salinity (Figs. 14 to 17).

Gentle temperature gradients within the fault block and the lack of a regular pattern of salinity values make reservoir volume the main criterion for evaluating geothermal potential. Based on this criterion, the eastern fourth of the Bayou Hebert prospect has the most potential for development of the geopressured-geothermal resource, but reservoir volume will be affected by local differential permeability, the extent of hydrologic communication between individual sandstone units, and faults. Four seismic sections within the fault block, three dip and one strike, show no important faults near the top of geopressure aside from those recognized on electric log sections. The faults delineated in the interior of the fault block might still represent but a fraction of the total, yet alone could substantially fragment the total volume of shallow contiguous geopressured reservoirs.

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

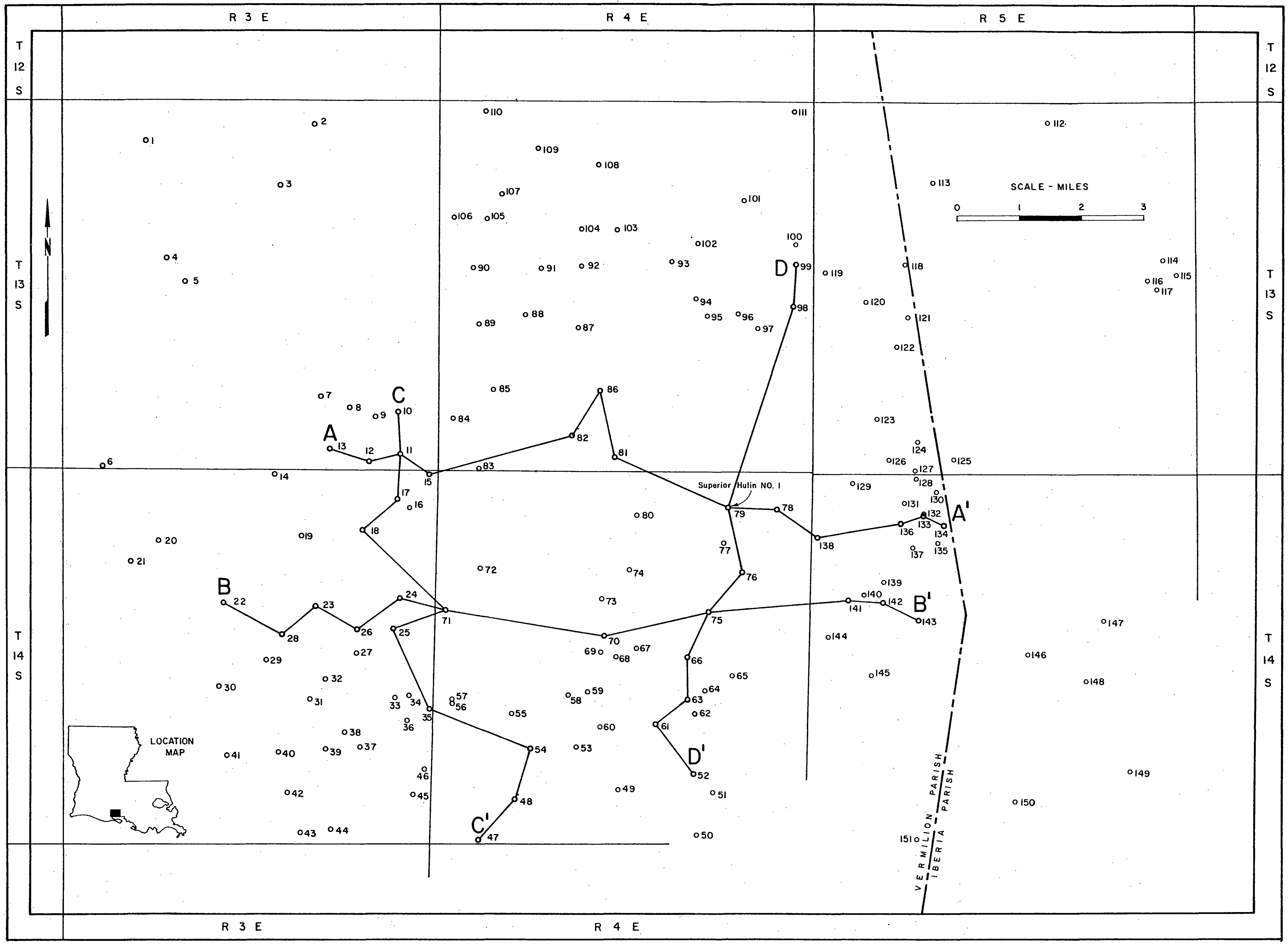


Figure 1. Location, well control, and cross sections, Bayou Hebert prospect.

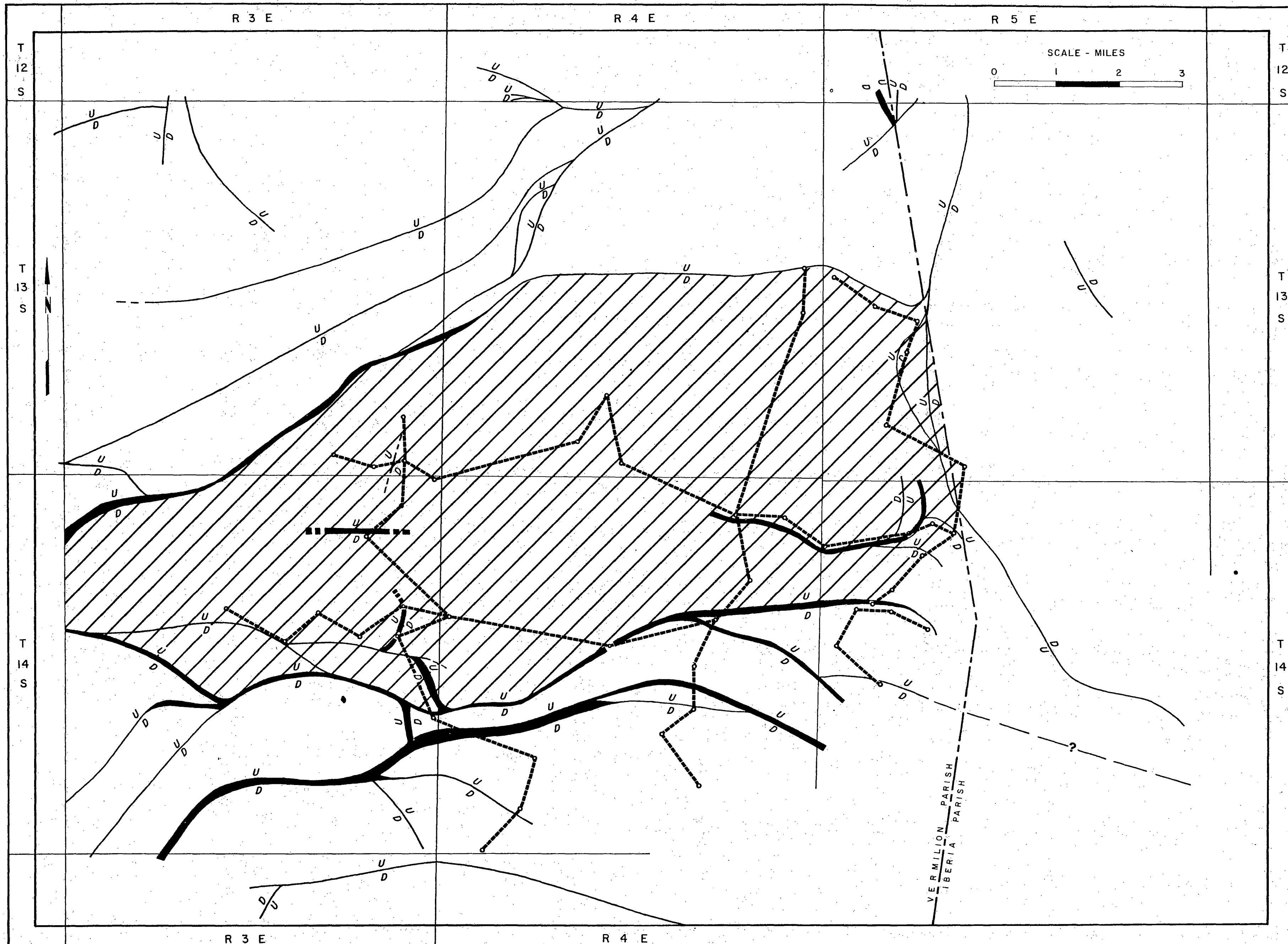


Figure 2. Growth faults near and below the top of geopressure in the Bayou Hebert prospect area, ruled (after Geomap).

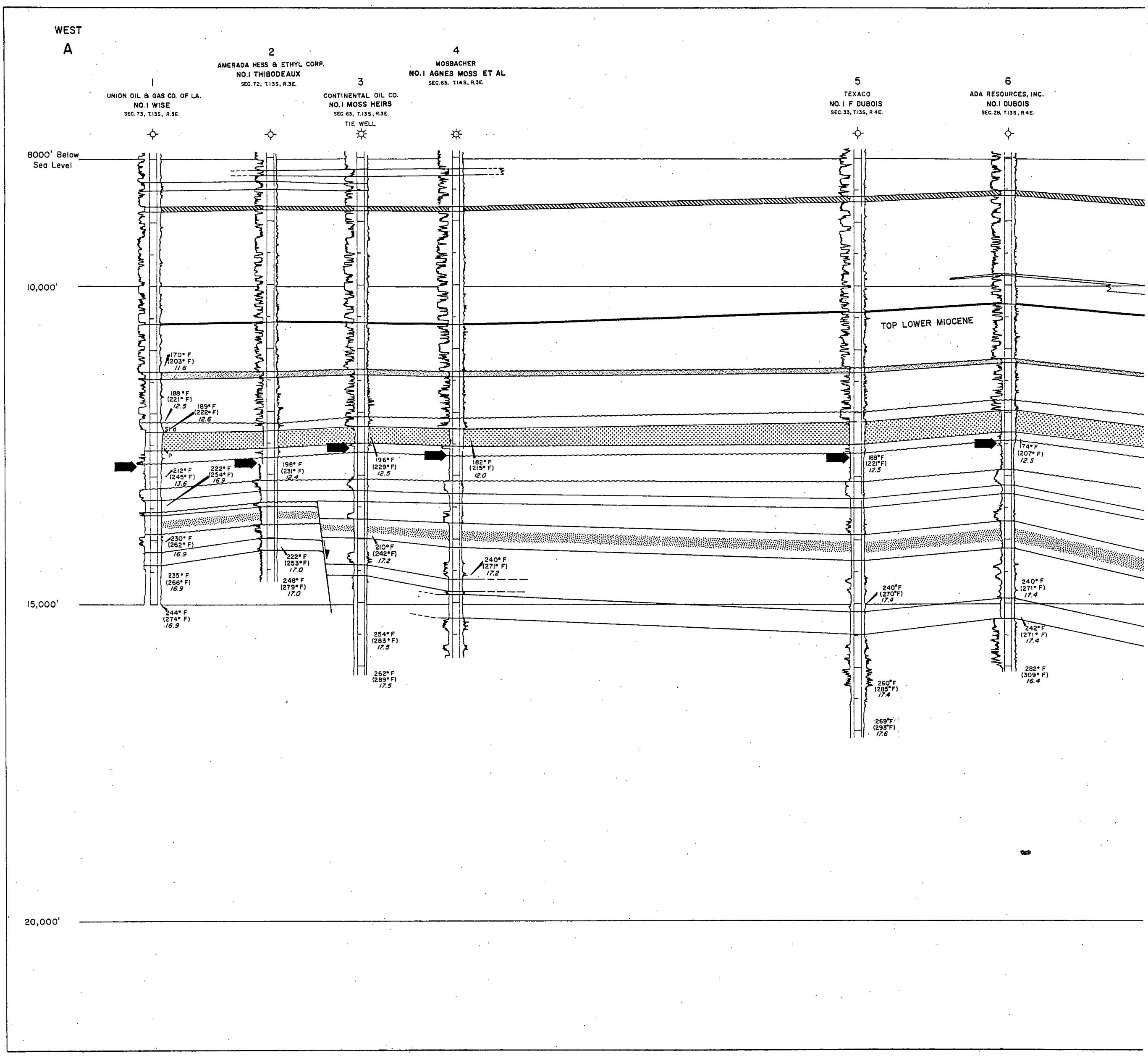


Figure 3. Cross section A-A', Bayou Hebert prospect.

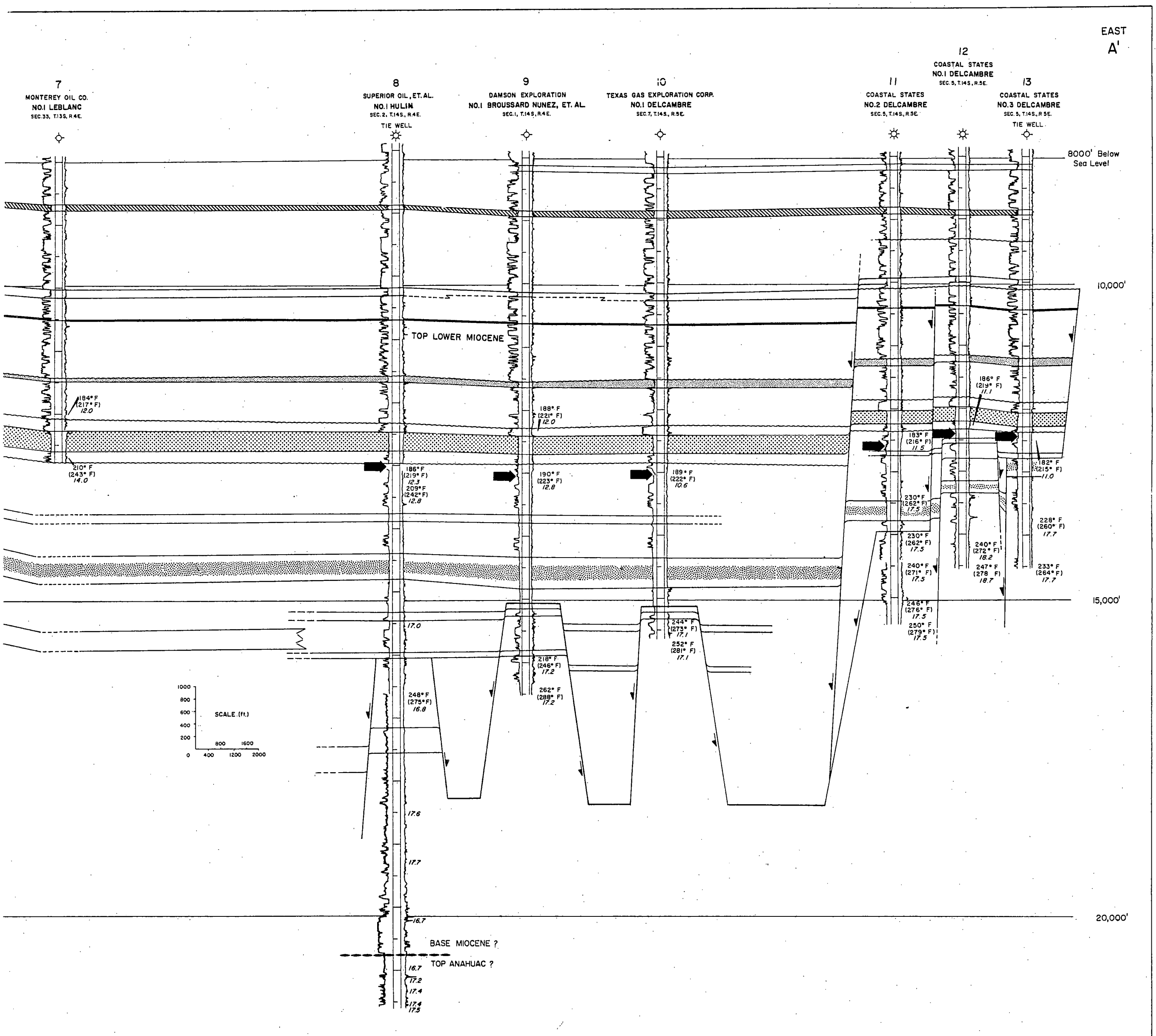


Figure 3, contd.

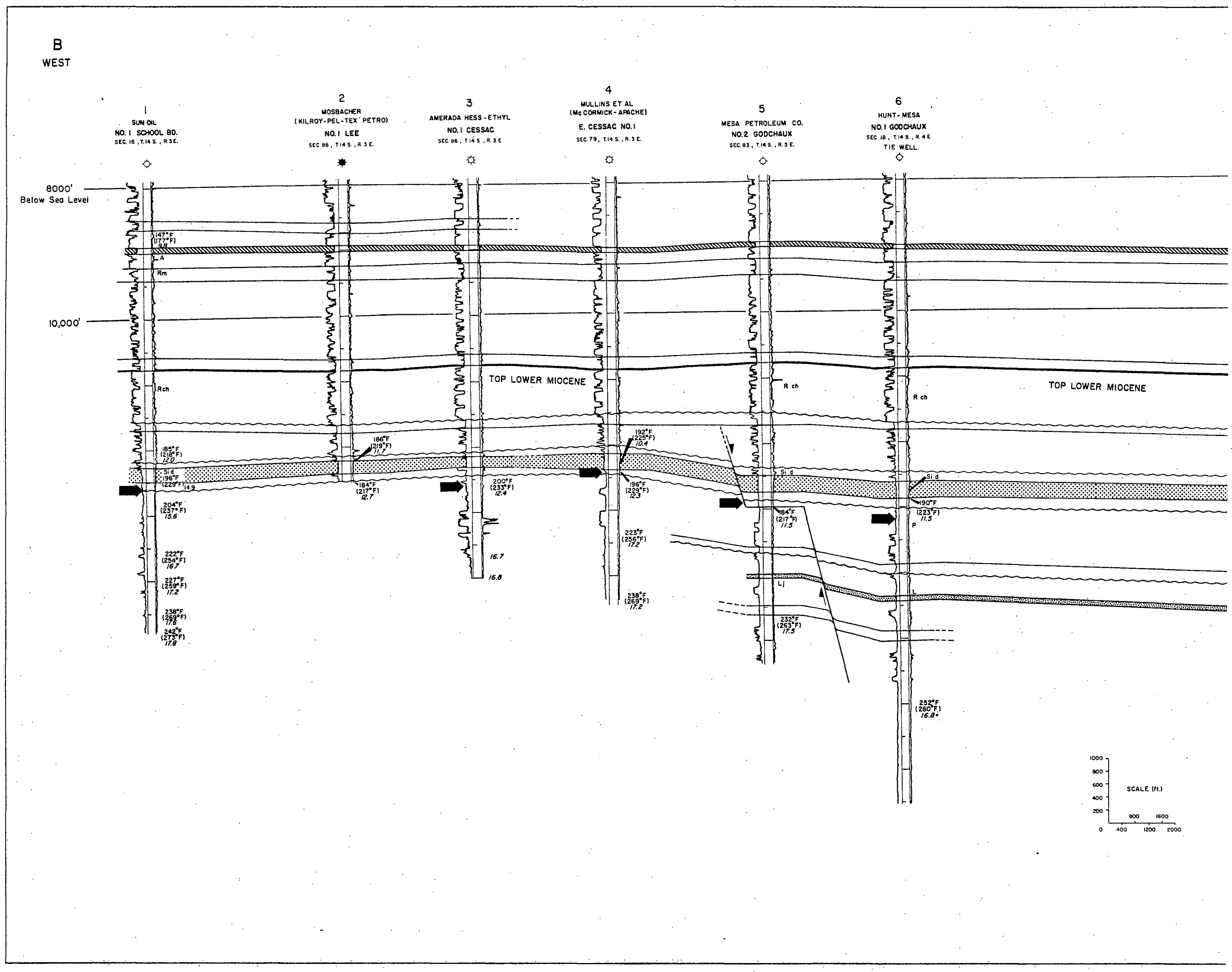
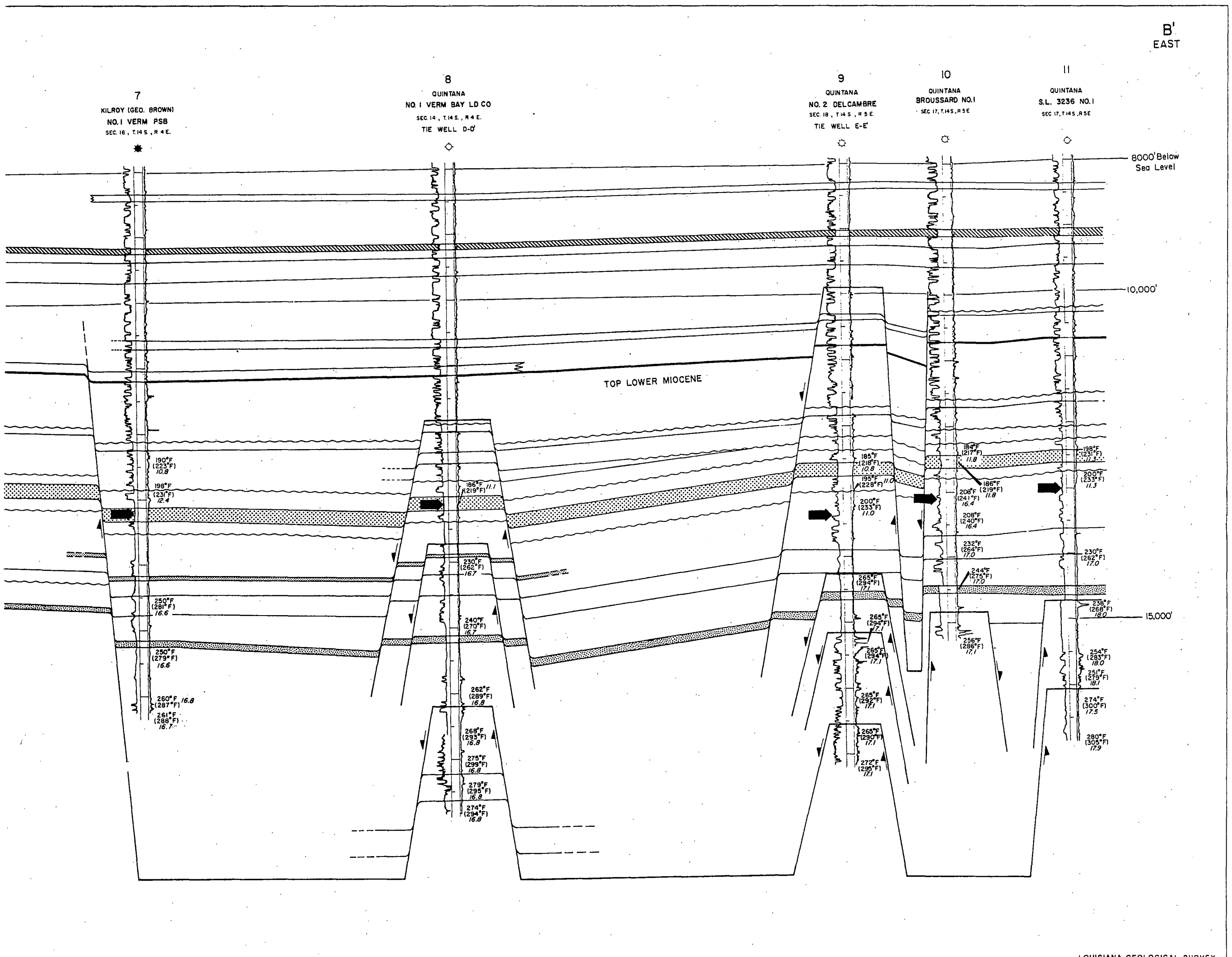


Figure 4. Cross section B-B', Bayou Hebert prospect.



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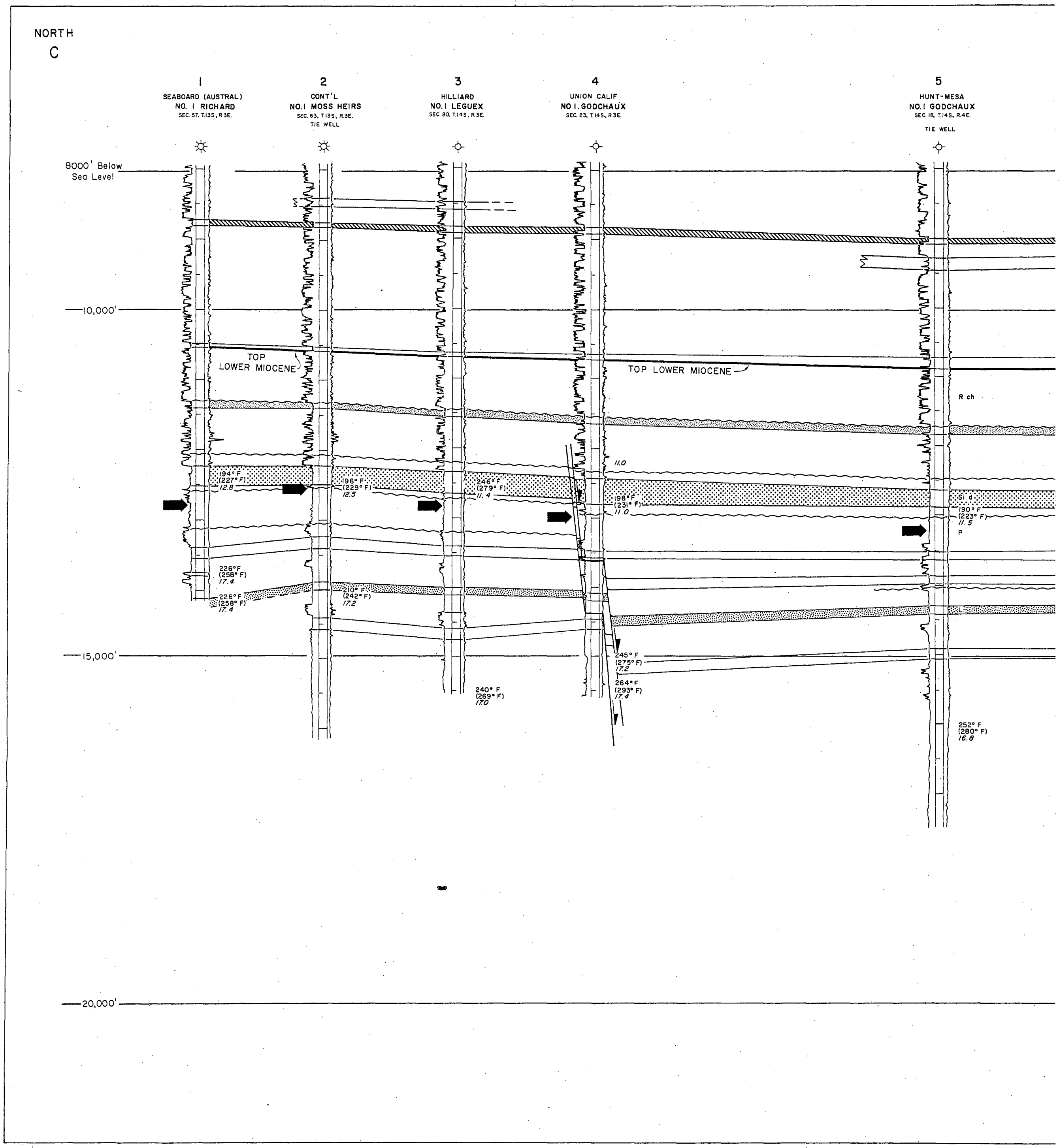


Figure 5. Cross section C-C', Bayou Hebert prospect.

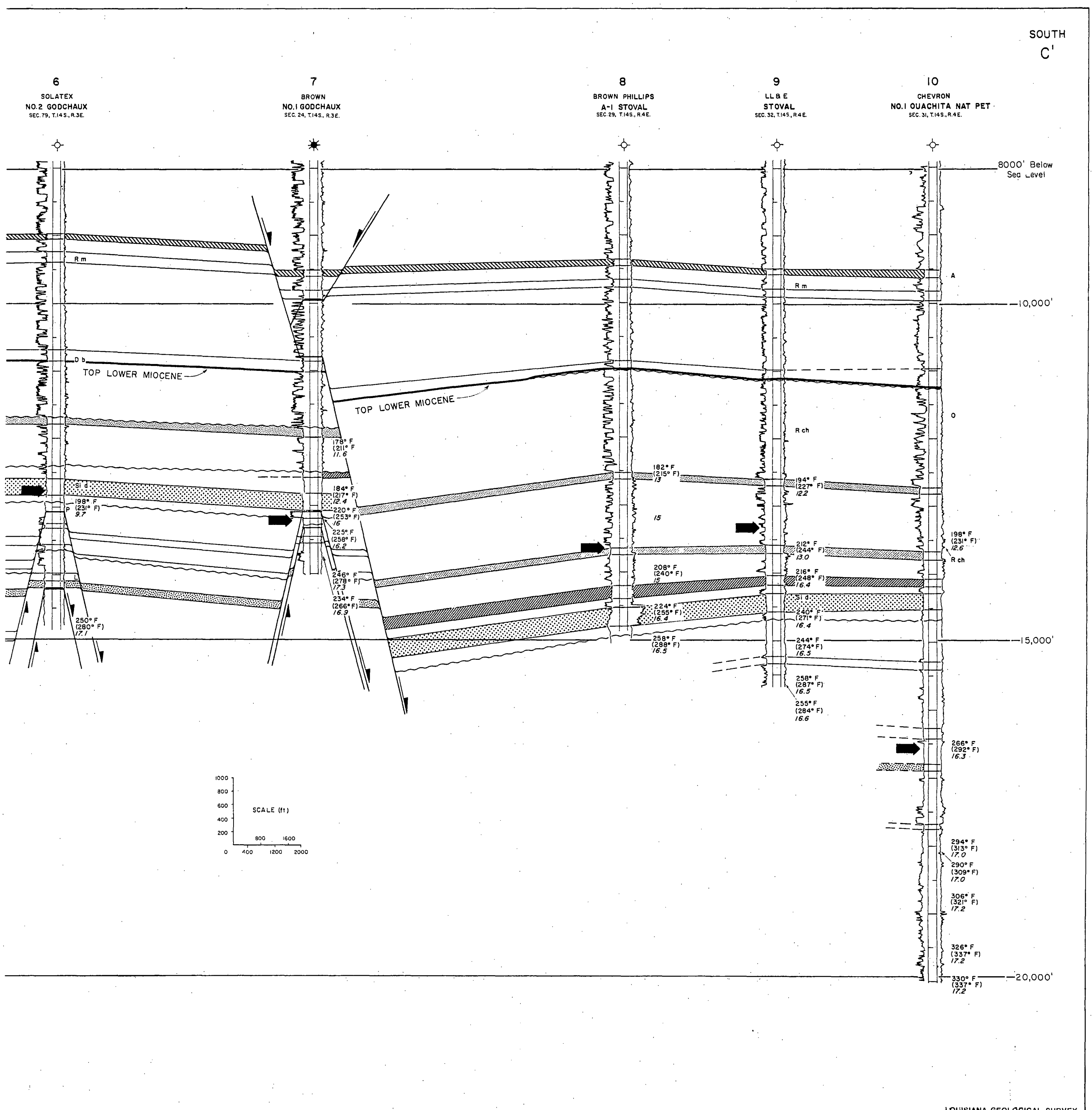


Figure 5, contd.

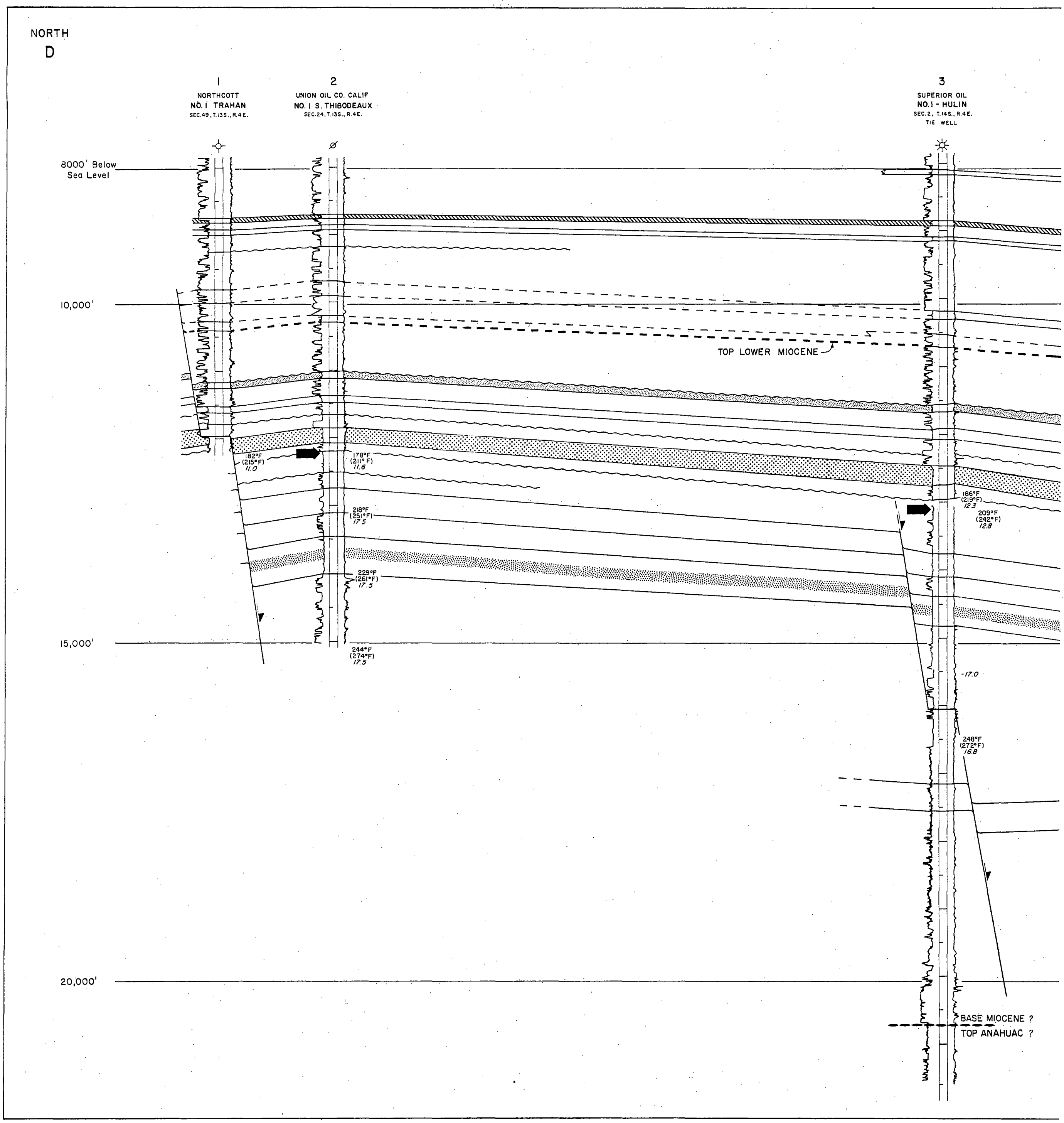
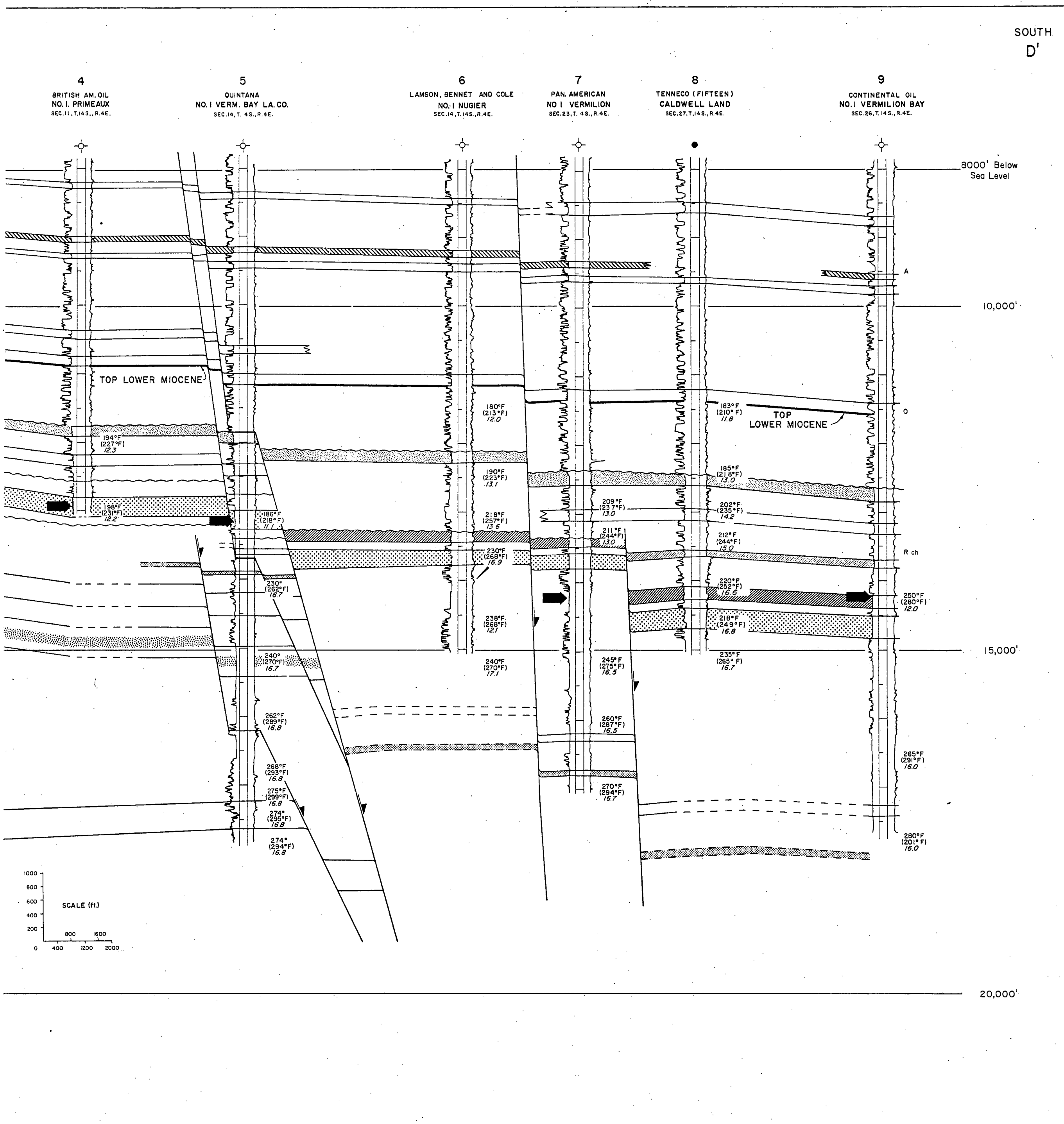


Figure 6. Cross section D-D', Bayou Hebert prospect.



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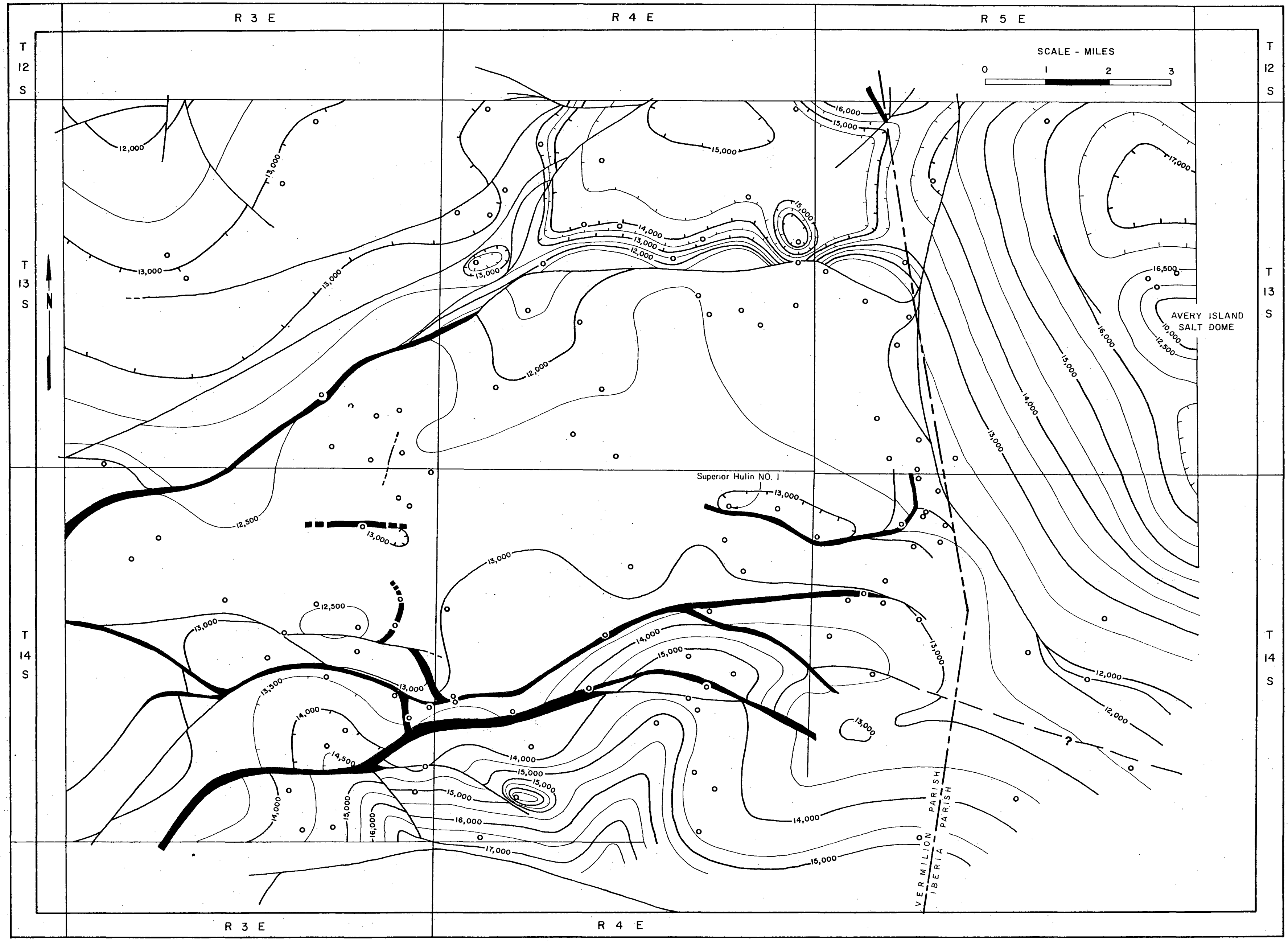


Figure 7. Depth to the top of geopressure (ft). Inferred from Geomap structure contours where control is lacking. Contour interval = 500 ft; contour interval expanded on Avery Island salt dome (faults after Geomap).

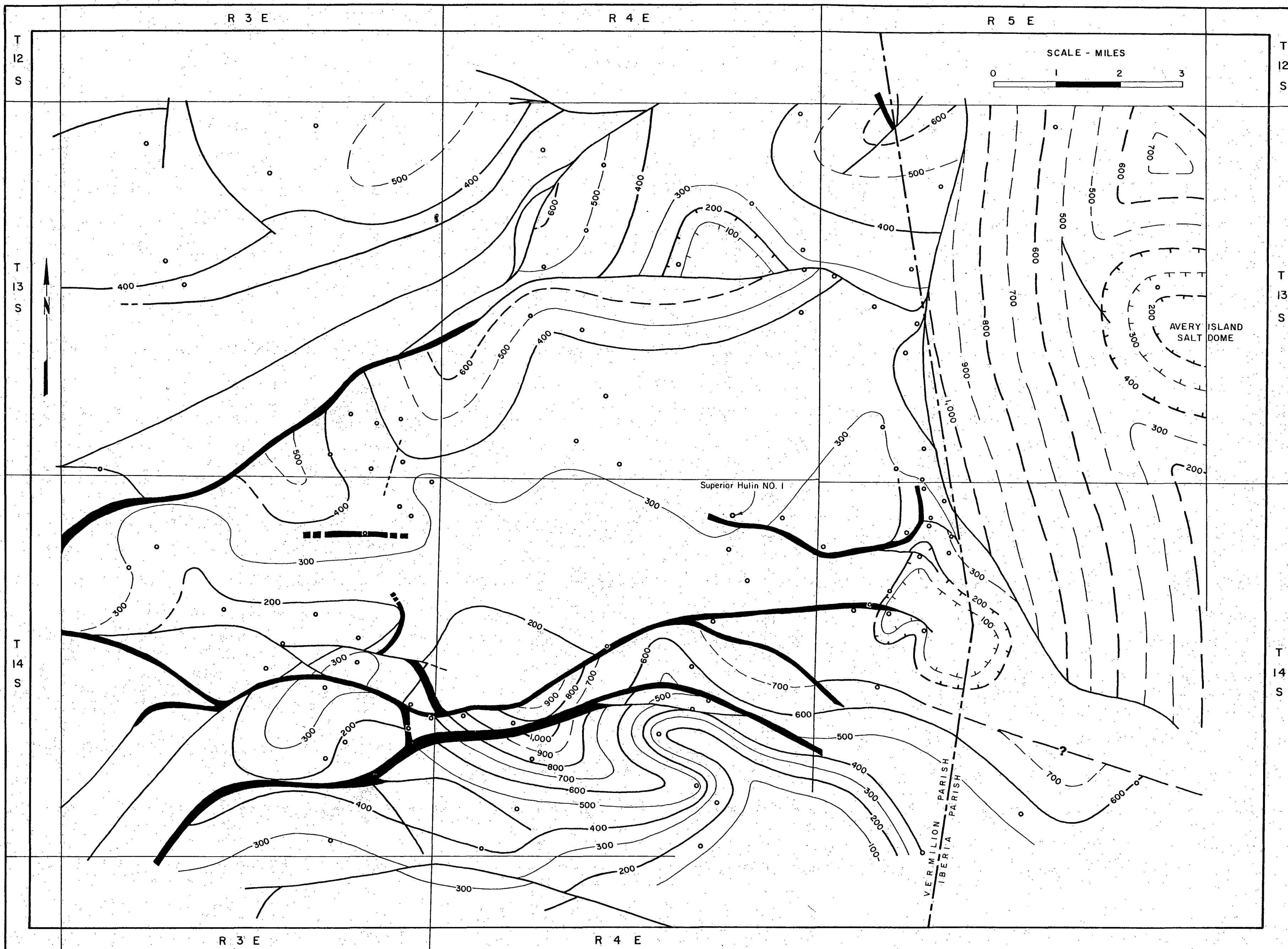


Figure 8. Net-sandstone isopach for interval between two marker beds immediately above the top of geopressure. Contour interval = 100 ft (faults after Geomap).

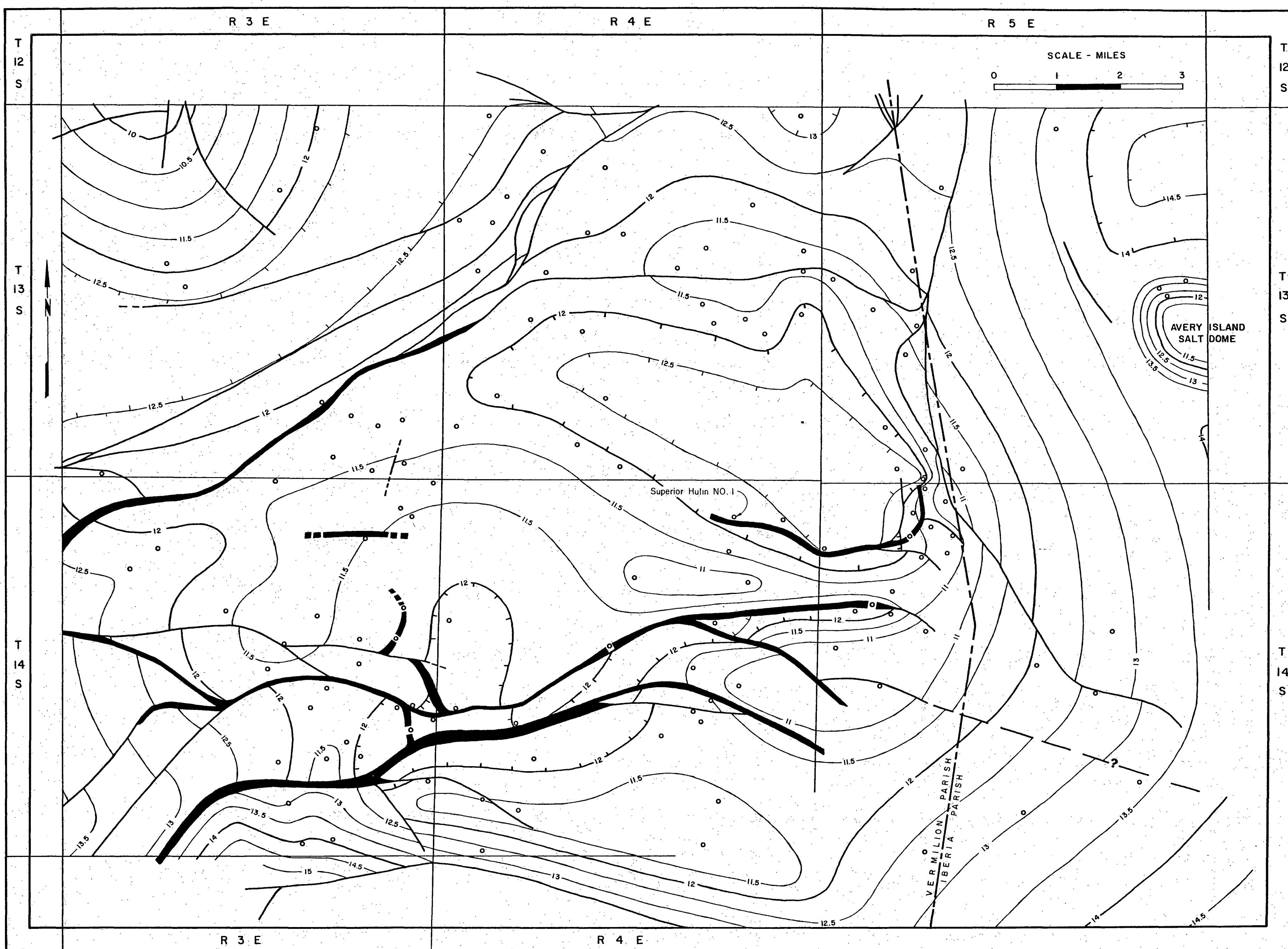


Figure 9. Depth to 212°F isotherm (thousands of feet). Contour interval = 500 ft (faults after Geomap).

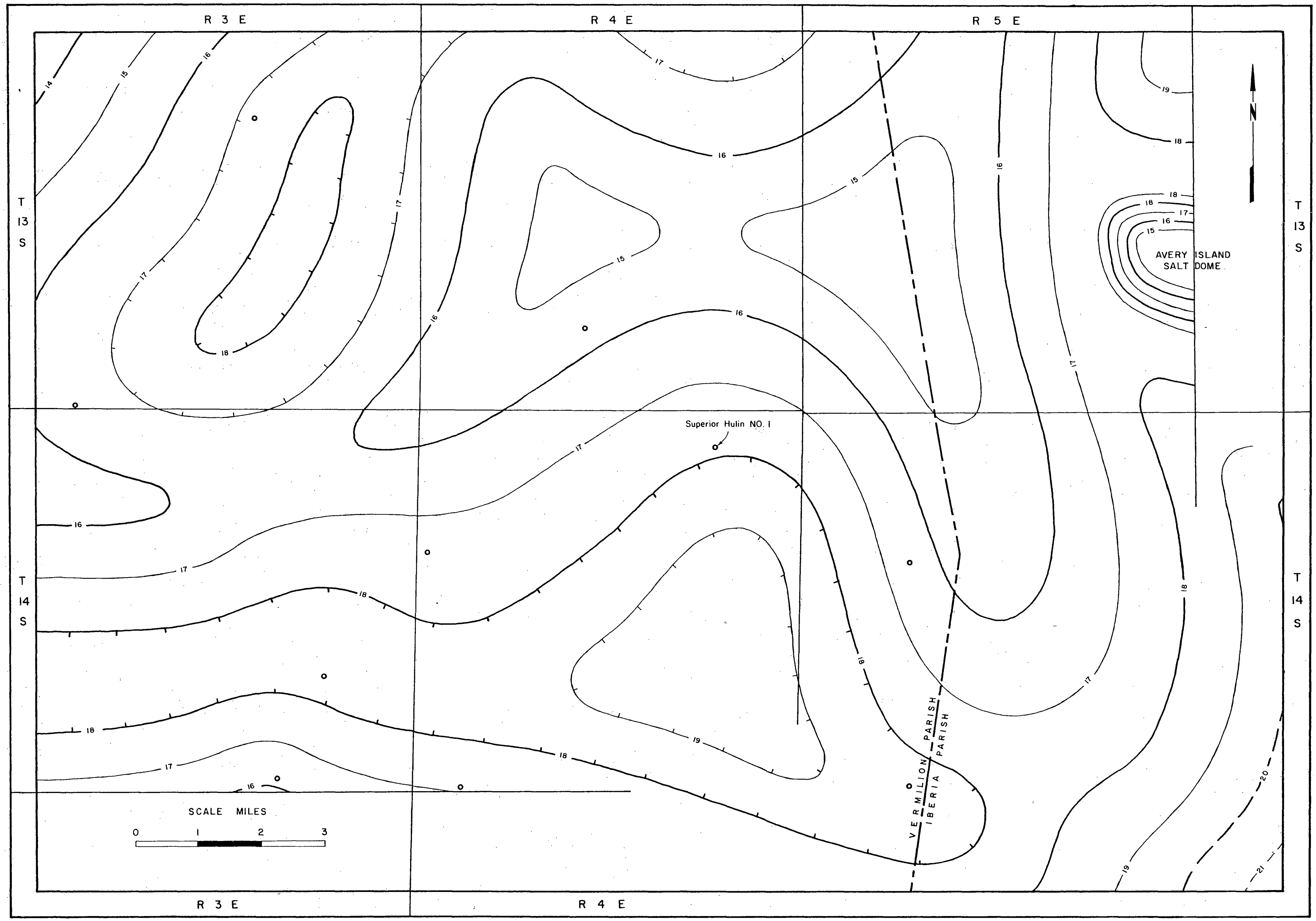


Figure 10. Depth to 300°F isotherm (thousands of feet). Contour interval = 1000 ft (partly inferred from Geomap structure contours).

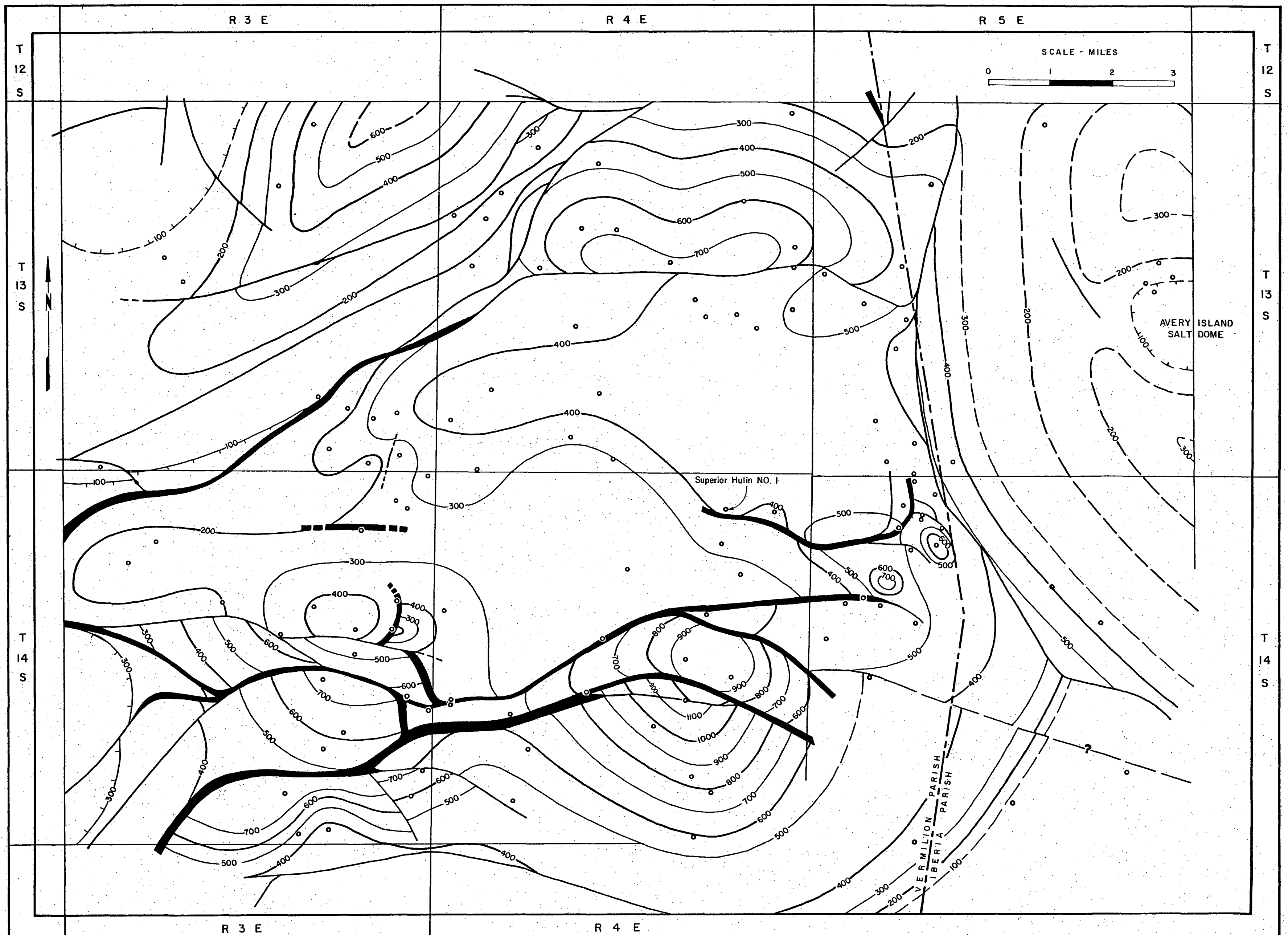


Figure 11. Net-sandstone isopach for interval between two marker beds immediately below the top of geopressure. Contour interval = 100 ft (faults after Geomap).

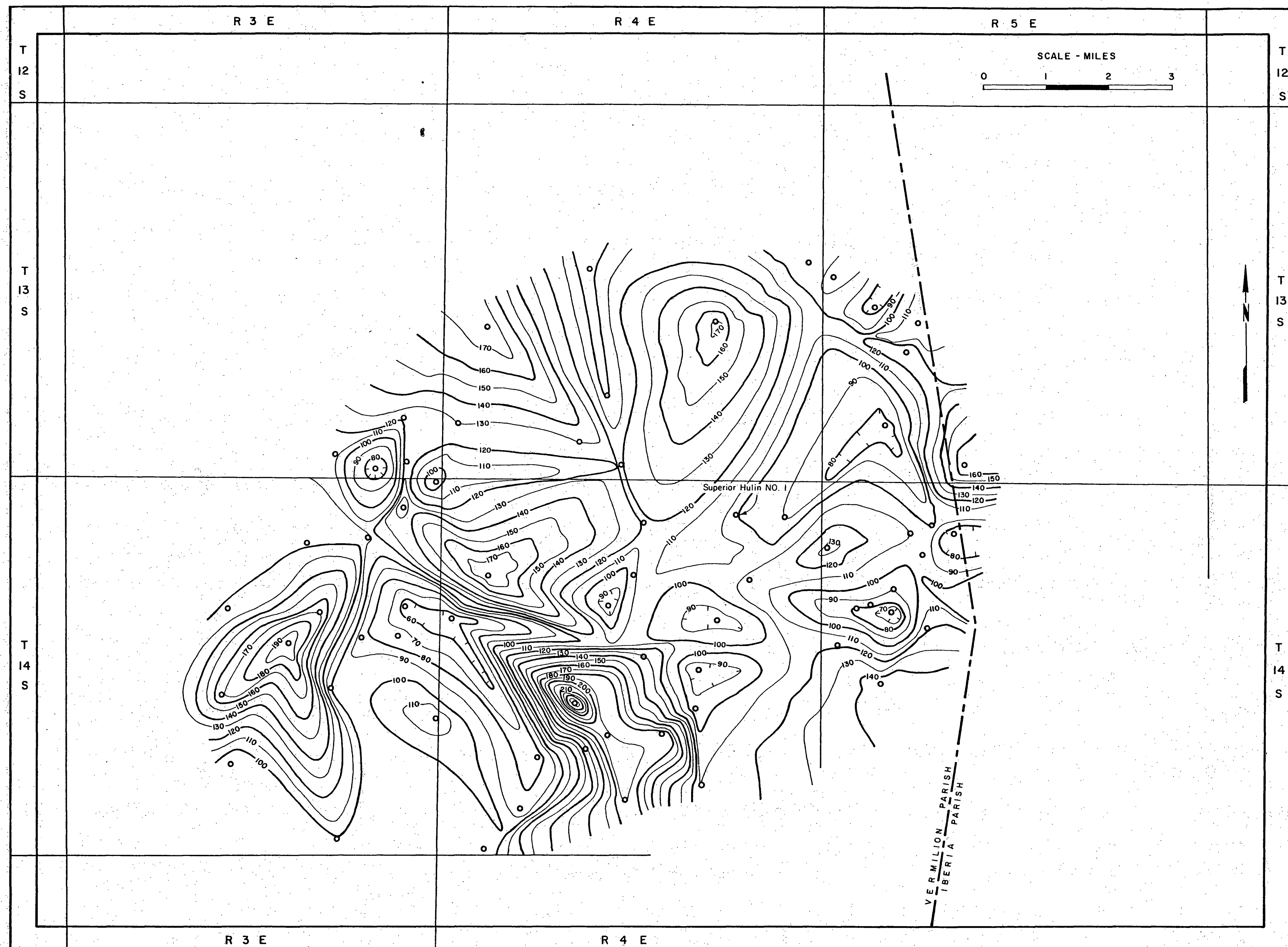


Figure 12. Salinity (ppm) of waters in sandstones between two marker beds immediately above the top of geopressure. Contour interval = 10 ppm.

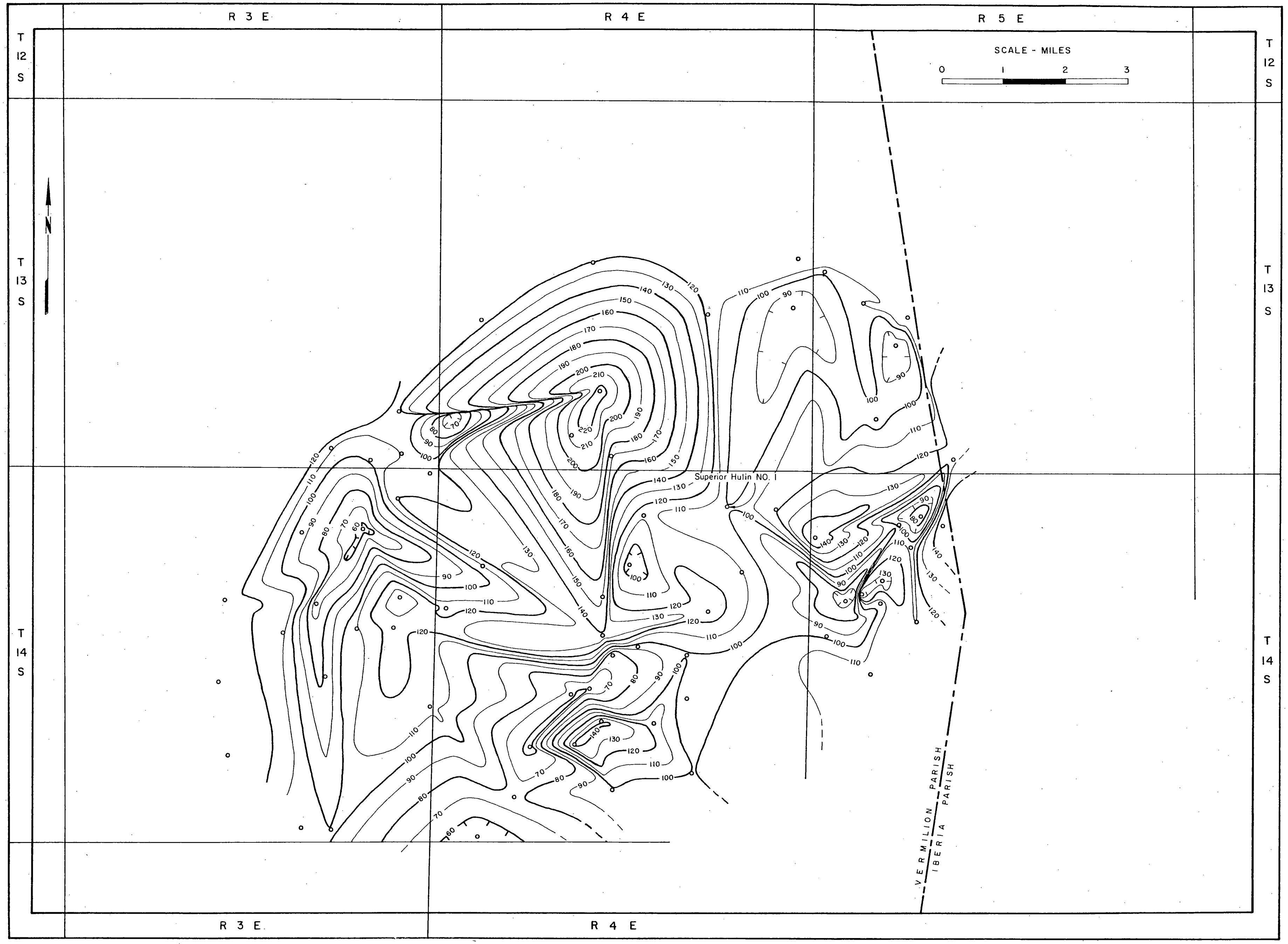


Figure 13. Salinity (ppm) of waters in sandstones between two marker beds immediately below the top of geopressure. Contour interval = 10 ppm.

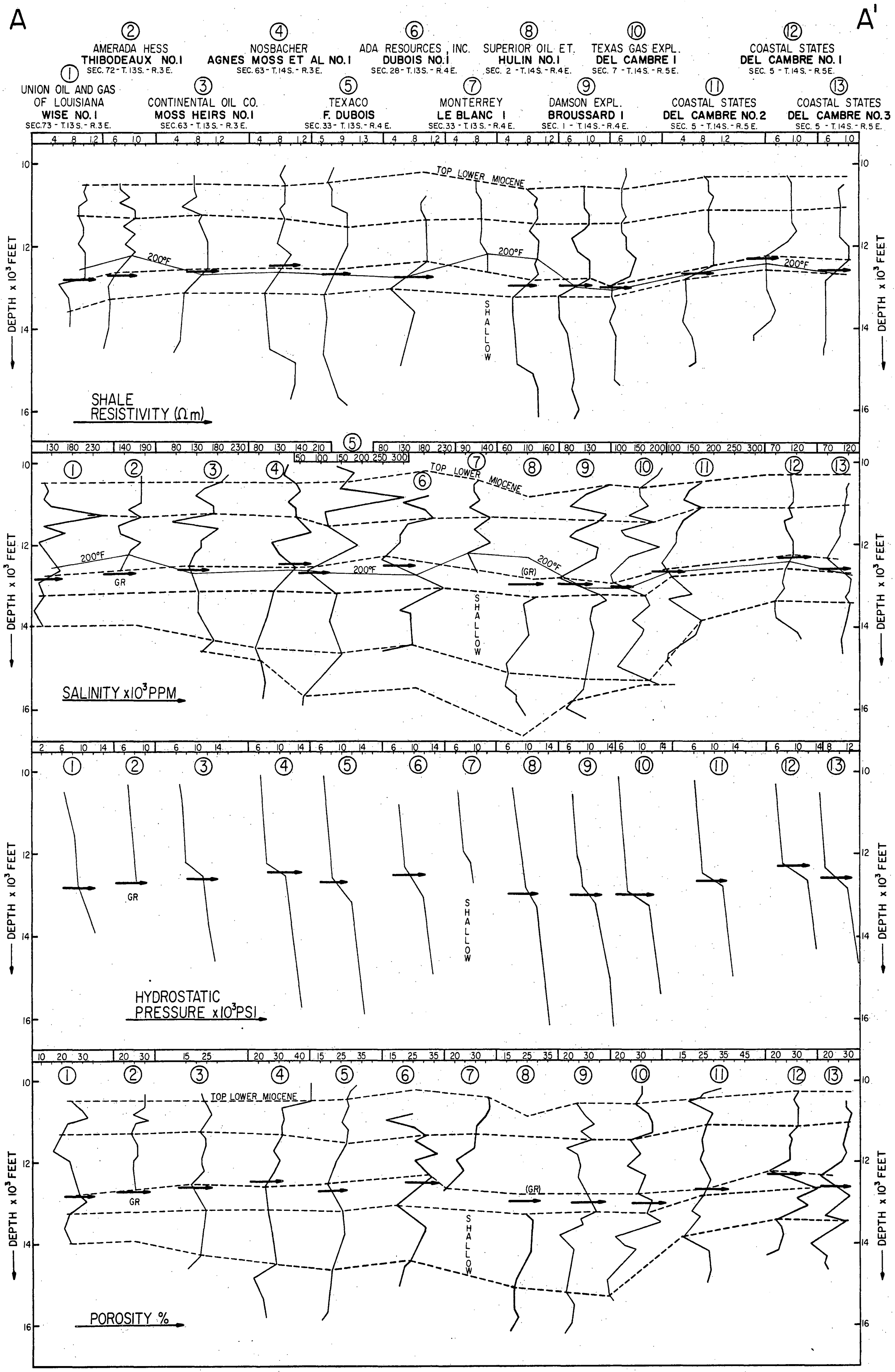


Figure 14. Profiles of log-derived parameters for cross section A-A', Bayou Hebert prospect.

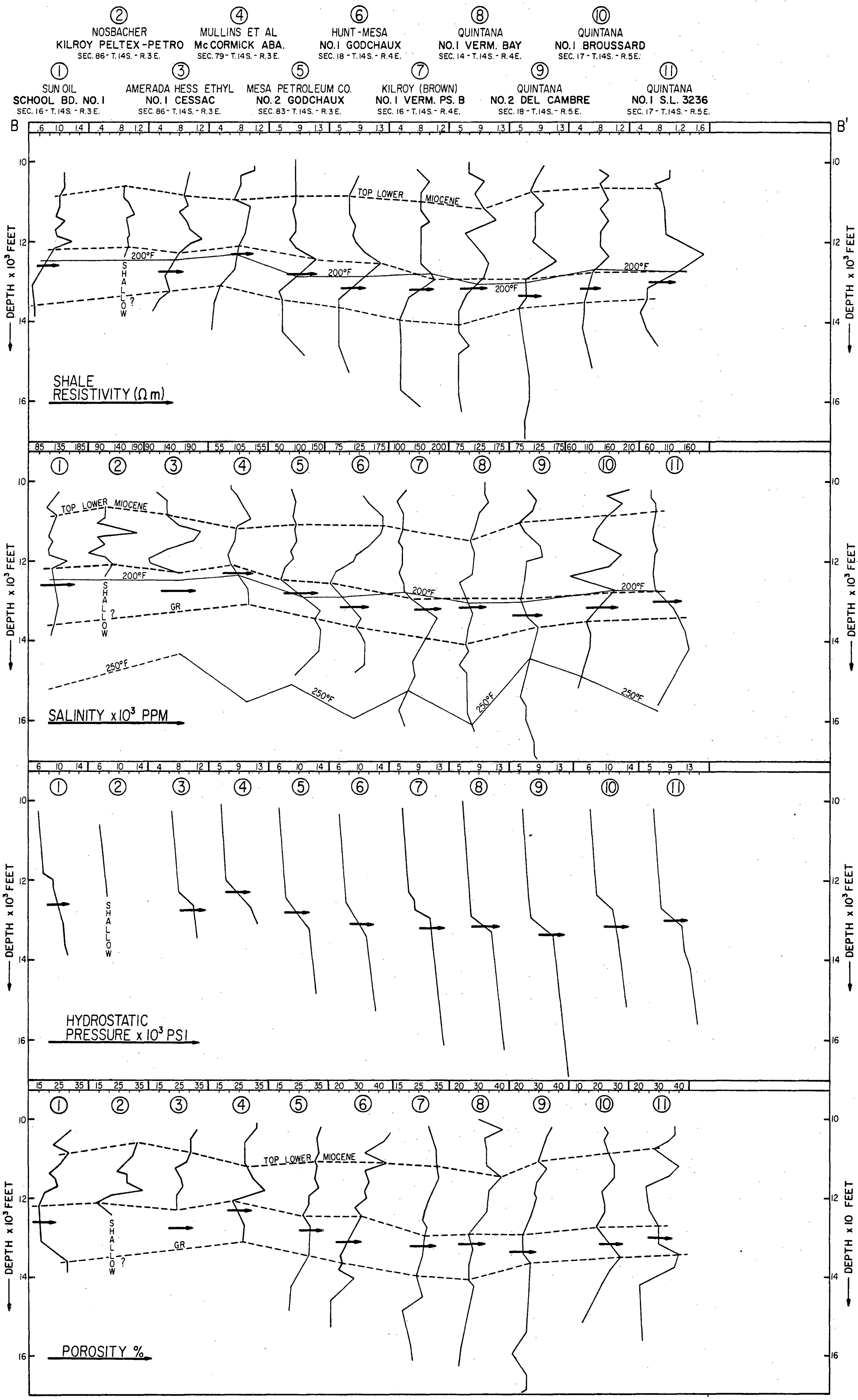


Figure 15. Profiles of log-derived parameters for cross section B-B', Bayou Hebert prospect.

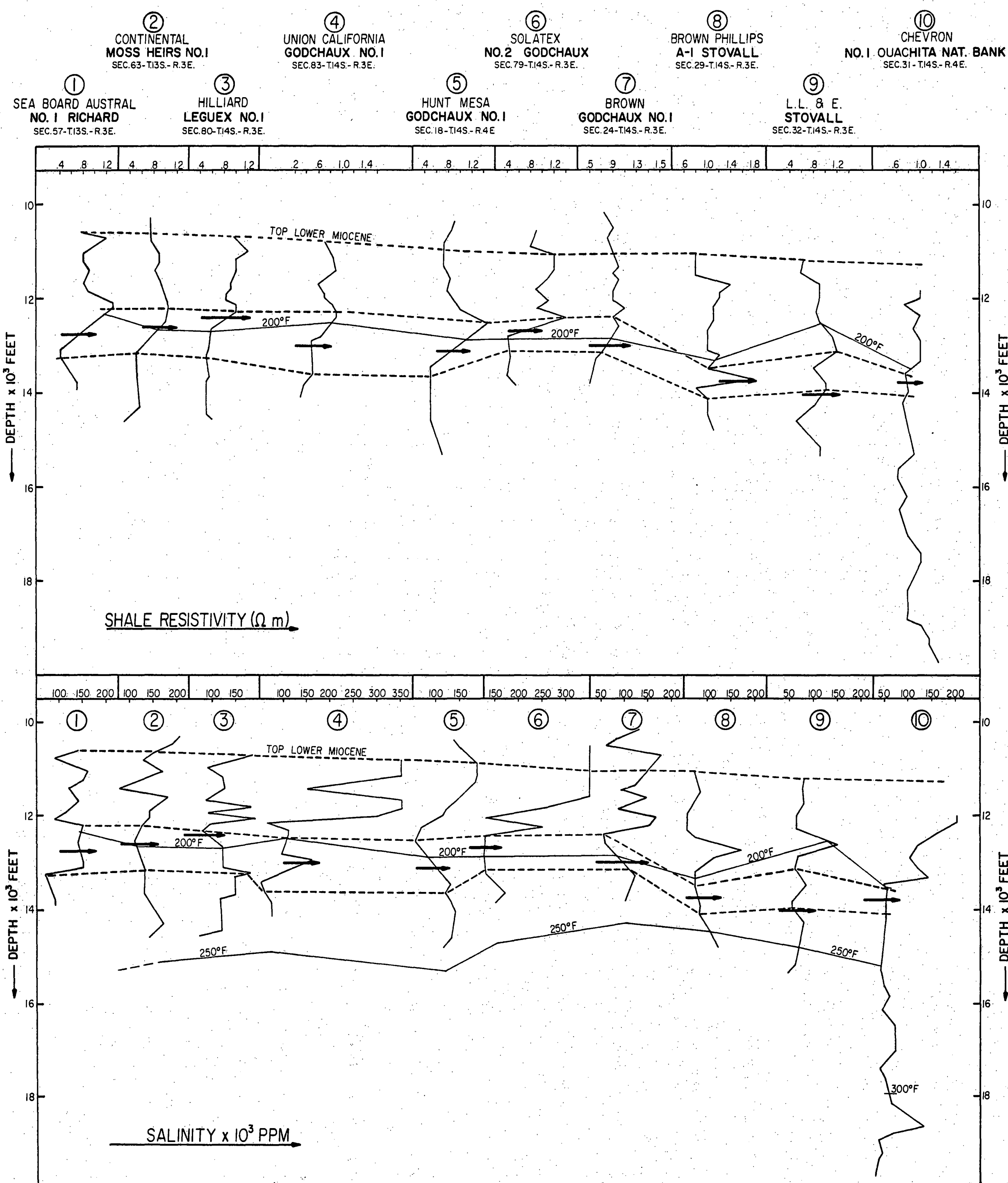


Figure 16a. Profiles of log-derived parameters for cross section C-C' Bayou Hebert prospect.

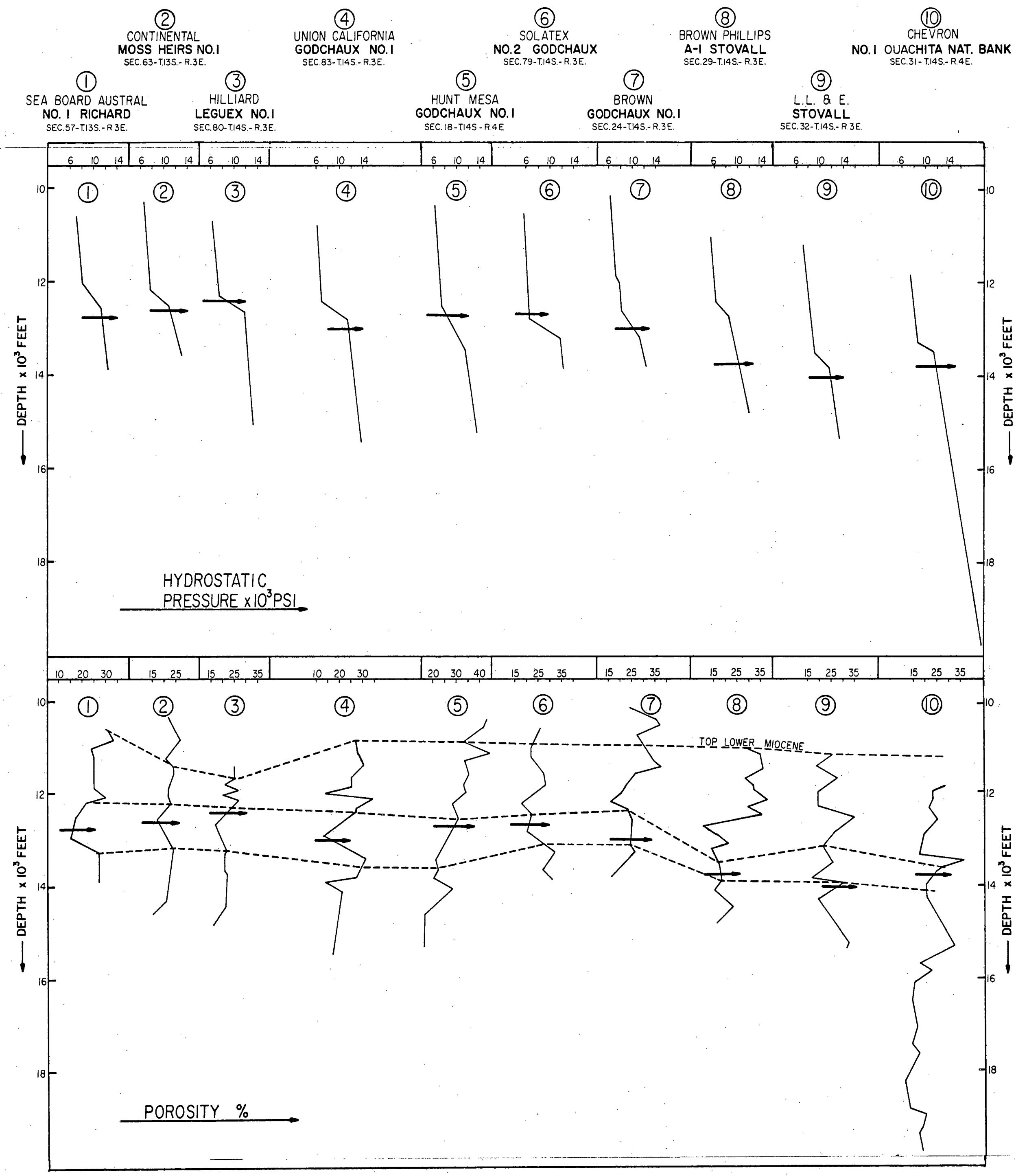


Figure 16b. Profiles of log-derived parameters for cross section C-C' Bayou Hebert prospect.

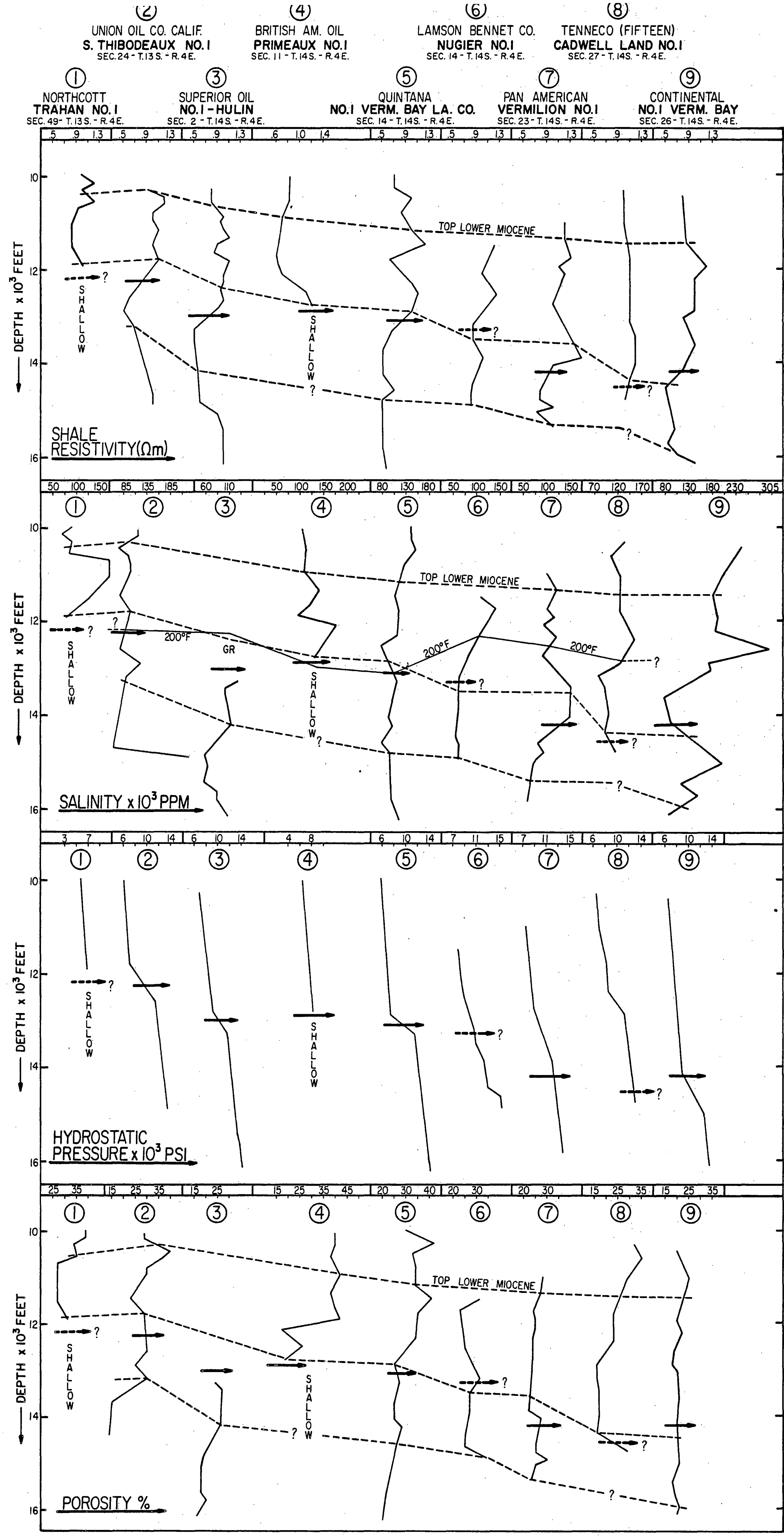


Figure 17. Profiles of log-derived parameters for cross section D-D', Bayou Hebert prospect.

APPENDIX

WELLS USED IN GEOTHERMAL EVALUATION, BAYOU HEBERT PROSPECT

Well Number	Well Identification
1	Texas Gas Exploration Corp. Victoria Noel No. 2 Sec. 5, 13S - 3E TD 12,300'
2	W. T. BURTON George Eldrige No. 1 Sec. 66, 13S - 3E TD 14098
3	W. T. BURTON Veazey No. 1 Sec. 45, 13S - 3E TD 18,085'
4	TENNESSEE GAS TRANSMISSION CO. Luke Detraz No. 1 Sec. 17, 13S - 3E TD 13,146'
5	SINCLAIR OIL & GAS CO. Louise Mestepey No. 1 Sec. 15, 13S - 3E TD 15455
6	TRICE PRODUCTION CO. Caldwell - Moresi No. 1 Sec. 65, 13S - 3E TD 17,184'
7	SEABOARD OIL CO. K. S. Weill No. 1 Sec. 58, 13S - 3E TD 12,160'
8	AMERADA HESS - ETHYL CORP. Lewis Faciane No. 2 Sec. 59, 13S - 3E TD 13,743'

Well Number	Well Identification
9	AMERADA HESS - ETHYL CORP. Lewis Faciane No. 3 Sec. 59, 13S - 3E TD 14426
10	SEABOARD (AUSTRAL OIL CO.) Richard No. 1 Sec. 57, 13S - 3E TD 14,122
11	CONTINENTAL OIL CO. Moss No. 1 Sec. 63, 13S - 3E TD 16,114'
12	AMERADA HESS, et al. Thibodeaux, et. al. No. 1 Sec. 72, 13S - 3E TD 14,677'
13	UNION OIL & GAS CO. OF LOUISIANA Wise No. 1 Sec. 73, 13S - 3E TD 15,000'
14	SOUTHERN NATURAL GAS CO. Wise et al. Unit A No. 1 Sec. 3, 14S - 3E TD 12,313'
15	MOSBACHER et al. Moss et al., No. 1 Sec. 63, 14S - 3E TD 15,855'
16	GREAT PLAINS EXPLORATION CO. F. A. Godchaux, et al. No. 1 Sec. 80, 14S - 3E TD 15,620'
17	HILLIARD OIL AND GAS INC. C. J. Lequeux No. 1 Sec. 80, 14S - 3E TD 15,500'

Well Number	Well Identification
18	UNION OF CALIFORNIA F. A. Godchaux No. 1 Sec. 83, 14S - 3E TD 15,580'
19	HURT E. Cessac et al. No. 1 Sec. 82, 14S - 3E TD 12,400'
20	AMERADA - HESS CORP., ETHYL CORP. C. Lee No. 1 Sec. 8, 14S - 3E TD 14,205'
21	AMERADA HESS - ETHYL CORP. Sagrera No. 1 Sec. 8, 14S - 3E TD 14,602'
22	SUN OIL CO. School Board No. 1 Sec. 16 14S - 3E TD 14, 749'
23	AMERADA HESS - ETHYL CORP. E. Cessac No. 1 Sec. 86, 14S - 3E TD 14,002'
24	MESA PETROLEUM CO. F. A. Godchaux No. 2 Sec. 83, 14S - 3E TD 15,404'
25	SOLATEX F. A. Godchaux, et al. No.2 Sec. 79, 14S - 3E TD 14,726'
26	McCORMICK OIL & GAS - APACHE EXPL. CORP. E. Cessac No. 1 Sec. 79, 14S - 3E TD 14,328'

Well Number	Well Identification
27	HOUSTON OIL CO. OF TEXAS F. A. Godchaux No. 6 Sec. 85, 14S - 3E TD 12,773'
28	MOSBACHER (KILROY CO. et al.) R. Lee No. 1 Sec. 86, 14S - 3E TD 15,100'
29	KILROY CO. OF TEXAS D. White No. 1 Sec. 87, 14S - 3E TD 14,500'
30	PET. TEXAS Exxon No. 1 Sec. 21, 14S - 3E TD 12,485'
31	HOUSTON OIL CO. OF TEXAS I. White No. 1 Sec. 87, 14S - 3E TD 13,180'
32	SUPERIOR OIL CO. D. White No. 1 Sec. 86, 14S - 3E TD 14,000'
33	HOUSTON OIL CO. OF TEXAS F. A. Godchaux No. 2 Sec. 85, 14S - 3E TD 13,364'
34	G. R. BROWN F. A. Godchaux No. 2 Sec. 85, 14S - 3E TD 13,990'
35	G. R. BROWN F. A. Godchaux No. 1 Sec. 24, 14S - 3E TD 14,025'
36	E. L. COX, et al. F. A. Godchaux No. 1 Sec. 88, 14S - 3E TD 14,025'

Well Number	Well Identification
37	HOUSTON OIL CO. OF TEXAS F. A. Godchaux No. 3 Sec. 88, 14S - 3E TD 13,145'
38	ATLANTIC REFINING CO. F. A. Godchaux No. 7 Sec. 88, 14S -3E TD 17, 057'
39	HOUSTON OIL CO. OF TEXAS F. A. Godchaux et al. No. 4 Sec. 88, 14S - 3E TD 14,973'
40	SINCLAIR OIL & GAS CO. M. Broussard No. 2 Sec. 90, 14S - 3E TD 14,998'
41	SINCLAIR OIL & GAS CO. M. Broussard No. 1 Sec. 90, 14S - 3E TD 13,400
42	SINCLAIR OIL & GAS CO. M. Broussard No. 3 Sec. 90, 14S-3E TD 14,500'
43	COX & LASALLE OIL CO. F. Stovall No.2 Sec. 89, 14S - 3E TD 16,105'
44	McCORMICK - BINTLIFF - PETTIT F. Stovall No. 2 Sec. 89, 14S - 3E TD 15,300'
45	McCORMICK - BINTLIFF - PETTIT F. Stovall No. 3 Sec. 36, 14S - 3E TD 15,317'

Well Number	Well Identification
46	LA SALLE, et al. F. Stovall No. 1 Sec. 25, 14S - 3E TD 13,700'
47	CHEVRON OIL CO. F. Stovall No.1 Sec. 31, 14S - 4E TD 20,000'
48	LOUISIANA LAND & EXPL. CO. F. Stovall No. 1 Sec. 32, 14S - 4E TD 15,643'
49	SOCONY F. Stovall No. 2 Sec. 33, 14S - 4E TD 13,616'
50	KERN COUNTY LAND CO. S/L 4112 No. 1 Sec. 35, 14S - 4E TD 14,368'
51	KERN COUNTY LAND CO. Broussard No. 1 Sec. 35, 14S - 4E TD 14,300'
52	CONTINENTAL OIL Verm. Bay No. 1 Sec. 26, 14S - 4E TD 18,117'
53	FRANKEL F. Stovall No. 1 Sec. 28, 14S - 4E TD 13,155'
54	G. R. BROWN F. Stovall No. A-1 Sec. 29, 14S - 4E TD 15,053'

Well Number	Well Identification
55	BALLARD & CORDELL F. Stovall No. 1 Sec. 20, 14S - 4E TD 13,115'
56	BRADCO OIL & GAS CO. F. A. Godchaux No1 Sec. 19, 14S - 4E TD 14,062'
57	GLASSCOCK et al. F. A. Godchaux No. 1 Sec. 19, 14S - 4E TD 12,500'
58	TEX GAS et al. Verm. Bay Ld. No. 1 Sec. 21, 14S - 4E TD 11,490'
59	NEWMONT OIL CO. Verm. Bay Ld. No. 1 Sec. 21, 14S - 4E TD 15,830'
60	CYPRUS F. Stovall No. 1 Sec. 28, 14S - 4E TD 13,020'
61	TENNECO (Fifteen Oil & Bel Oil Co.) Caldwell Ld. No. 1 Sec. 27, 14S - 4E TD 14,990'
62	TEXAS GULF PROD. CO. Verm. Bay Ld. No. 1 Sec. 23, 14S - 4E TD 13,000'
63	PAN AMERICAN PETROLEUM CORP. Verm. Bay Ld. No. 1 Sec. 23, 14S - 4E TD 17,000'

Well Number	Well Identification
64	DIVERSA, INC. Vermilion Bay Ld. B No. 4 Sec. 23, 14S - 4E TD 13,992'
65	PHILLIPS PETROLEUM CO. Coastal A-1 Sec. 23, 14S - 4E TD 14,002'
66	LAMSON, BENNETT, & COLE Nugier Unit No. 1 Sec. 15, 14S - 4E TD 15,026'
67	KILROY Nugier No. 1 Sec. 15, 14S - 4E TD 12,944'
68	PETROLEUM TEX Vermilion PSB No. 1 Sec. 16,14S - 4E TD 12,700'
69	L.G.S. EXPLORATION, INC. Vermilion PSB No.1 Sec. 16, 14S - 4E TD 12,950'
70	G. R. BROWN Vermilion PSB No. 1 Sec. 16, 14S - 4E TD 16,200'
71	H. HUNT, et al. F. A. Godchaux No. 1 Sec. 18, 14S - 4E TD 16,000'
72	KIRBY OIL Magee Sec. 7, 14S - 4E TD 12,505'

Well Number	Well Identification
73	LACAL Vermilion PSB No. 1 Sec. 16, 14S - 4E TD 12,500'
74	Mc CORMICK et al. Nugier et al. No. 1 Sec. 10,14S - 4E TD 14,129'
75	QUINTANA PETROLEUM CORP. Vermilion Bay Ld. No. 1 Sec. 14, 14S - 4E TD 17,790'
76	BRITISH AMERICAN OIL PROD. CO. O. Primeaux No. 1 Sec. 11, 14S - 4E TD 12,998'
77	FORMAN EXPLORATION CO. E. T. Primeaux No. 1 Sec. 11, 14S - 4E TD 12,850'
78	DAMSON EXPLORATION CORP. Nunez et al. No. 1 Sec. 1, 14S - 4E TD 16,500'
79	SUPERIOR OIL CO. W. Hulin No. 1 Sec. 2, 14S - 4E TD 21,550'
80	LINCOLN ROCK Leblanc No. 1 Sec. 3, 14S - 4E TD 12,503'
81	MONTEREY OIL CO. S. B. Le Blanc No. 1 Sec. 33, 13S - 4E TD 12,757'

Well Number	Well Identification
82	TEXACO OIL CO. F. Dubois No. 1 Sec. 33, 13S - 4E TD 17,100'
83	GULF OIL CORP. W. J. Stelly No. 1 Sec. 31, 13S - 4E TD 12,500'
84	ADA RESOURCES INC. Hebert No. 1 Sec. 31, 13S - 4E TD 14,450
85	TEXAS CO. Mrs. R. S. Henry No. 1 - B Sec. 30, 13S - 4E TD 12,005'
86	ADA RESOURCES, INC. R. Dubois No. 1 Sec. 28, 13S - 4E TD 16,030'
87	TEXAS CO. Erath Unit No. 38-7 Sec. 21, 13S - 4E TD 16,000'
88	PHILLIPS PETROLEUM CO. Burt No. 1 Sec. 20, 13S - 4E TD 11,687'
89	PAN AMERICAN PETROLEUM CORP. A. Butaud No. 1 Sec. 45, 13S - 4E TD 12,805'
90	PAN AMERICAN PETROLEUM CORP. A. Broussard No. 1 Sec. 43, 13S - 4E TD 13,500'

Well Number	Well Identification
91	TEXAS CO. Erath Unit U Sec. 17, 13S - 4E TD 11,850'
92	TEXAS CO. Erath Unit Sec. 16, 13S - 4E TD 15,900'
93	SKELLY OIL CO. L. J. Eleazar No. 1 Sec. 15, 13S - 4E TD 13,602'
94	COLE E. Dugas No. 1 Sec. 23, 13S - 4E TD 14,500'
95	DYNAMIC EXPLORATION, INC. E. Dugas No. 1 Sec. 23, 13S - 4E TD 12,415'
96	COLE E. Broussard No. 1 Sec. 23, 13S - 4E TD 12,330'
97	UNION OF CALIFORNIA B. Sonnier Unit P-9 No. 1 Sec. 24, 13S - 4E TD 11,860'
98	UNION OF CALIFORNIA S. Thibodeaux No. 1 Sec. 24, 13S - 4E TD 15,012'
99	NORTHCOTT EXPLORATION CO. E. S. Trahan No. 1 Sec. 49, 13S - 4E TD 12,150'

Well Number	Well Identification
100	TEXACO INC. B. Le Blanc No. 1 Sec. 49, 13S - 4E TD 16,000'
101	TEXACO INC. Edwards No. 1 Sec. 11, 13S - 4E TD 14,500'
102	G. H. Vaughn A Bouillon No. 1 Sec. 49, 13S - 4E TD 11,991'
103	STRAKE PETROLEUM INC. V. L. Caldwell et al. No. 1 Sec. 41, 13S - 4E TD 11,615'
104	PHILLIPS PETROLEUM CO. Belaire No. 1 Sec. 41, 13S - 4E TD 14014'
105	PHILLIPS PETROLEUM CO. Thibodeaux No. 1 Sec. 42, 13S - 4E TD 13,209'
106	PAN AMERICAN PETROLEUM CORP. School Board Sand Unit S-9 No. 1 Sec. 42, 13S - 4E TD 12,900'
107	PHILLIPS PETROLEUM CO. Caesar No. A-1 Sec. 42, 13S - 4E TD 12,463'
108	PHILLIPS PETROLEUM CO. Caldwell G. No. 1 Sec. 40, 13S - 4E TD 14,702'

Well Number	Well Identification
109	TIDEWATER ASSOC. OIL CO. R. Y. Rose No. 1 Sec. 40, 13S - 4E TD 14,000'
110	TIDEWATER ASSOC. OIL CO. Broussard Unit B-10 Sec. 40, 13S - 4E TD 12,612'
111	HAWTHORNE OIL & GAS CORP. Del Cambre No. 1 Sec. 1, 13S - 4E TD 14,950'
112	H. HUNT, INC. J. B. Vice No.1 Sec. 40, 13S - 5E TD 15,000'
113	ATLANTIC REFINING CO. F. Landry No. 1 Sec. 8, 13S - 5E TD 15,581'
114	L L & E Petit Anse No. 2 Sec. 55, 13S -5E TD 5,873'
115	TEXAS CRUDE, INC. Petit Anse No. 2 Sec, 55, 13S - 5E TD 15,720'
116	TEXAS CRUDE INC. Petit Anse No.1 Sec. 55, 13S - 5E TD 14,806'
117	HUMBLE OIL & REFINING CO. Petit Anse No. 26 Sec. 38, 13S - 5E TD 12,312'

Well Number	Well Identification
118	MOBIL OIL CORP. Landry No. 1 Sec. 17, 13S - 5E TD 13,770'
119	COASTAL STATES GAS PROD. CO. R. Broussard No. 1 Sec. 18, 13S - 5E TD 15,200'
120	FRANKS PETROLEUM et al. C. Dugas No. 1 Sec. 19, 13S - 5E TD 14,700'
121	EMERALD OIL COMPANY Landry - Meaux No. 1 Sec. 20, 13S - 5E TD 15,020'
122	FRANKS PETROLEUM et al. F. Dugas "A" No. 1 Sec. 20, 13S - 5E TD 14,512'
123	UNION OF CALIFORNIA E. Dugas No. 6 Sec. 31, 13S - 5E TD 14,894'
124	UNION OF CALIFORNIA Billeaud Planters No. 3 Sec. 32, 13S - 5E TD 13,939'
125	UNION OF CALIFORNIA Billeaud Planters No. B-1 Sec. 33, 13S - 5E TD 15,048'
126	UNION OF CALIFORNIA E. Dugas No. 8 Sec. 32, 13S - 5E TD 14,485'
127	UNION OF CALIFORNIA E. Dugas No. 7 Sec. 32, 13S - 5E TD 14,235'

Well Number	Well Identification
128	UNION OF CALIFORNIA Broussard No. 9 Sec. 5, 14S - 5E TD 13,721'
129	UNION OF CALIFORNIA E. Dugas No. 6 Sec. 6, 14S - 5E TD 8,372'
130	COASTAL STATES GAS PROD. CO. T. B. Lee No. 1 Sec. 5, 14S - 5E TD 13,745'
131	UNION OF CALIFORNIA Broussard No. 8 Sec. 5, 14S - 5E TD 14,040'
132	COASTAL STATES GAS PROD. CO. E. Delcambre No. 4 Sec. 5, 14S - 5E TD 14,020'
133	COASTAL STATES et al. E. Delcambre No. 1 Sec. 5, 14S - 5E TD 14,500'
134	COASTAL STATES et al. E. Delcambre No. 3 Sec. 5, 14S - 5E TD 15,000'
135	COASTAL STATES GAS PROD. CO. I. Delcambre No. 1 Sec. 8, 14S - 5E TD 14,314'
136	COASTAL STATES et al. E. Delcambre No. 2 Sec. 5, 14S - 5E TD 15,407'

Well Number	Well Identification
137	L. HUNT E. Delcambre No. 1 Sec. 8, 14S - 5E TD 14,500'
138	TEXAS GAS EXPLORATION CORP. E. Delcambre No. 1 Sec. 7, 14S - 5E TD 15,605'
139	QUINTANA PETROLEUM CORP. E. Delcambre No. 1 Sec. 8, 14S - 5E TD 16,803'
140	TEXAS GAS EXPLORATION CORP. (MARTIN) I. Delcambre No. 1 Sec. 7, 14S - 5E TD 15,600'
141	QUINTANA PETROLEUM CORP. I. Delcambre No. 2 Sec. 18, 14S - 5E TD 17,120'
142	QUINTANA PETROLEUM CORP. Broussard No. 1 Sec. 17, 14S - 5E TD 15,215'
143	QUINTANA PETROLEUM CORP. S/L 3236 No. 1 Sec. 17, 14S - 5E TD 16,819'
144	DELTA ENERGY E. Delcambre et al. No. 1 Sec. 18, 14S - 5E TD 16,500'
145	QUINTANA PETROLEUM CORP. Broussard et al. No. 1 Sec. 19, 14S - 5E TD 16,950'
146	UNION OF CALIFORNIA St. Lse 3236 No. 1 Sec. 15, 14S - 5E TD 14,000'

Well Number	Well Identification
147	CALIFORNIA OIL CO. Vermilion Bay Ld. No. 1 Sec. 14, 14S - 5E TD 14,000'
148	SAMEDAN - CHEVRON S/L 2903 No. 1 Sec. 23, 14S - 5E TD 14,701'
149	L.V.O. et al. S/L 5857 No. 1 Sec. , 14S - 5E TD 14,056
150	LOUISIANA LAND & EXPLORATION CO. S/L 4587 No. 1 Sec. , 14S - 5E TD 15,683'
151	CONSOLIDATED GAS SUPPLY CORP. S/L 4859 No. 1 Sec. 29, 14S - 5E TD 20,600'

SITE-SPECIFIC STUDIES

R. H. Pilger, Jr., and T. Cavanagh

Introduction

During FY 1981, three prospects were studied in terms of their structural-stratigraphic setting using well logs and seismic reflection profiles. These prospects include Southeast Pecan Island, South White Lake, and Kaplan. The Southeast Pecan Island study, a continuation of work initiated under contract number DE-AC08-78ET27019, has been completed. A discussion of this work is included here, together with copies of maps and cross sections.

South White Lake studies were still in progress at the end of FY 1981 and are expected to be completed by the end of FY 1982. Considerable success has been obtained in acquiring access to seismic data in the prospect.

Work on Kaplan was inhibited by the inability to acquire adequate seismic coverage of the prospect. In addition, preliminary studies indicated very limited lateral extent of the prospective sandstones. Consequently, work on the prospect was terminated.

Seismic data were also obtained for Bayou Hebert prospect. Initial study of the prospect was undertaken by Richard McCulloh through the Resource Assessment portion of this project. Interpretation of the seismic data is being undertaken jointly by him and R. Pilger and is to be completed in FY 1982.

Southeast Pecan Island-South Freshwater Bayou Prospect

The work on Southeast Pecan Island prospect was conducted by Thomas Cavanagh, a geology graduate student, under the supervision of R. Pilger.

From a combination of seismic reflection profiles and well logs, T. Cavanagh established the detailed structural-stratigraphic setting of the prospect. During the study, it became apparent that the Freshwater Bayou area of Southeast Pecan Island (near well number 128 of Fig. 1) represents the best design test-well site. An earlier study of this prospect had recommended a site near well number 84. To distinguish this alternate location, South Freshwater Bayou prospect has been delineated, centered on S10, T17S, R2E.

The structural-stratigraphic setting of the prospect is defined in three structure contour maps (Figs. 2 to 5), three interval isopach maps (Figs. 6 to 8), and two net-sandstone maps (Figs. 9 and 10). In addition, a calculated salinity map for the Eponides ellisorae horizon was prepared (Fig. 11). Cross sections have been constructed incorporating almost all of the deep wells of the prospect; three dip sections (A-A', B-B', and E-E') are included here (Figs. 12 to 14). One strike section (Fig. 15) is included because it includes the key well (84) for the original Southeast Pecan Island prospect study.

Regionally, the main fault block (bounded by faults A and C) represents a withdrawal basin for a salt structure developed offshore and south of the prospect. The withdrawal basin has apparently served as a locus of sedimentation, forming the main target reservoir of South Freshwater Bayou prospect - the Marginulina ascensionensis sands (Section E-E', Fig. 14). From section E-E', it is apparent that the MARG-ASC sandstones are well developed between faults A and D, with net sand thickness exceeding 500 ft. The sands are also well developed near South Pecan Island field (Section B-B', Fig. 13), south of Fault D.

Lack of deep well content near the Gulf outlet of Freshwater Bayou limits the ability to infer the lateral extent of the thick MARG-ASC sandstones. Conceivably, much of the two faults block, between Faults A and D and between

Faults D and C, may include significant sand accumulations. In light of the available control, Section 10 or 14, T17S, R2E, appears to be the best location for a possible test well.

A final report on Southeast Pecan Island - South Freshwater Bayou prospects is being prepared and should be completed by May 1982.

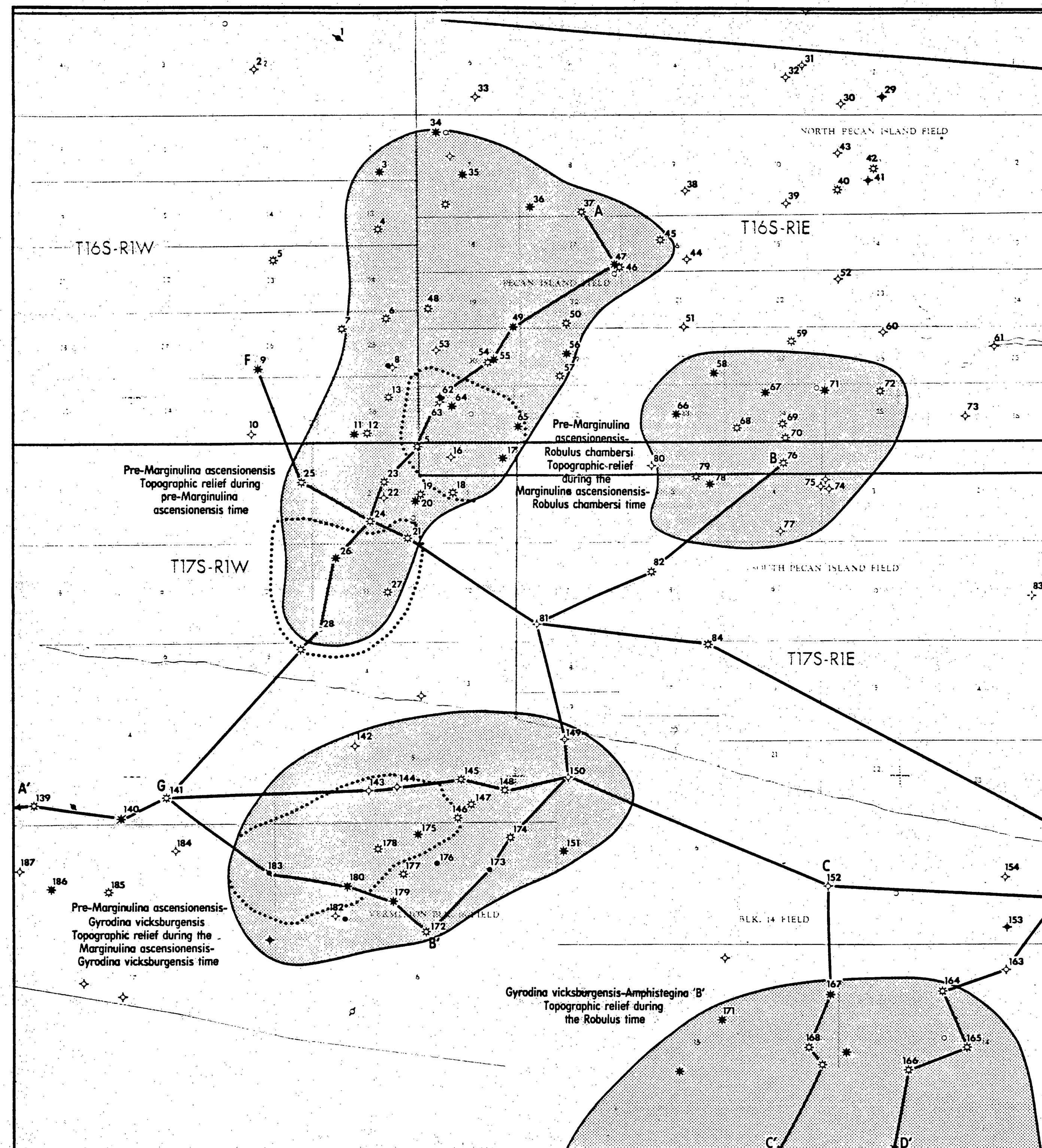


Figure 1.

LEGEND

- Dry Hole
- Oil
- Gas
- Gas Condensate
- NR-Not Reached
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available
- Field boundaries
- Areas and timing of local Tectonic features

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: LOCATION MAP OF WELLS AND CROSS SECTIONS

2,000 0 2,000

Feet

Geology by Thomas Cavanagh Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

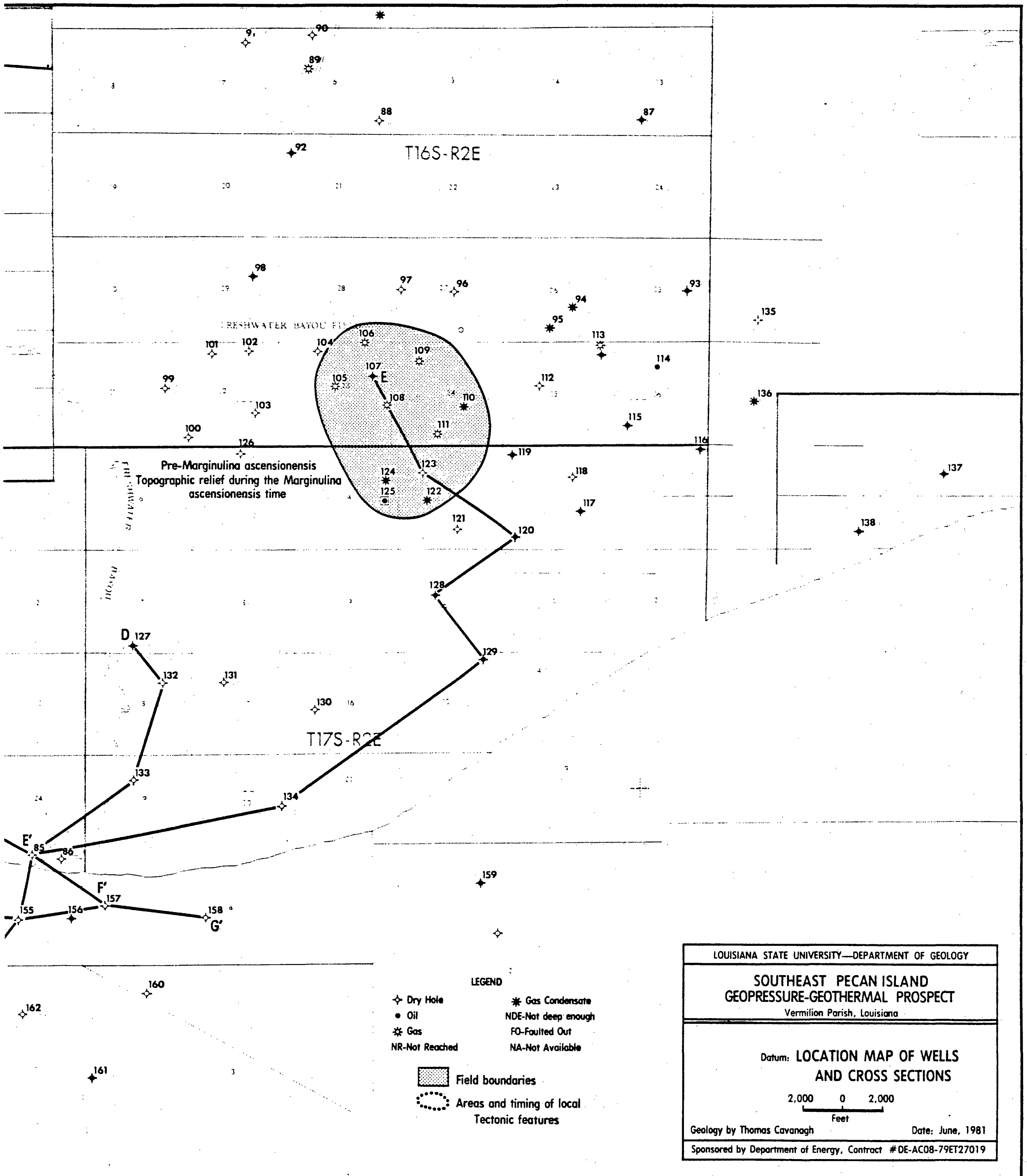


Figure 1, contd.

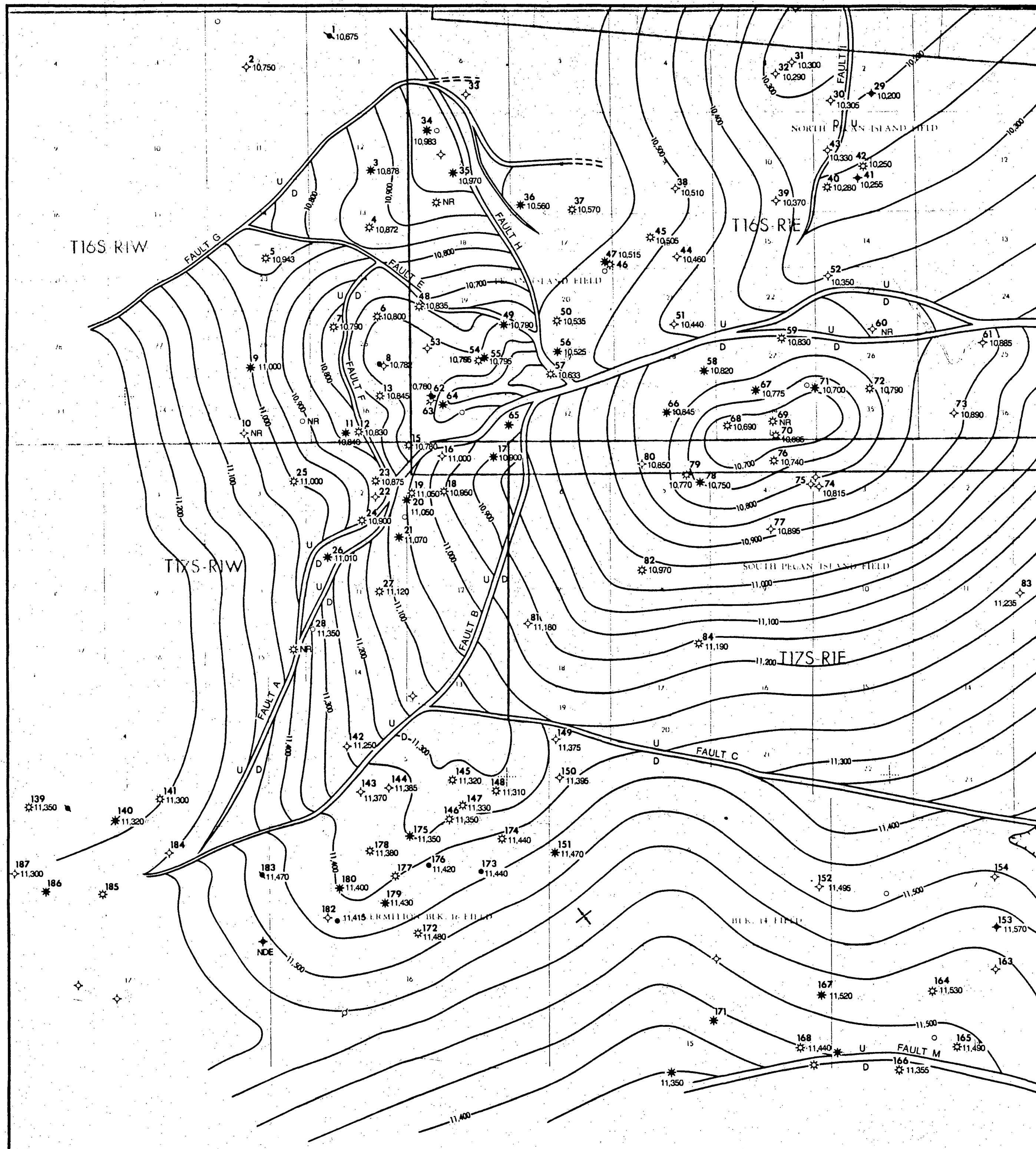


Figure 2.

LEGEND

- Dry Hole
- Oil
- Gas
- NR-Not Reached
- Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Robulus 'L' Sandstone (Robulus '43' L)

CI: 50'

2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

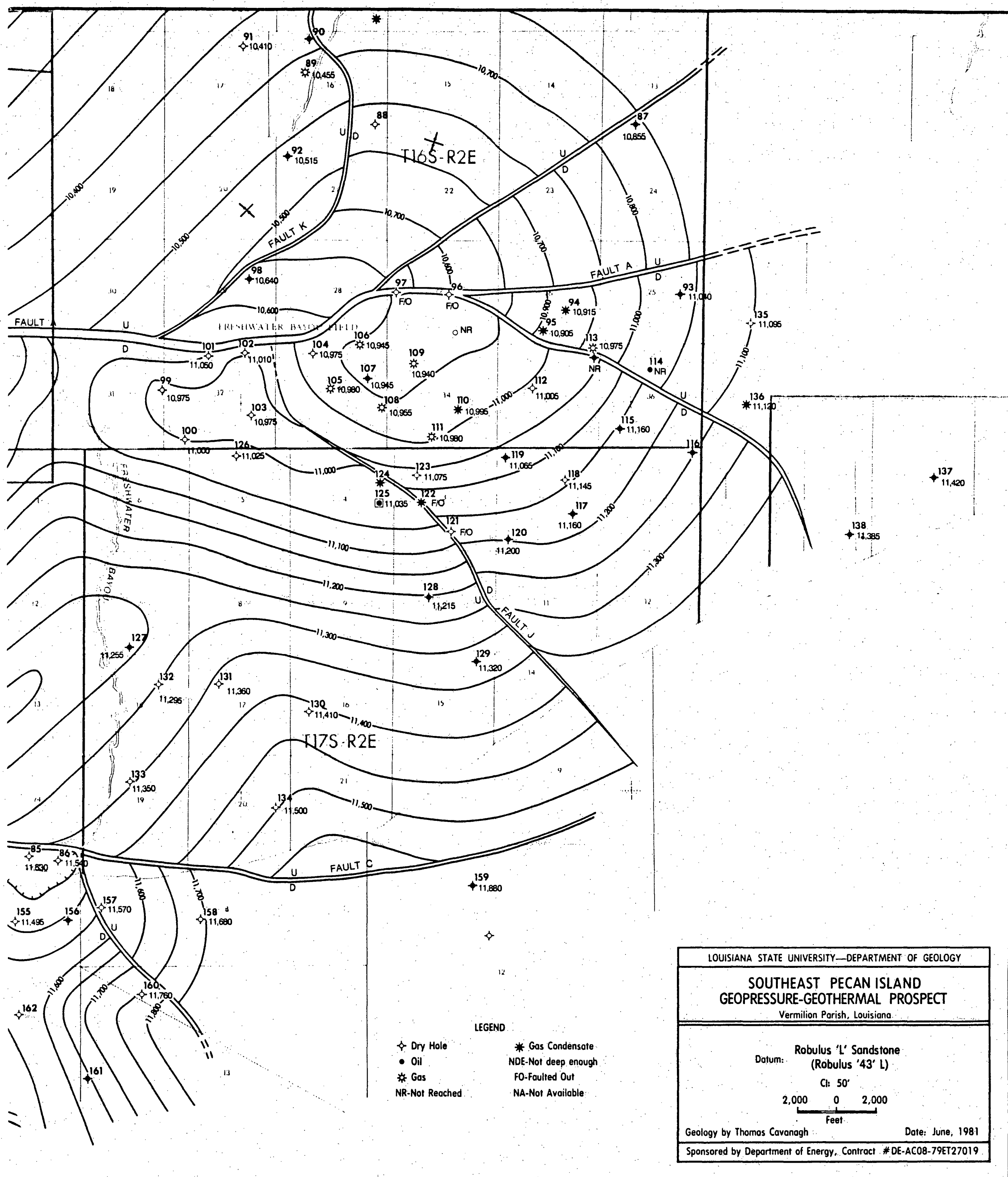


Figure 2, contd.

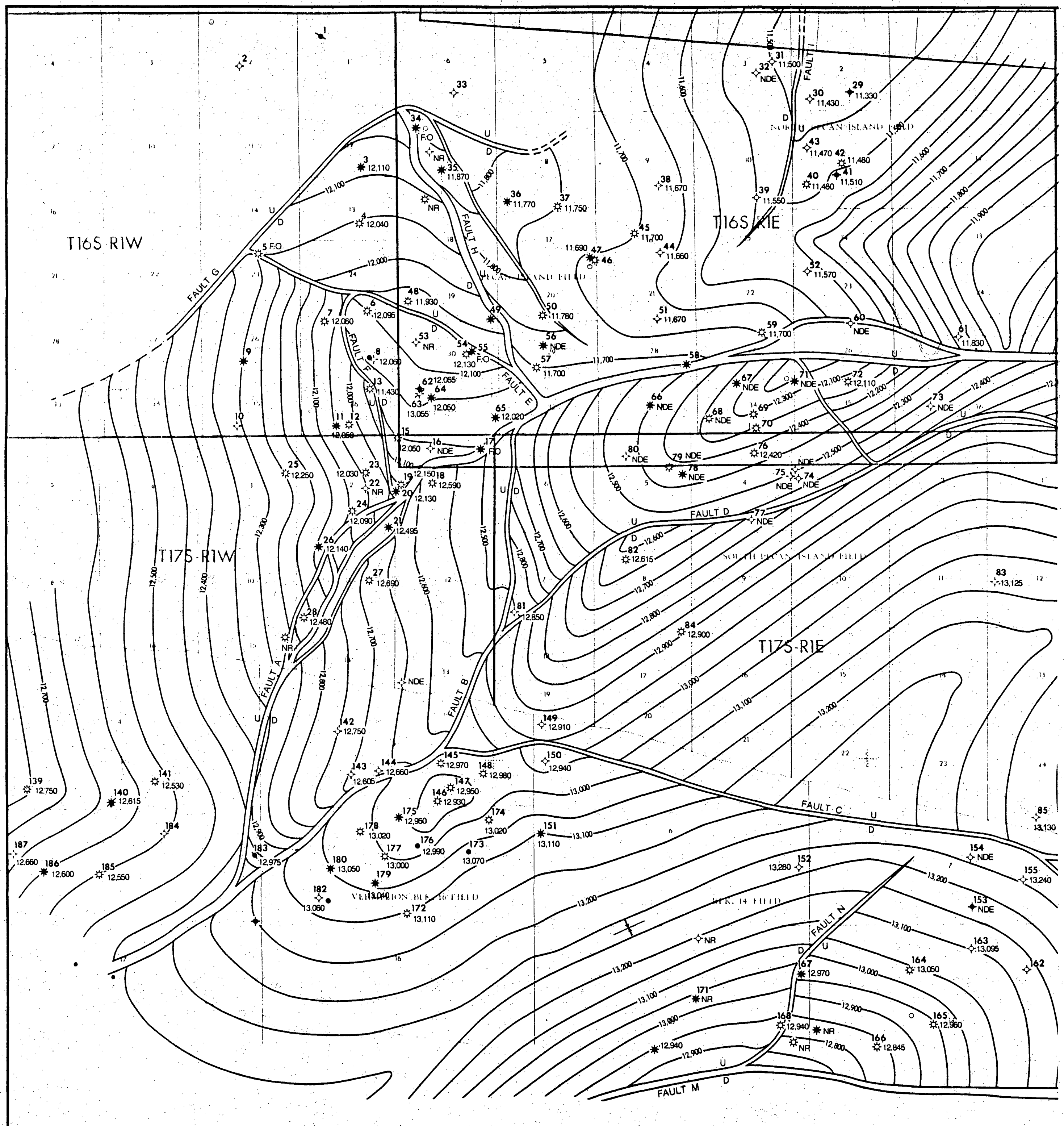


Figure 3.

LEGEND

- Dry Hole
- Oil
- Gas
- NR-Not Reached
- Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

Datum: Robulus 54A Sandstone

CI: 50'

2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract # DE-AC08-79ET27019

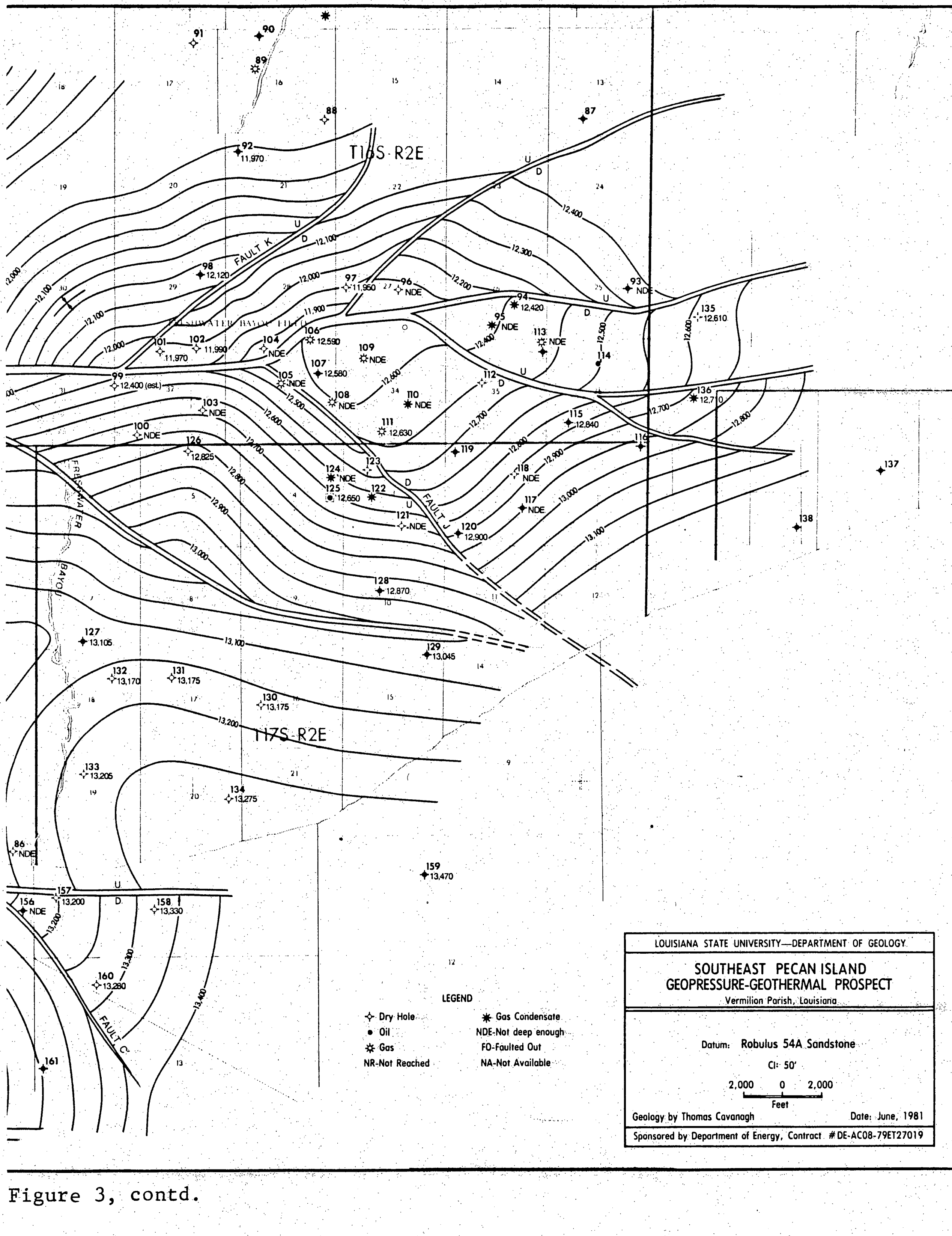


Figure 3, contd.

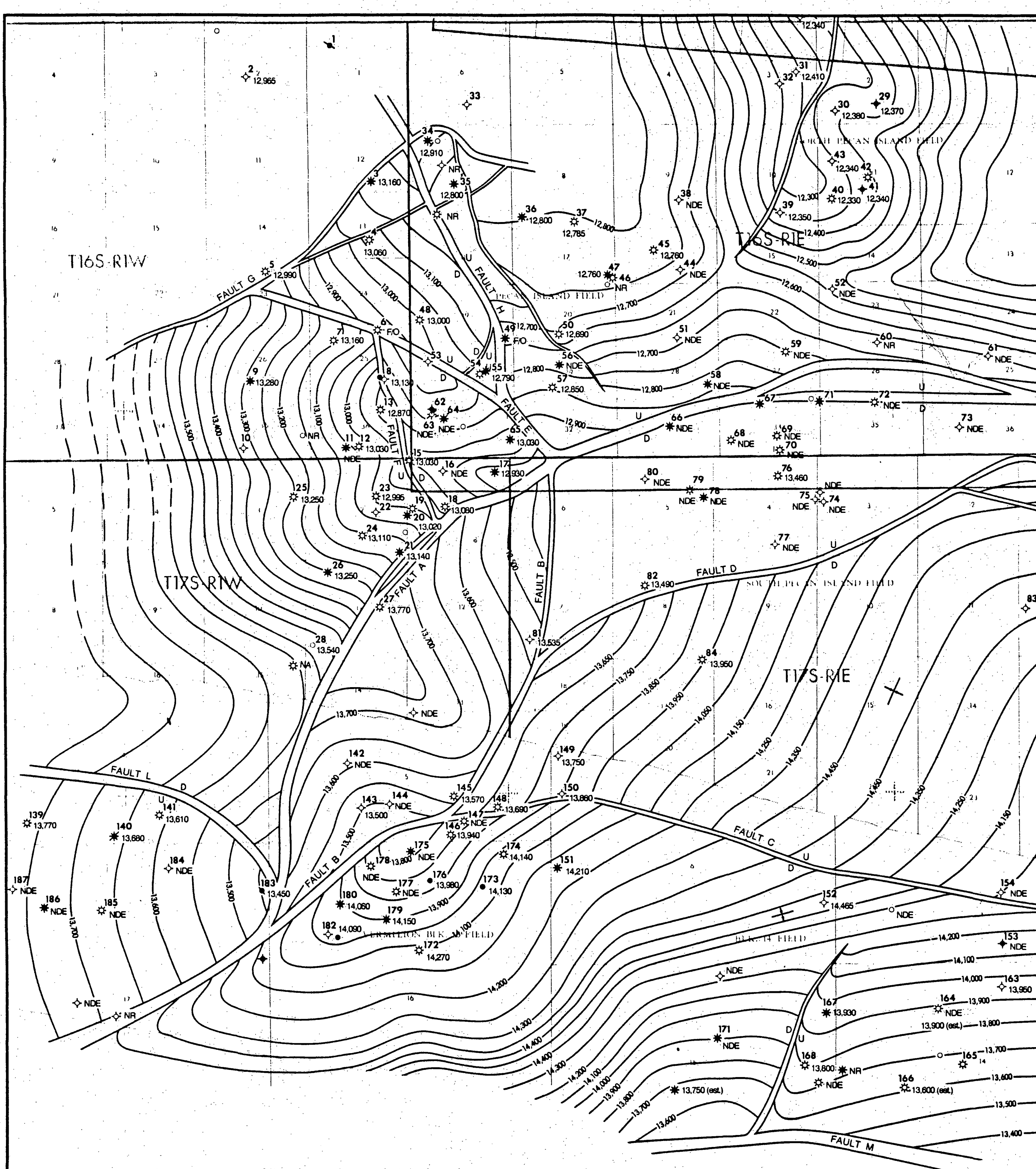


Figure 4.

LEGEND

✧ Dry Hole	✱ Gas Condensate
• Oil	NDE-Not deep enough
☼ Gas	FO-Faulted Out
NR-Not Reached	NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Operculinoides 9 Sandstone (Gyrodina Vicksburgensis)

CI: 50′ and 100′

2,000 0 2,000

Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

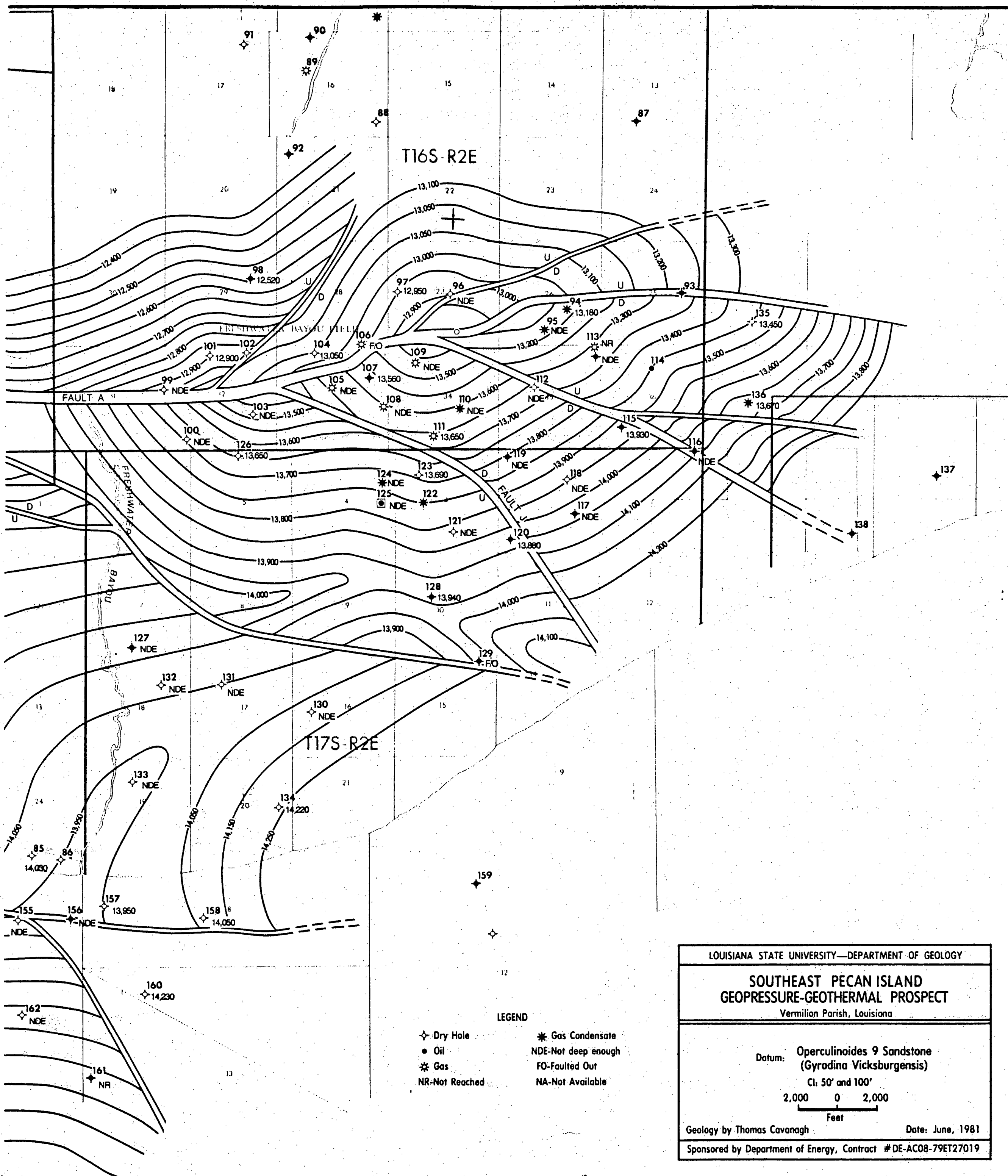


Figure 4, contd.

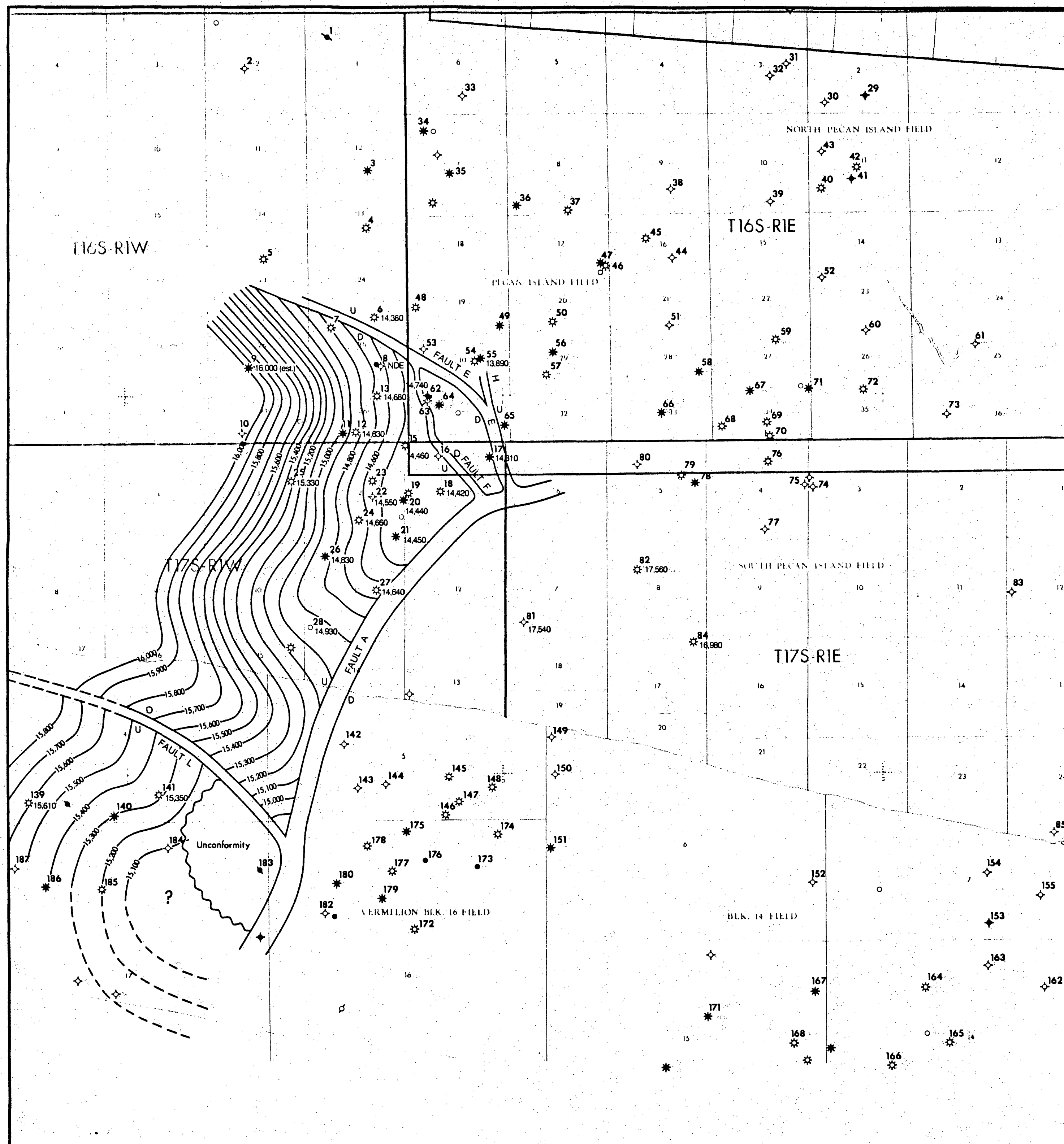


Figure 5.

LEGEND

Dry Hole	Gas Condensate
Oil	NDE-Not deep enough
Gas	FO-Faulted Out
NR-Not Reached	NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Marginulina Ascensionensis 36 A4 Sandstone

CI: 100'

2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

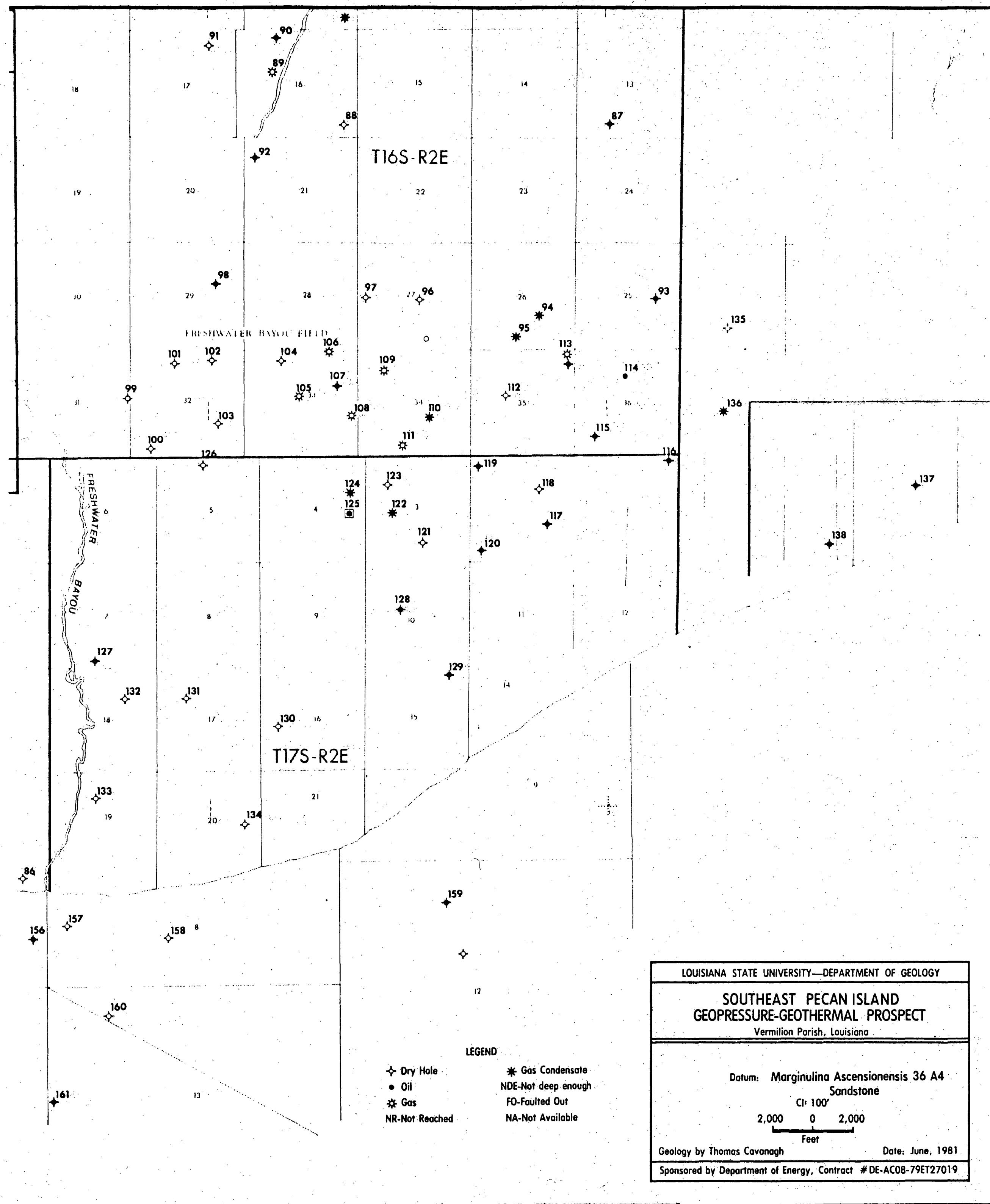


Figure 5, contd.

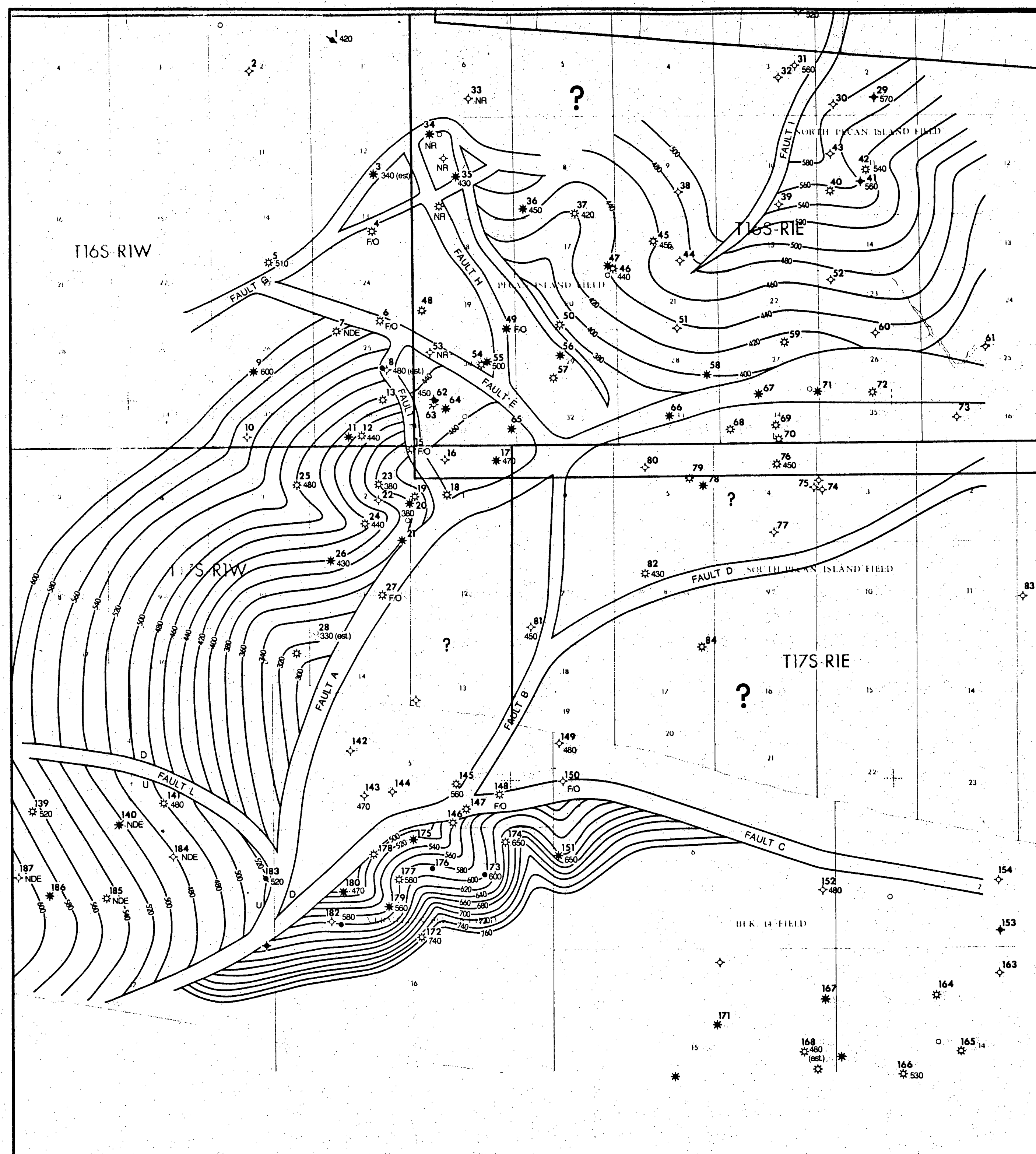


Figure 6.

LEGEND

- ✧ Dry Hole
- • Oil
- ☼ Gas
- NR-Not Reached
- ✱ Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Operculinoides 9—Resistivity Isopach

CI: 20'

2,000 0 2,000

Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

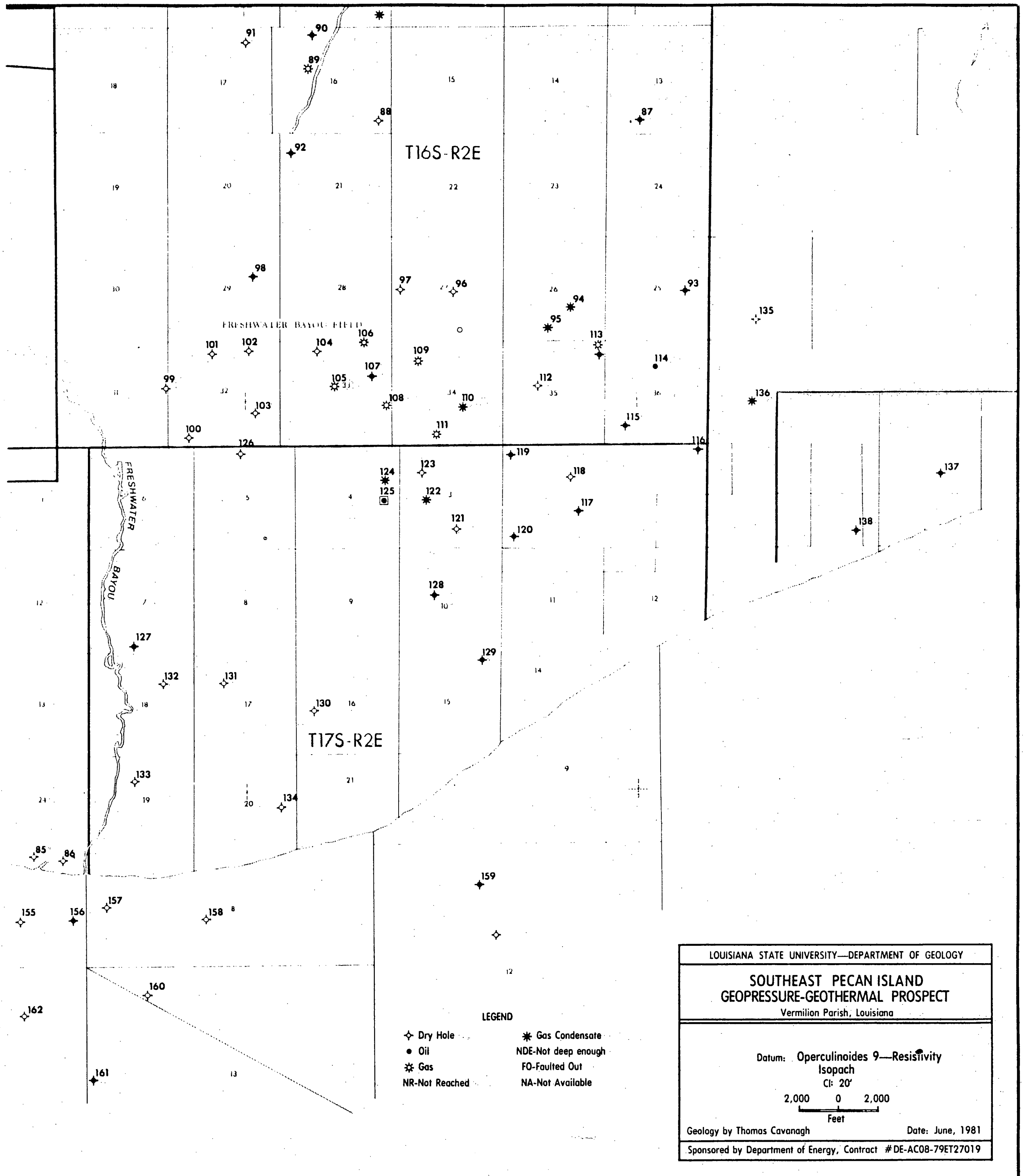


Figure 6, contd.

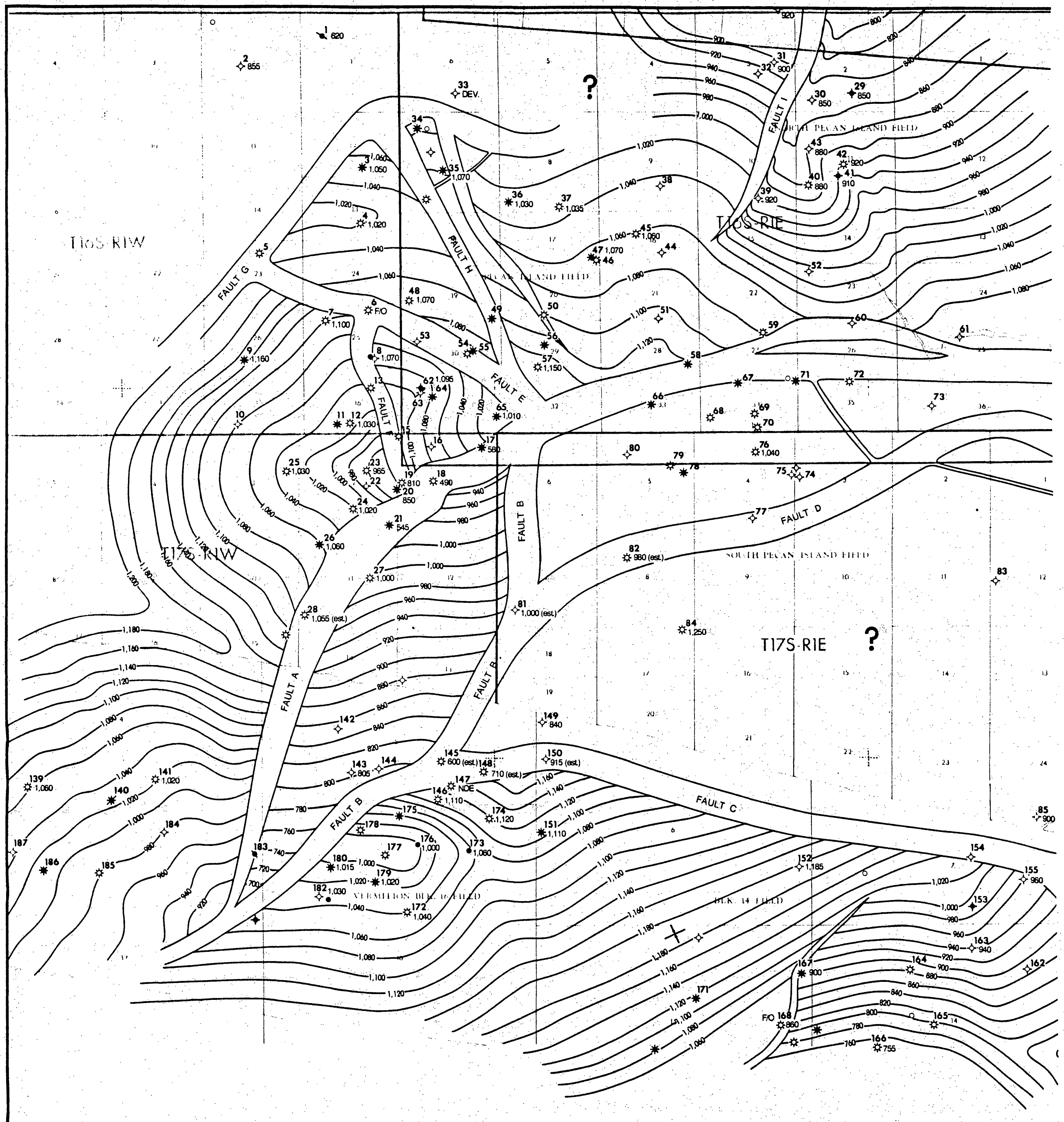


Figure 7.

LEGEND

- Dry Hole
- Oil
- Gas
- NR-Not Reached
- Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

Datum: Robulus 54A—Operculinoides 9
Isopach
CI: 20'

2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

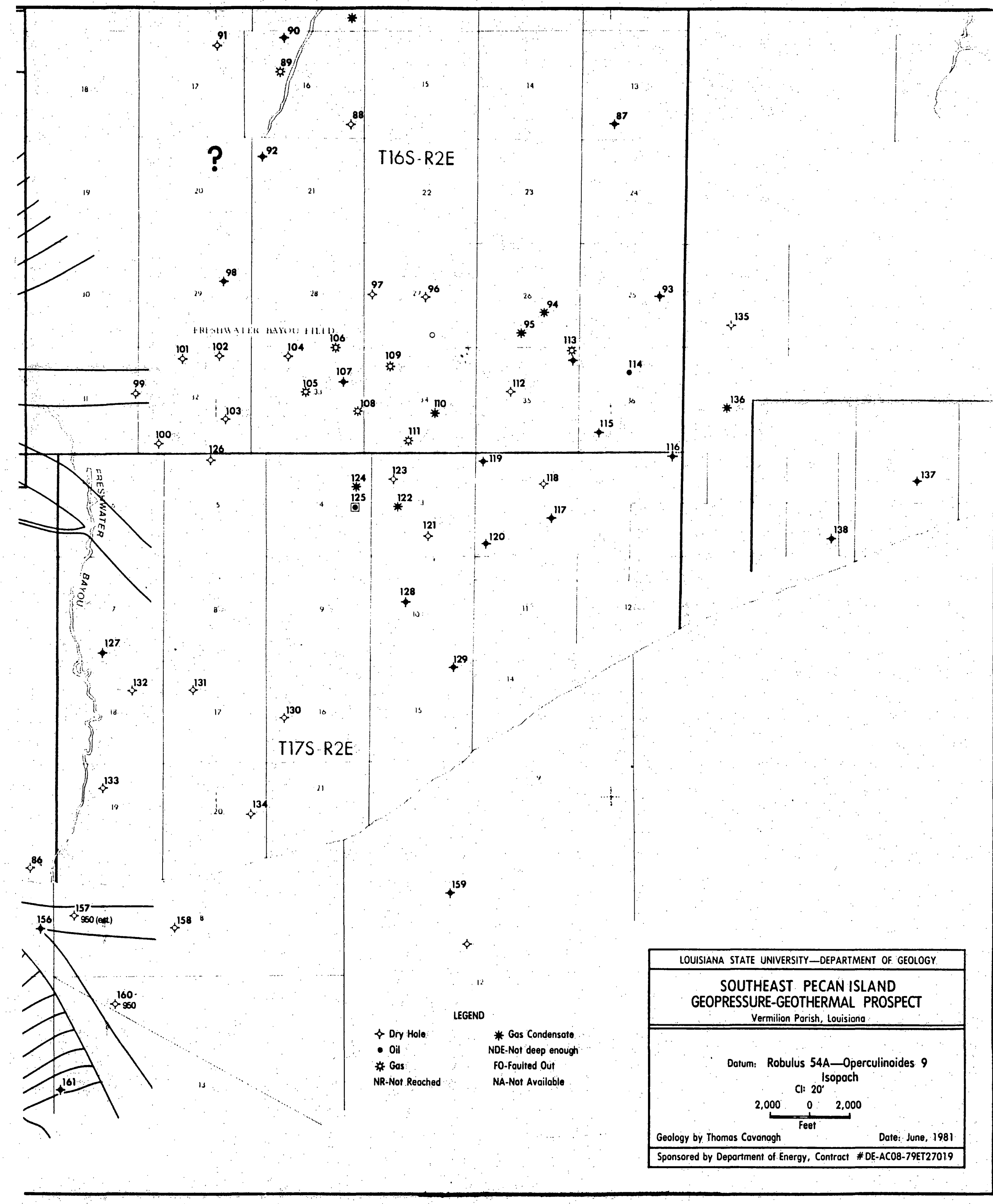


Figure 7, contd.

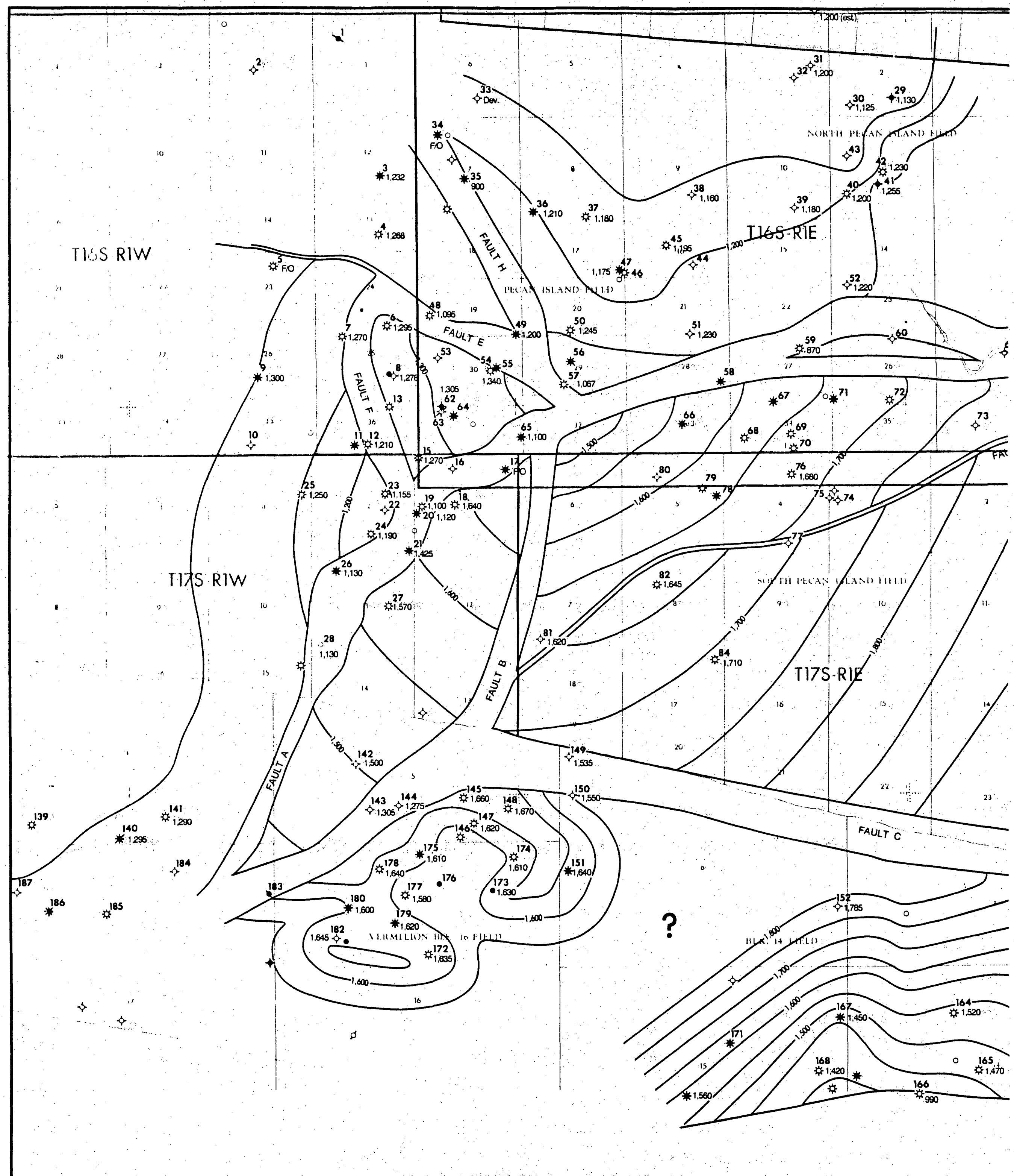


Figure 8.

LEGEND

- Dry Hole
- Oil
- Gas
- NR-Not Reached
- Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Robulus 'L'—Robulus 54A
Isopach
CI: 50'

2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

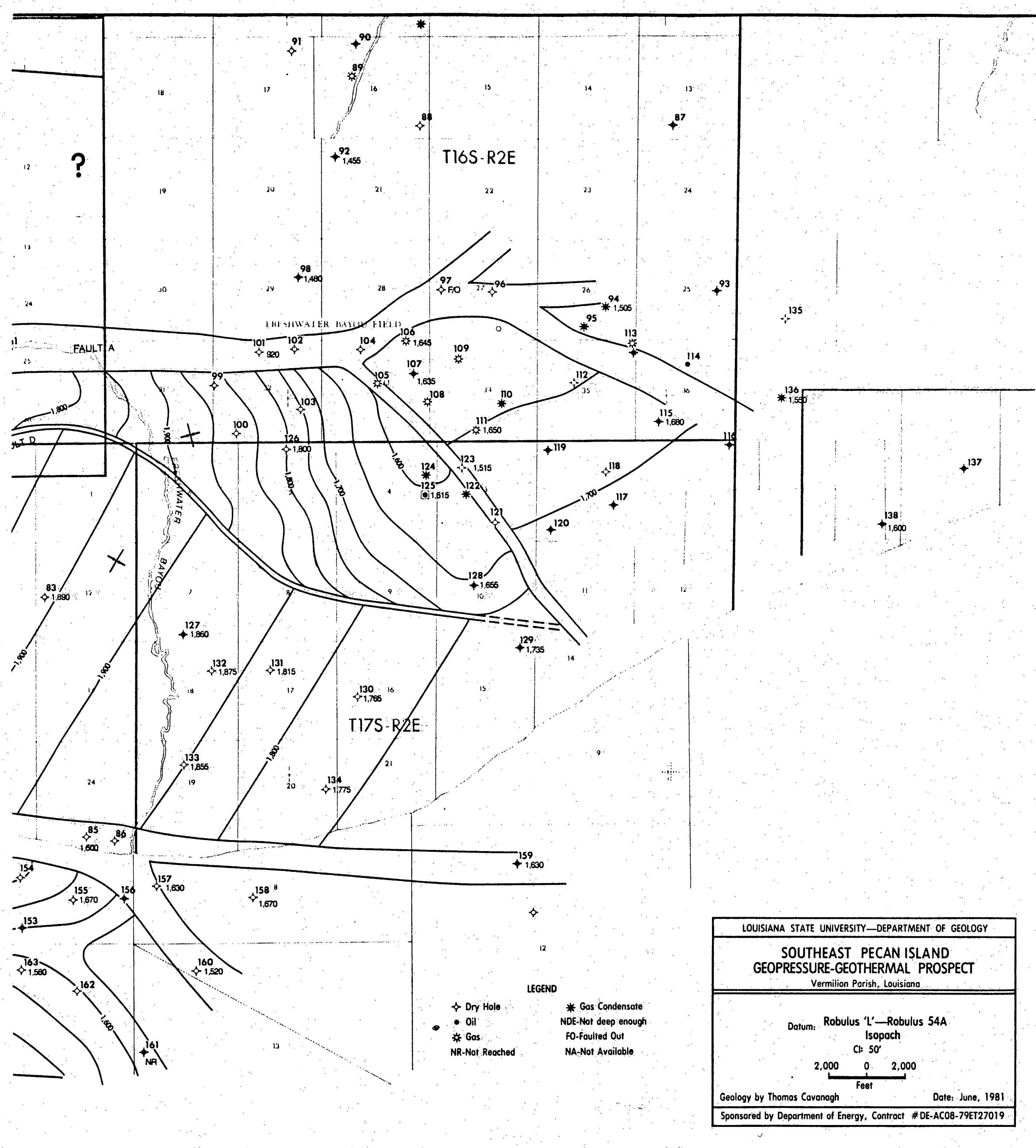


Figure 8, contd.

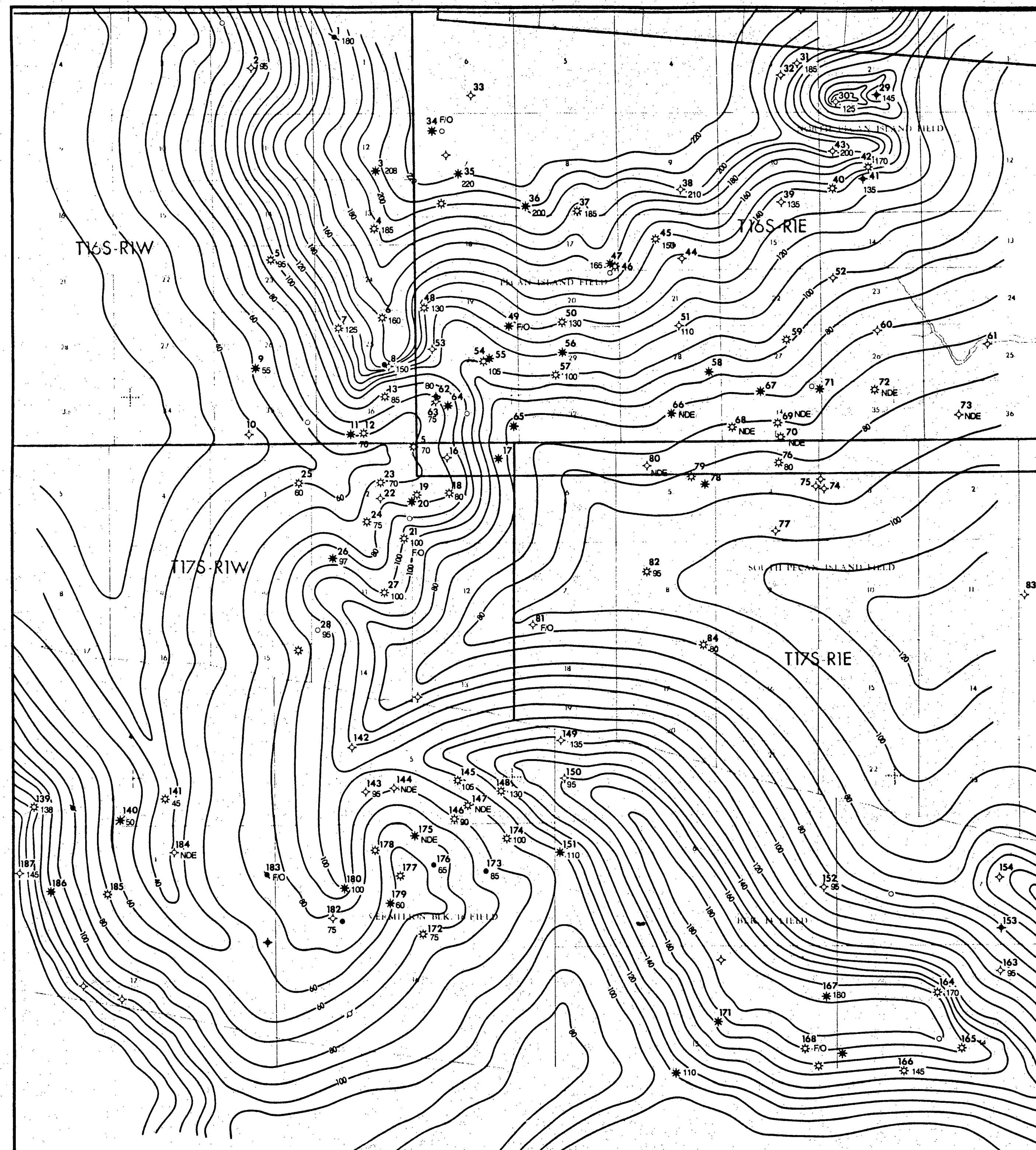


Figure 9.

LEGEND

- ✧ Dry Hole
- • Oil
- ☼ Gas
- NR-Not Reached
- ✱ Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

Datum: Operculinoides 9—Resistivity
Net Sandstone
CI: 10'
2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

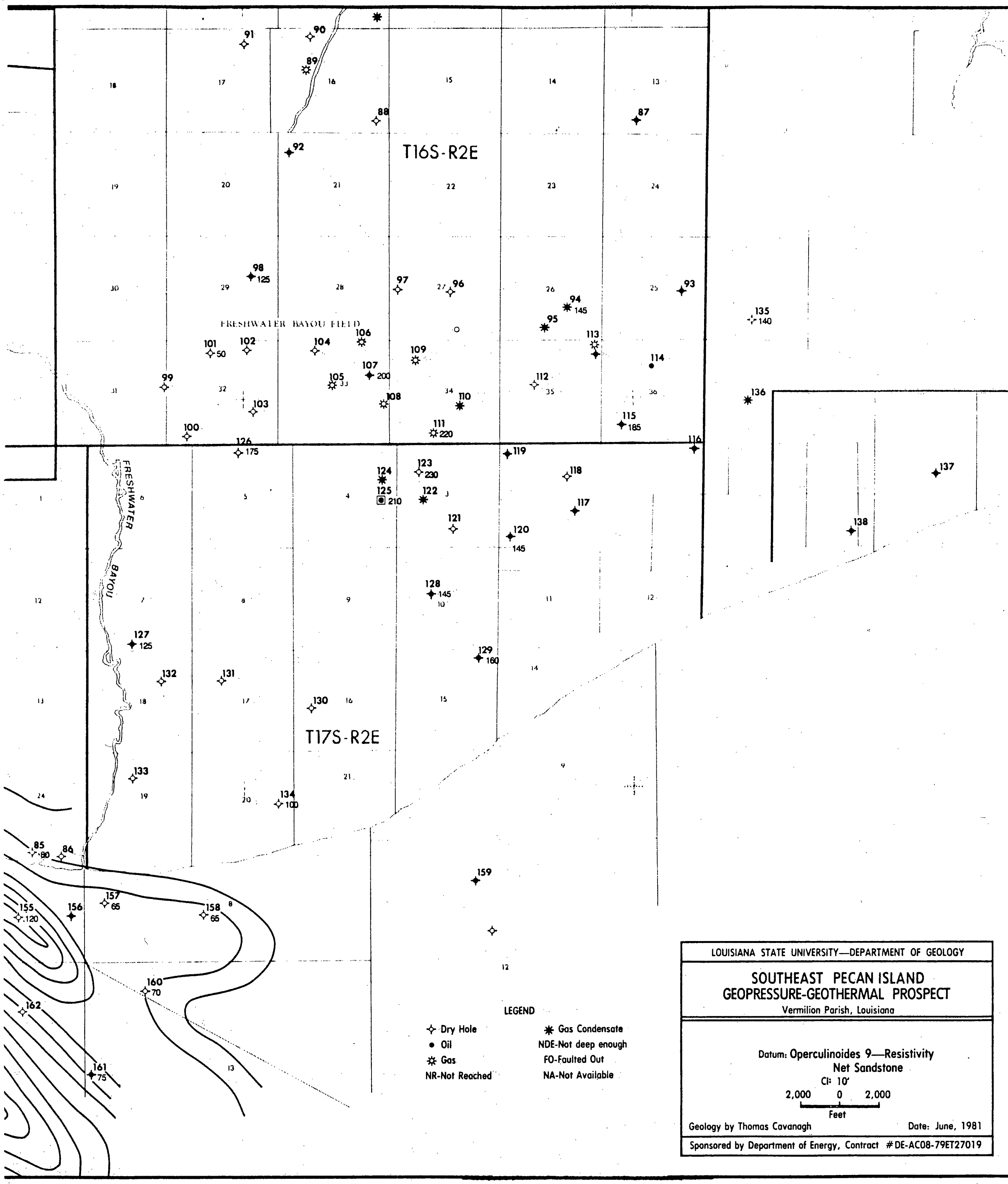


Figure 9, contd.

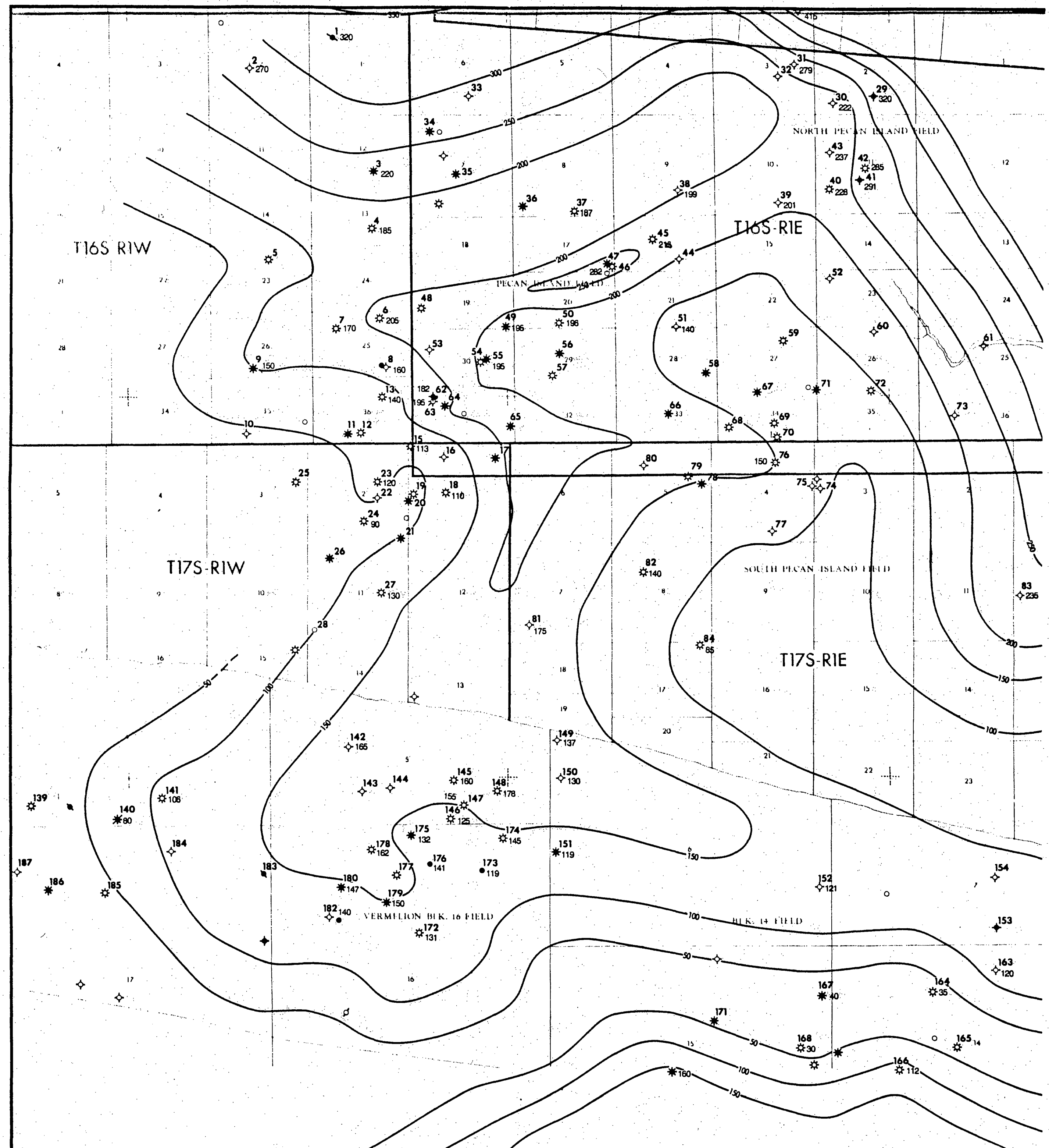


Figure 10.

LEGEND

- ✧ Dry Hole
- ● Oil
- ☼ Gas
- NR-Not Reached
- ✱ Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Robulus 'L'—Robulus 54A
Net Sandstone
CI: 50'

2,000 0 2,000
Feet

Geology by Thomas Cavanagh Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

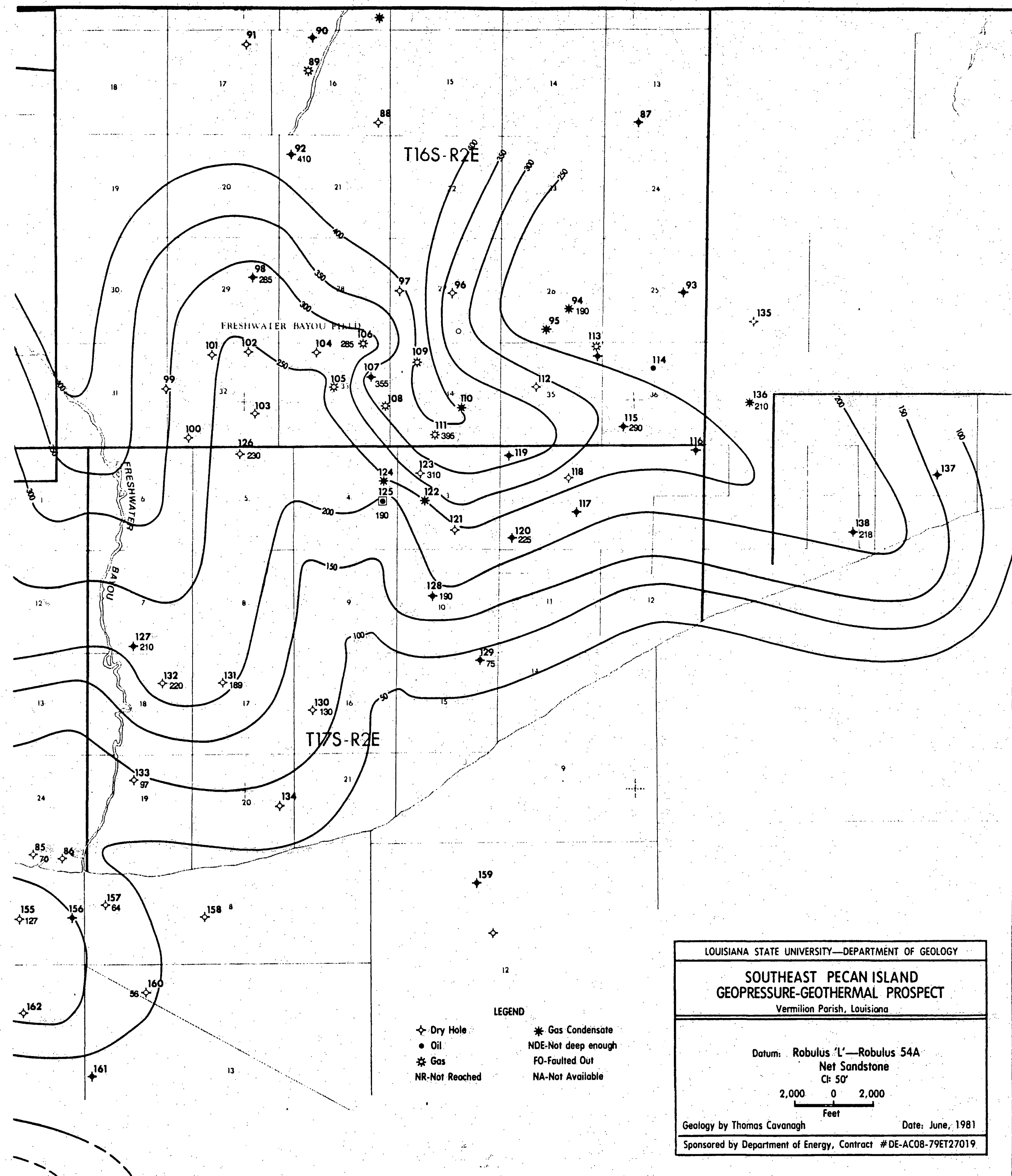


Figure 10, contd.

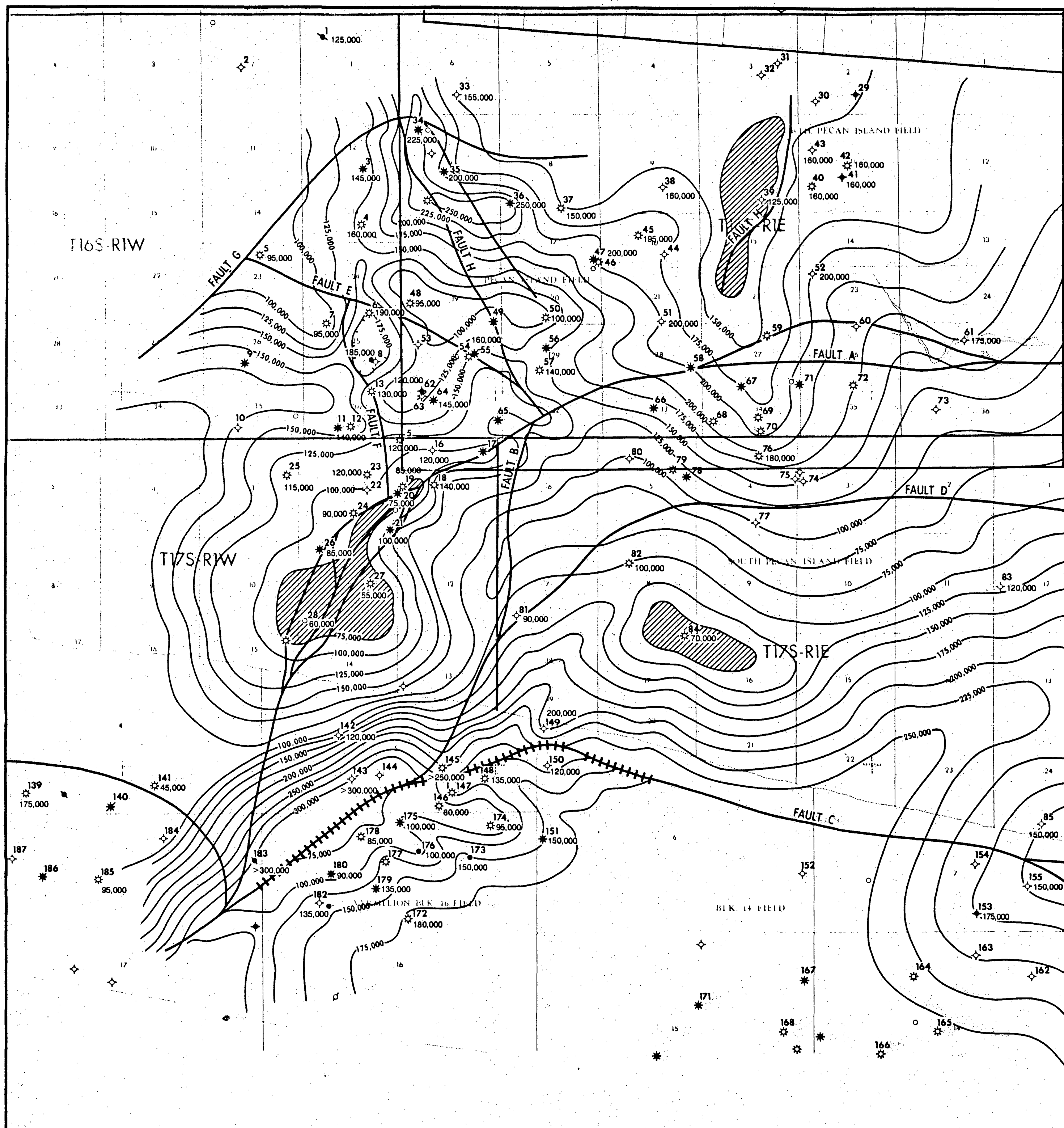


Figure 11.

LEGEND

- Dry Hole
- Oil
- Gas
- NR-Not Reached
- Gas Condensate
- NDE-Not deep enough
- FO-Faulted Out
- NA-Not Available
- Low Salinity Areas
- Trace of Faults
- Zone of Sealing Faults

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

Datum: Eponides ellisorae Sand Salinity

*CI: 25,000 ppm

2,000 0 2,000
Feet

Geology by Thomas Cavanagh

Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

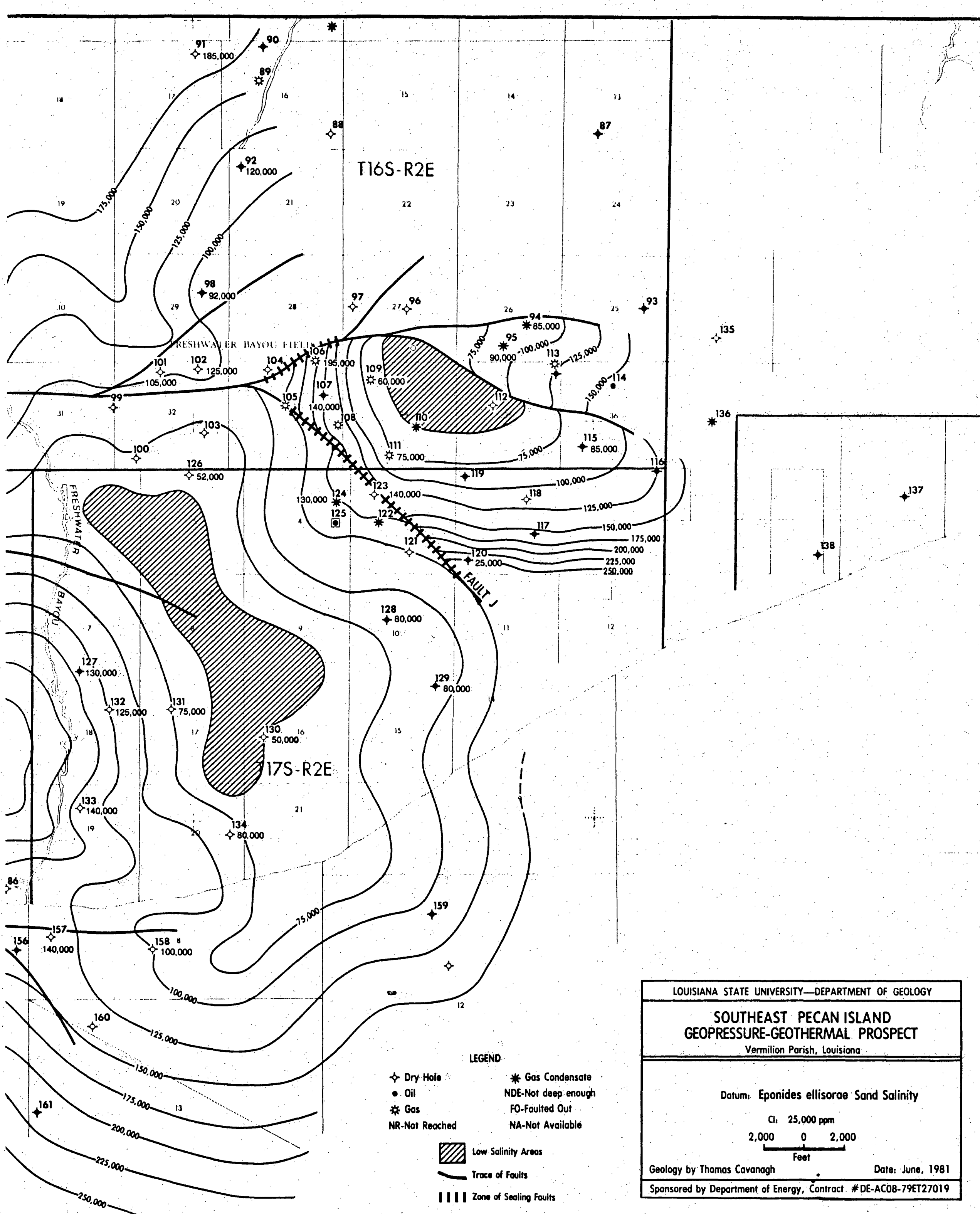
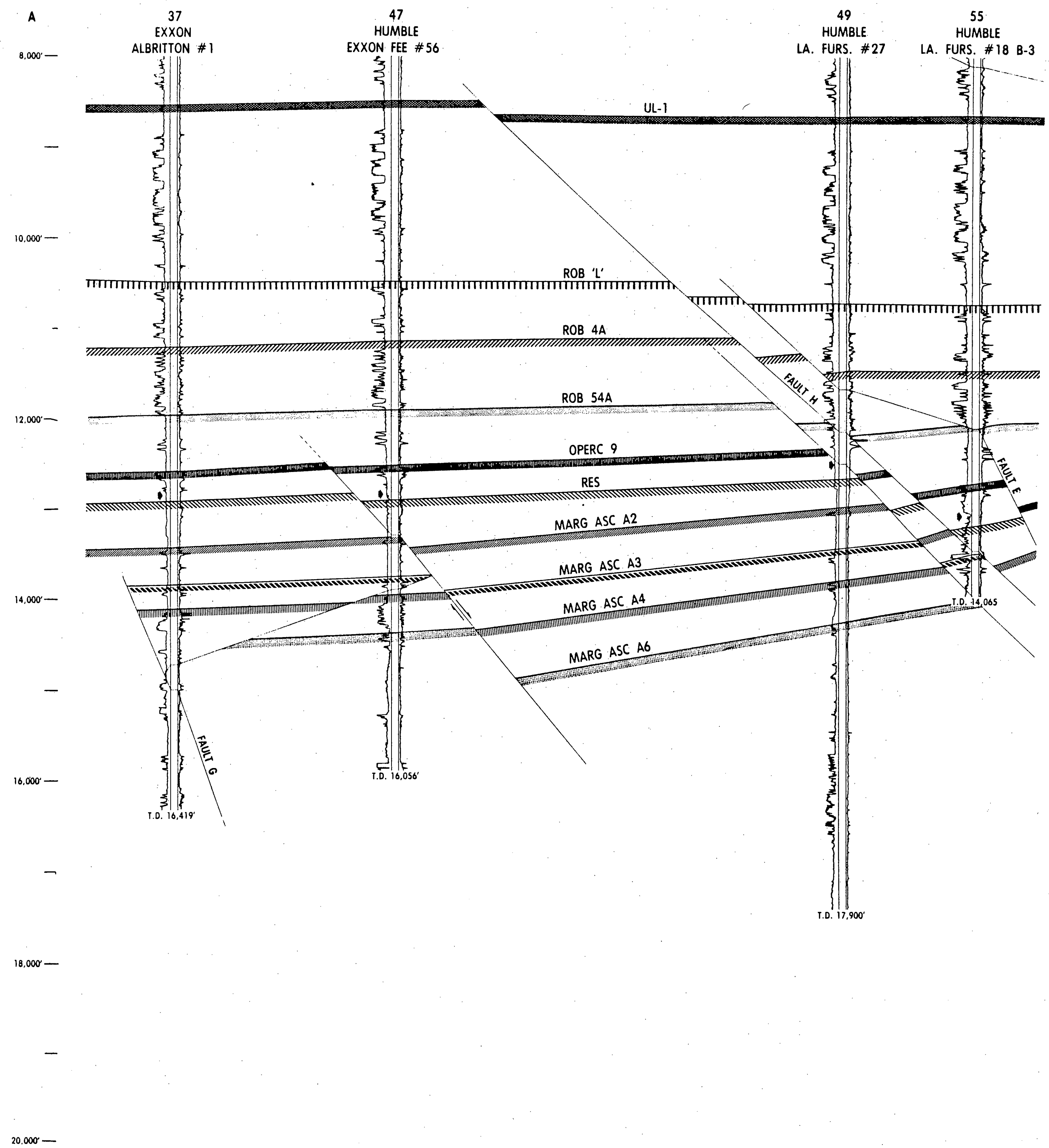


Figure 11, contd.



Legend

UL-1	Bigenerina humblei
	Robulus "43"
ROB 4A	Robulus 4A
ROB 54A	Robulus 54A
OPERC 9	Operculinoides 9
RES	Resistivity marker 2
MARG ASC A2	Marginulina ascensionensis 36 A2
MARG ASC A3	Marginulina ascensionensis 36 A3
MARG ASC A4	Marginulina ascensionensis 36 A4
MARG ASC A6	Marginulina ascensionensis 36 A6
♦	Top 'hard' abnormal pressure (≅ .7 psi/ft)
~~	Unconformity

Figure 12.

1:1.5 Vertical Exaggeration

1000 2000

Feet

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

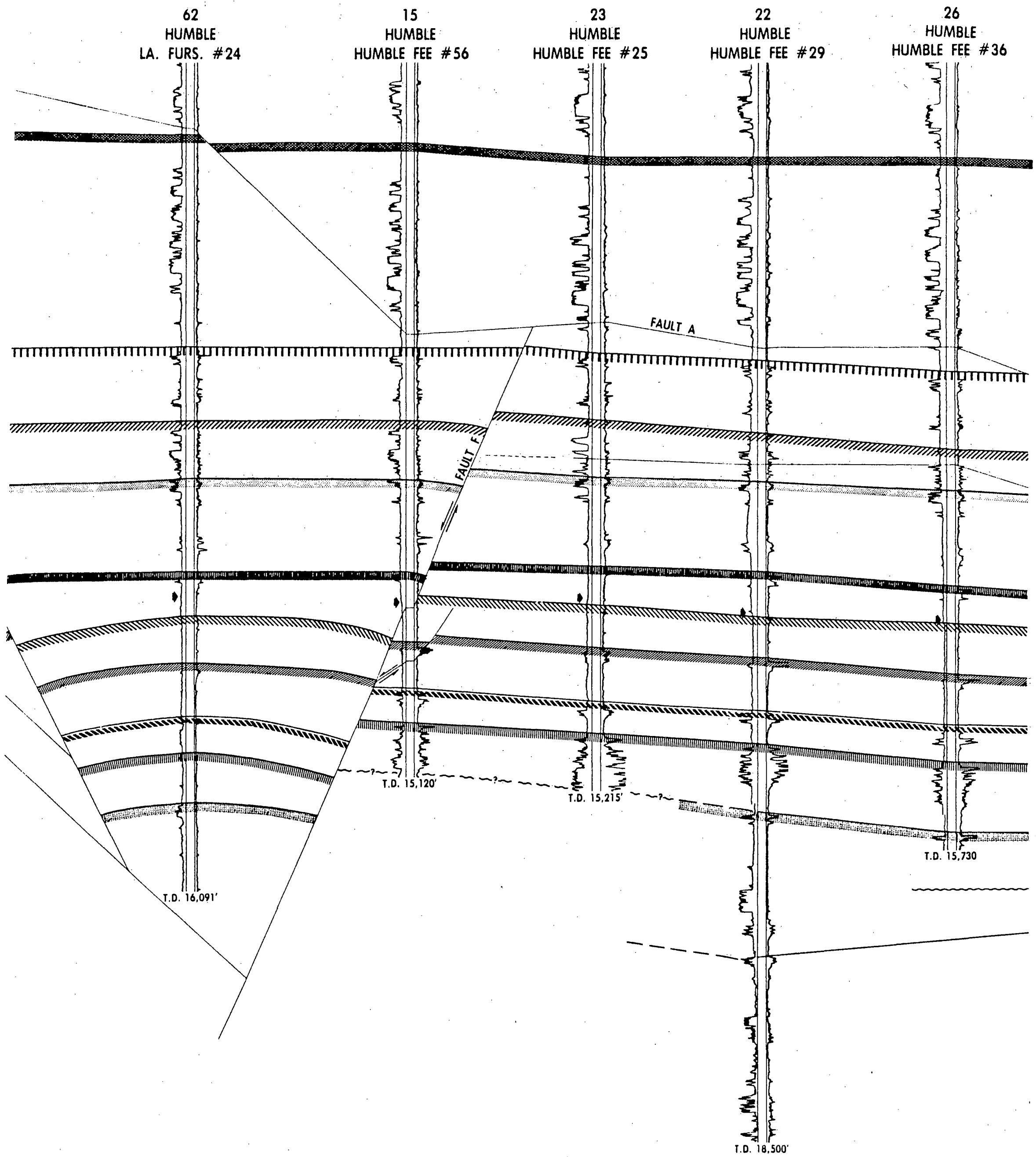
SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT

Vermilion Parish, Louisiana

A-A'
PECAN ISLAND DIP

Geology by Thomas Cavanagh   Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019



1:1.5 Vertical Exaggeration

1000 2000

Feet

Legend

UL-1	Bigenerina humblei
	Robulus "43"
ROB 4A	Robulus 4A
ROB 54A	Robulus 54A
OPERC 9	Operculinoides 9
RES	Resistivity marker 2
MARG ASC A2	Marginulina ascensionensis 36 A2
MARG ASC A3	Marginulina ascensionensis 36 A3
MARG ASC A4	Marginulina ascensionensis 36 A4
MARG ASC A6	Marginulina ascensionensis 36 A6
➧	Top 'hard' abnormal pressure (≅ .7 psi/ft)
~~	Unconformity

Figure 12, contd.

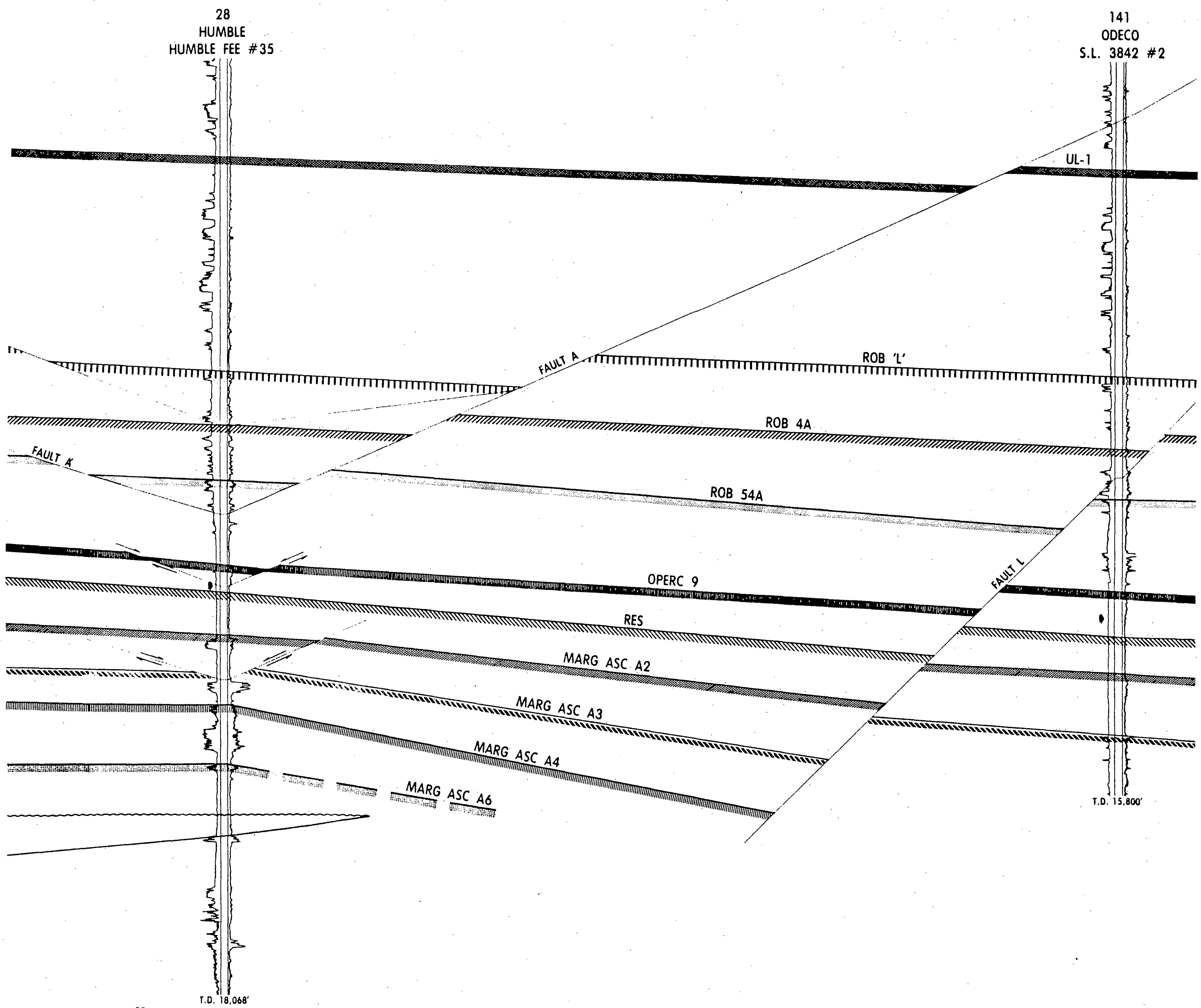
LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

A-A'
PECAN ISLAND DIP

Geology by Thomas Cavanagh Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019



Legend

UL-1	Bigenerina humblei
	Robulus "43"
ROB 4A	Robulus 4A
ROB 54A	Robulus 54A
OPERC 9	Operculinoides 9
RES	Resistivity marker 2
MARG ASC A2	Marginulina ascensionensis 36 A2
MARG ASC A3	Marginulina ascensionensis 36 A3
MARG ASC A4	Marginulina ascensionensis 36 A4
MARG ASC A6	Marginulina ascensionensis 36 A6
♦	Top 'hard' abnormal pressure ($\cong$ .7 psi/ft)
~~	Unconformity

1:1.5 Vertical Exaggeration

1000 2000

Feet

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

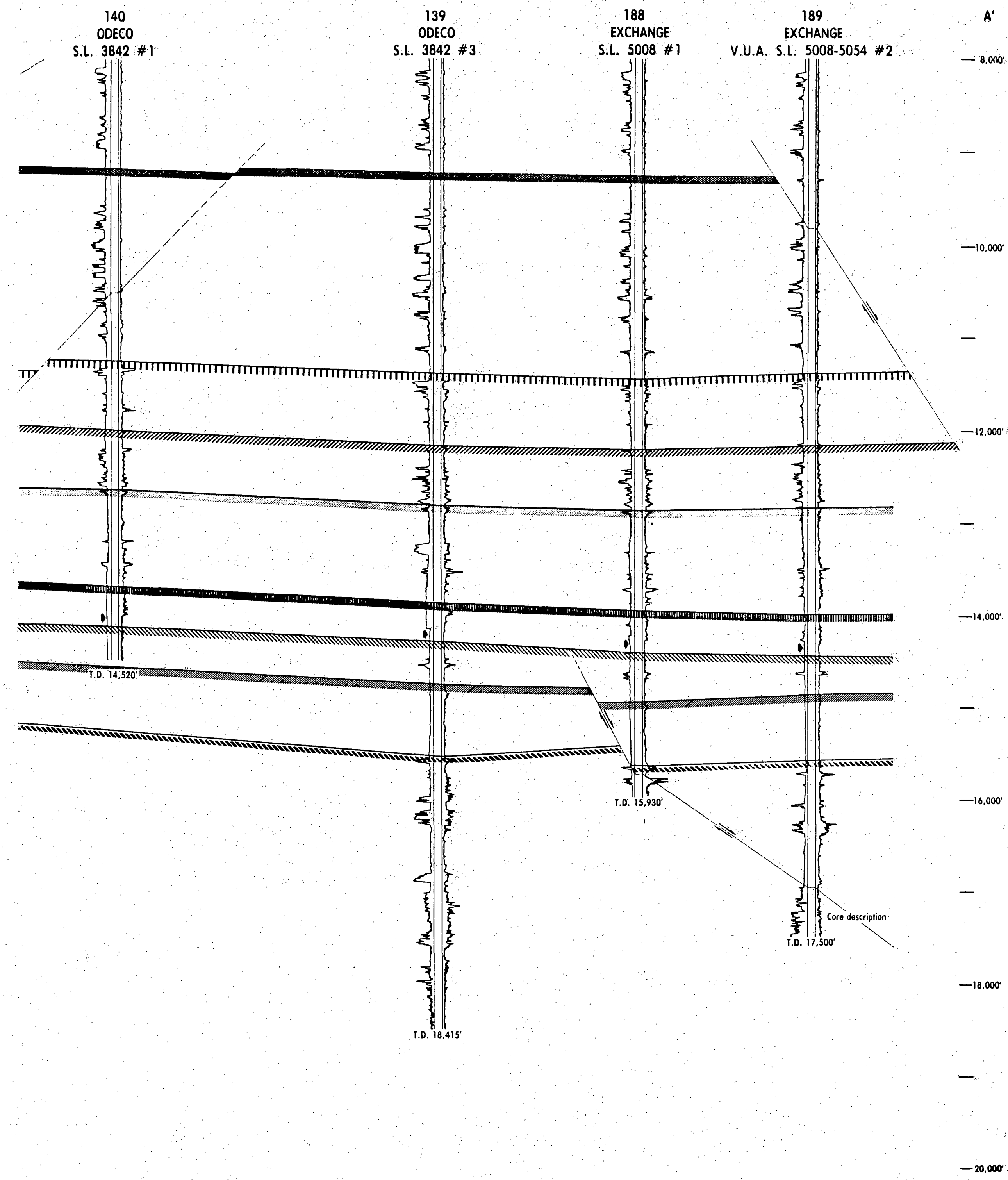
SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

A-A'
PECAN ISLAND DIP

Geology by Thomas Cavanagh Date June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

Figure 12, contd.



Legend

UL-1	Bigenerina humblei
	Robulus "43"
ROB 4A	Robulus 4A
ROB 54A	Robulus 54A
OPERC 9	Operculinoides 9
RES	Resistivity marker 2
MARG ASC A2	Marginulina ascensionensis 36 A2
MARG ASC A3	Marginulina ascensionensis 36 A3
MARG ASC A4	Marginulina ascensionensis 36 A4
MARG ASC A6	Marginulina ascensionensis 36 A6
⧫	Top 'hard' abnormal pressure (≅.7 psi/ft)
~~	Unconformity

1:1.5 Vertical Exaggeration

1000 2000

Feet

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

A-A'
PECAN ISLAND DIP

Geology by Thomas Cavanagh Date: June, 1981

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Figure 12, contd.

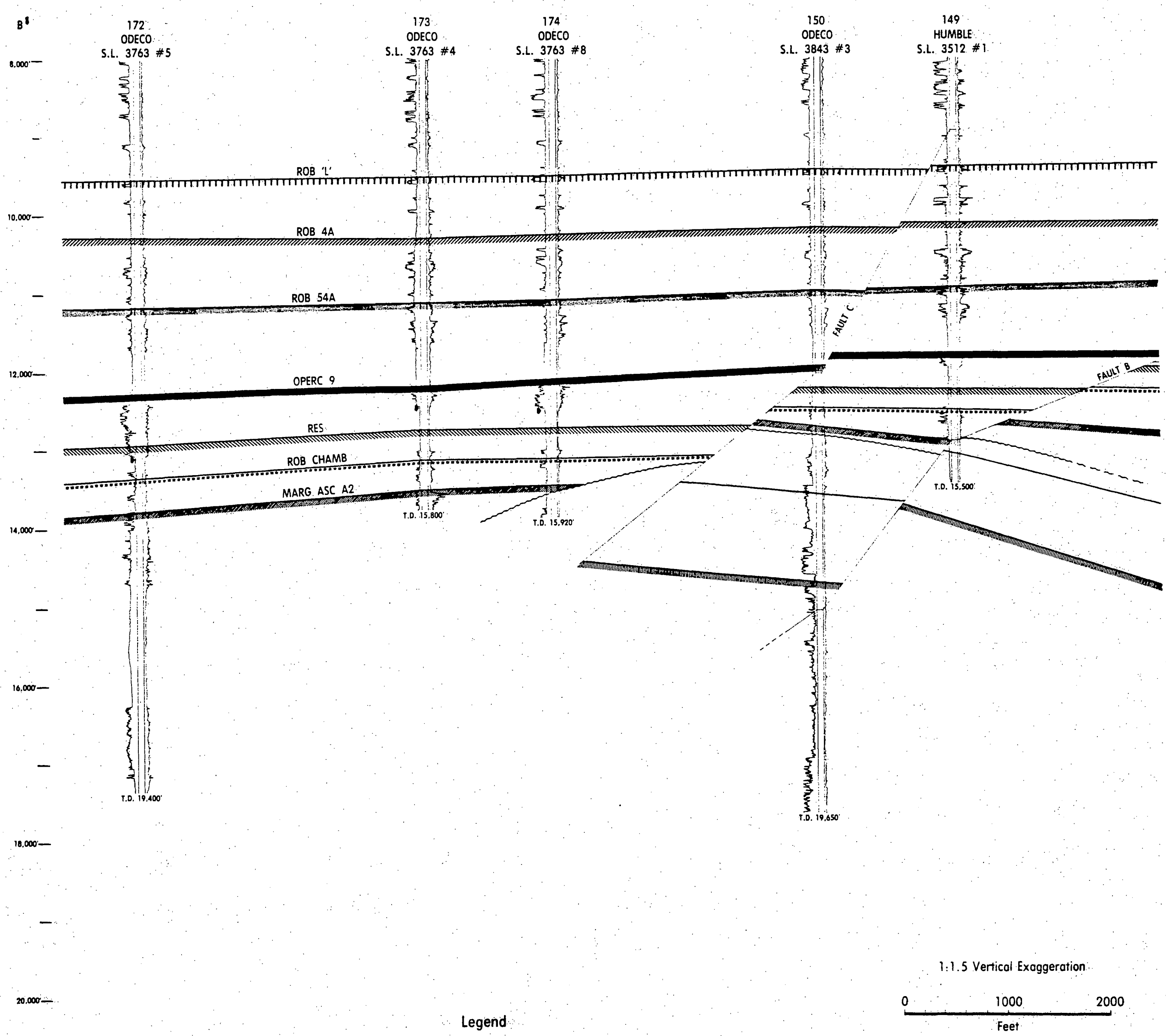


Figure 13.

Legend

ROB 'L'	Robulus "43"
ROB 4A	Robulus 4A
ROB 54A	Robulus 54A
OPERC 9	Operculinoides 9
RES	Resistivity marker 2
ROB CHAMB	Robulus chambersi
MARG ASC A2	Marginulina ascensionensis 36 A2
MARG ASC	Marginulina ascensionensis
MARG ASC A4	Marginulina ascensionensis 36 A4
⧫	Top 'hard' abnormal pressure (≅ .7 psi/ft)
~~	Unconformity

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

B-B'
SOUTH PECAN ISLAND DIP

Geology by Thomas Cavanagh — Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

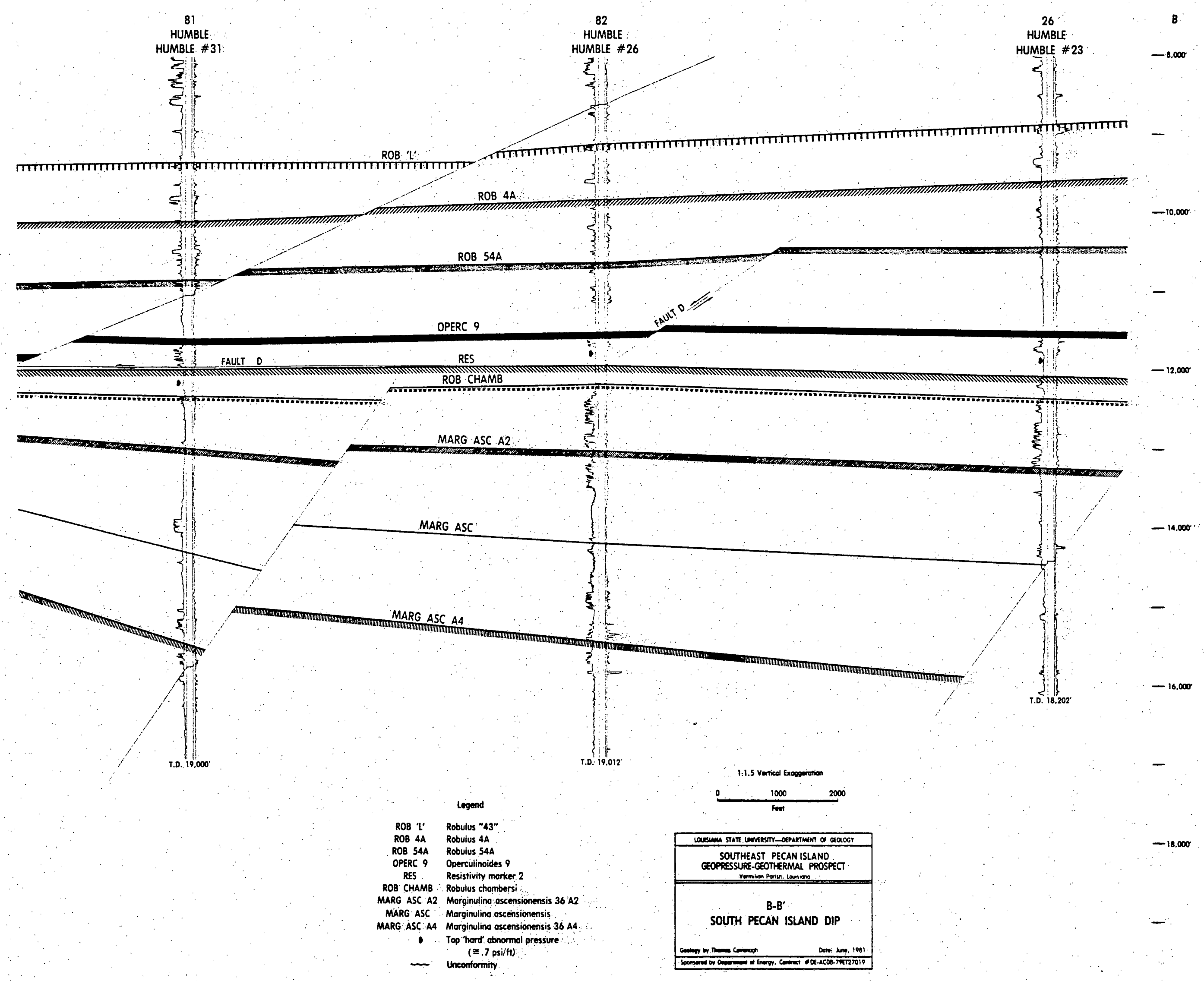


Figure 13, contd.

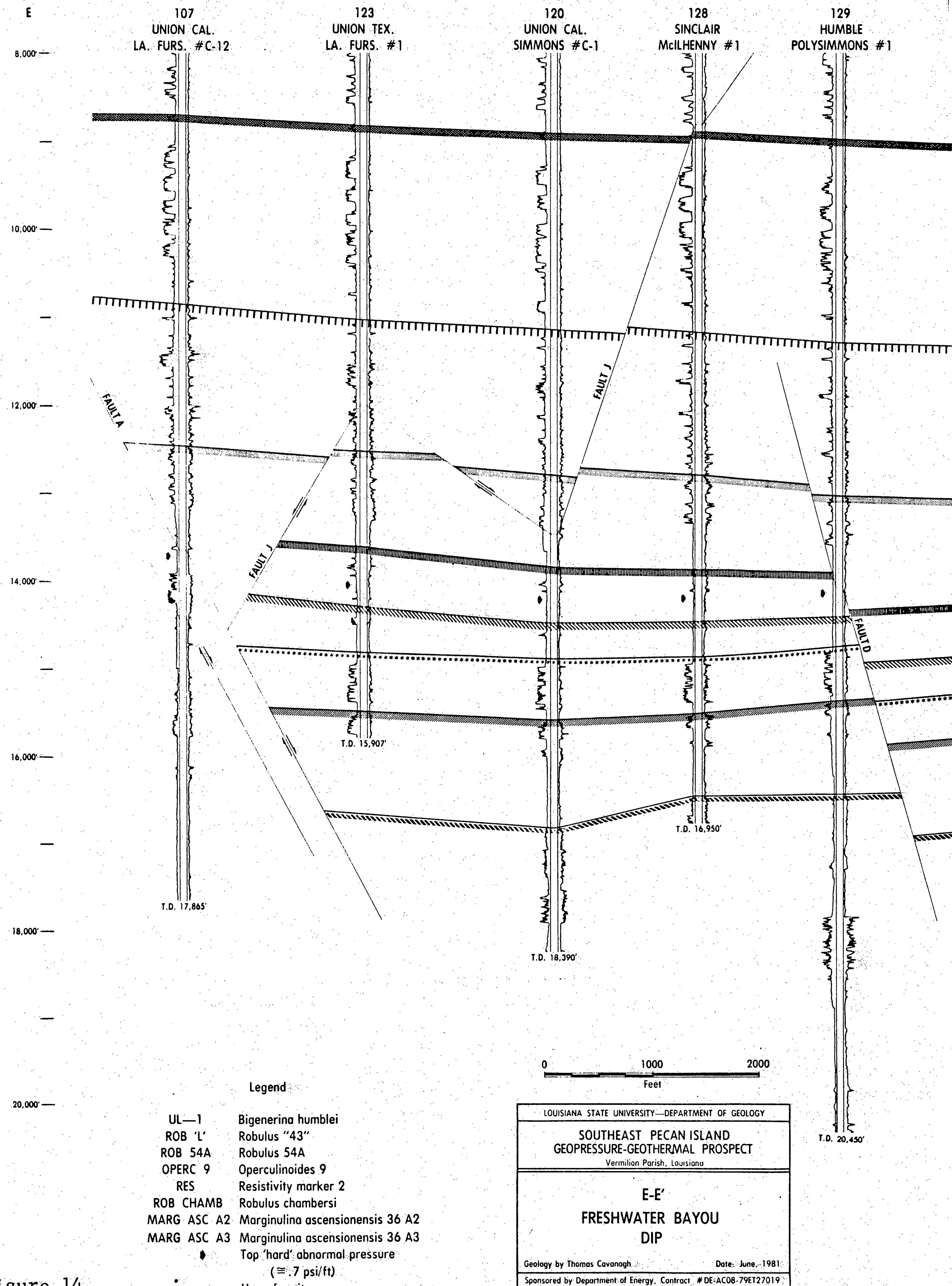

E
107
UNION CAL.
LA. FURS. #C-12
123
UNION TEX.
LA. FURS. #1
120
UNION CAL.
SIMMONS #C-1
128
SINCLAIR
McILHENNY #1
129
HUMBLE
POLYSIMMONS #1
8,000'
10,000'
12,000'
14,000'
16,000'
18,000'
20,000'
FAULT A
FAULT J
FAULT J
FAULT D
T.D. 15,907'
T.D. 16,950'
T.D. 17,865'
T.D. 18,390'
T.D. 20,450'
0
1000
2000
Feet
Legend
UL—1 Bigenerina humblei
ROB 'L' Robulus "43"
ROB 54A Robulus 54A
OPERC 9 Operculinoides 9
RES Resistivity marker 2
ROB CHAMB Robulus chambersi
MARG ASC A2 Marginulina ascensionensis 36 A2
MARG ASC A3 Marginulina ascensionensis 36 A3
Top 'hard' abnormal pressure (≅.7 psi/ft)
Unconformity
LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY
SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana
E-E'
FRESHWATER BAYOU
DIP
Geology by Thomas Cavanagh
Date: June, 1981
Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

Figure 14.

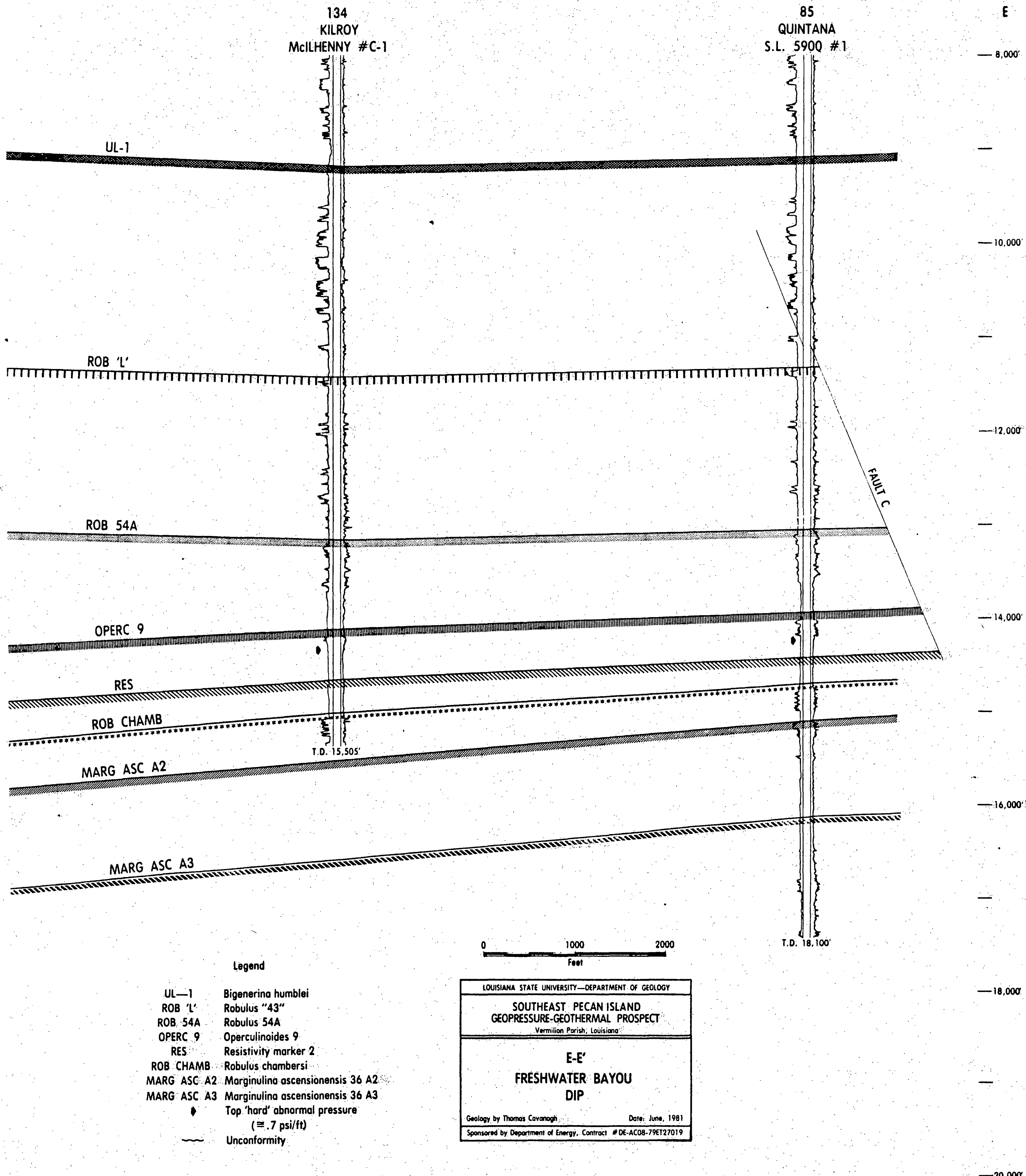
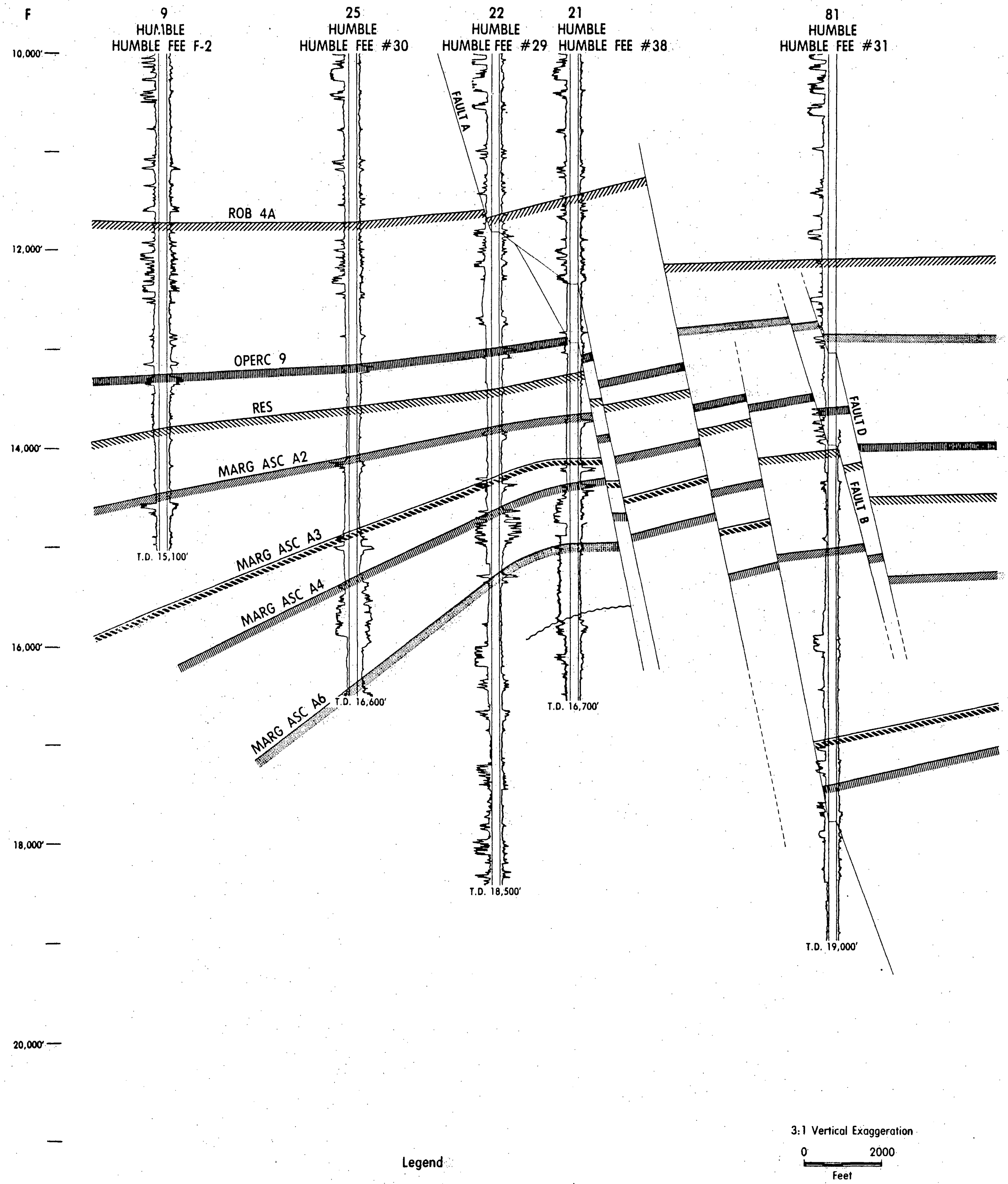


Figure 14, contd.



Legend

ROB 4A	Robulus 4A
ROB 54A	Robulus 54A
OPERC 9	Operculinoides 9
RES	Resistivity marker 2
MARG ASC A2	Marginulina ascensionensis 36 A2
MARG ASC A3	Marginulina ascensionensis 36 A3
MARG ASC A4	Marginulina ascensionensis 36 A4
MARG ASC A6	Marginulina ascensionensis 36 A6
◆	Top 'hard' abnormal pressure (≅ .7 psi/ft)
~~	Unconformity

LOUISIANA STATE UNIVERSITY—DEPARTMENT OF GEOLOGY

SOUTHEAST PECAN ISLAND
GEOPRESSURE-GEOTHERMAL PROSPECT
Vermilion Parish, Louisiana

F-F'
SOUTHWEST
PECAN ISLAND STRIKE

Geology by Thomas Cavanagh   Date: June, 1981

Sponsored by Department of Energy, Contract #DE-AC08-79ET27019

Figure 15.

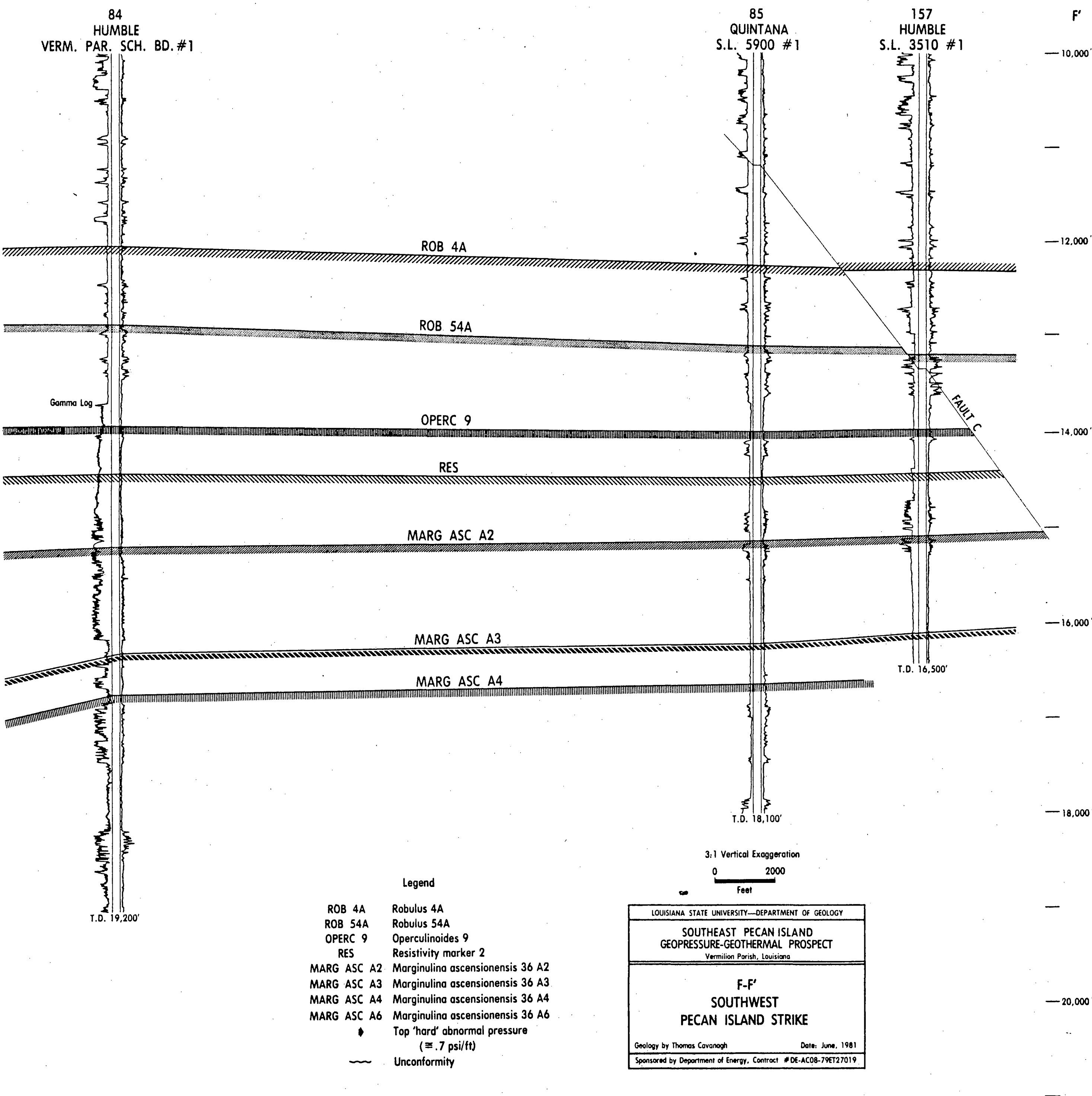


Figure 15, contd.

ROCK MECHANICS AND SUBSIDENCE MODELING

D. R. Carver and J. Janssen

Introduction

Dr. Dale R. Carver, Professor of Civil Engineering, and Mr. James Janssen, Graduate Research Assistant, Geology Department, at Louisiana State University (LSU) have worked in the general area of rock mechanics and subsidence theroy.

From the beginning of his association with the Energy Programs Office at LSU, Dr. Carver has devoted almost all of this time to the vast literature on theoretical rock mechanics. The study was initiated because of an early conviction that the compressibility coefficient used in early reservoir simulation studies was too large, thereby giving an overly optimistic prediction of flow rates and reservoir life. Carver thus reviewed essentially all of the fundamental papers on rock mechanics, paying particular attention to rock deformation as it affected reservoir drive and subsidence theory. Some of the most important of these papers are listed below:

1. Biot, M. A., 1941, General theory of three-dimensional consolidation: Jour. Applied Physics, vol. 12, p. 155-164.

2. Geertsma, J., 1957, The effect of fluid pressure decline on volumetric changes of porous rocks: Trans. AIME, vol. 331.

3. Hubbert, M. K., and W. W. Rubey, 1959, Role of fluid pressure in mechanics of overthrust faulting: Bull. Geol. Society of America, vol. 70, p. 115-166.

4. Lubinski, A., 1954, The theory of elasticity for porous bodies displaying a strong pore structure: Second National Congress of Applied Mechanics, Proceedings, p. 247-256.

5. Nur, A., and J. D. Byerlee, 1971, An exact effective stress law for elastic deformation of rock with fluids: Jour. Geophysical Research, vol. 76, p. 6414-6419.

6. Skempton, A. W., 1960, Effective stress in soils, concrete and rock, in Pore pressure and suction in soils: Butterworths, London, p. 1.

7. Terzaghi, K., 18 June 1936, Simple tests determine hydrostatic uplift: Engineering News Record, vol. 116, p. 872-875.

Carver also monitored rock mechanics laboratory test results as they became available from the Center for Earth Science and Engineering at the University of Texas at Austin and from Terra-Tek, 420 Wakara Way, Salt Lake City, Utah. These test results confirmed the fact that the value of a key physical property, the coefficient of uniaxial compaction, was indeed much lower than that which had been used speculatively in earlier studies. This parameter is of utmost importance in reservoir simulation and in subsidence studies.

The results of his study were published in the Proceedings of the Fifth Conference on Geopressured-Geothermal Energy, U. S. Gulf Coast, which was held at Louisiana State University on October 13-15, 1981. The paper is theoretical and would be difficult to summarize, but is surely of value to specialists in rock mechanics.

Dr. Carver and Mr. Janssen, with the support of the Louisiana Geological Survey and the Department of Energy, began work on subsidence in the fall of 1980. The project was undertaken to develop a method by which subsidence due to pressure depletion and compaction in a reservoir could be predicted. This subsidence problem with the geopressured-geothermal test wells must be considered because of the possibilities of flooding in low-lying areas in addition to structural and drainage problems in the more urban areas.

Background

Geertsma (1973), building on the work of Mendlin (1950) and Sen (1950), shows that the vertical displacment, u(r,z), evaluated at the surface, z=0, due to a pressure drop, Δ P, in a small volume of the aquifer, Δ V, is given in cylindrical coordinates by:

$$u(r,0) = \frac{-1 \; Cm(\; 1 - \nu \;) \; .D.\Delta P \nabla V}{\P \; (r^2 + D^2)^{3/2}} \qquad (1)$$

in which D is the depth of the volume Δ V and r is the horizontal distance from the point where the subsidence is computed to the volume Δ V (Fig. 1). In this equation, Cm is the coefficient of uniaxial compaction, as defined by Geertsma, i.e., the vertical strain per unit drop in pore pressure with lateral strain equal to zero. The constant ν is Poisson's ratio for the bulk rock material.

To compute the total subsidence at any point on the surface (directly above the aquifer or beyond its boundary), one establishes a grid of mesh points on the surface and partitions the aquifer itself into a finite number of small volumes. The subsidence at any point of the surface is calculated by summing over all of the differential volumes of the aquifer. This is done at each mesh point on the surface, giving the subsidence surface from which profiles or contours may be constructed.

Accuracy

There is, of course, loss of accuracy in numerical integration. The standard procedure is to refine the summation interval until there is negligible difference in numerical results. This refinement will be necessary when applying the program to a particular site. For the Parcperdue site, the surface was initially partitioned into 1000-ft square grid units. This was later reduced to 500 ft and, finally, to 125 ft; where the 125-ft grid was considered, 2380 block points were evaluated. CPU time on the IBM 3033 was 0.92 minutes for the final run. The Parcperdue reservoir is small (936 acres surface area), and for a vast reservoir a larger mesh interval will surely suffice. It is believed that if the model does not predict actual field behavior it will be due to the fundamental assumption inherent in the nucleus-of-strain theory as applied to earth subsidence rather than numerical procedure.

This theory is based on the premise that the earth is a linearly elastic, homogeneous, isotropic infinite half space. The Cm is equation (1) (as well as ν) should be the same elastic constant for this entire half space. Yet, in reality, the Gulf Coast region is made up of thick shale layers with interbedded sandstone and limestone layers and lenses. It is splintered by faults, and our knowledge of their location and behavior under load changes is sparse. If equation (1) is used, the Cm should be a weighted average of that of the shales and limestones above, below, and beyond the production zone. Attaining this weighted average would require an inordinate amount of coring and laboratory testing. Also, it is known that Cm for individual specimens is not a constant, even when tested at room temperature in the laboratory; rather, it depends in an unknown fashion on the confining and overburden stresses and upon time. The effect of temperature and actual in-situ brine saturation on this "elastic constant" has not yet been investigated or, at least, reported in the literature.

There is a direct analogy between poroelasticity and thermoelasticity. A pressure drop in a finite volume of an elastic half space is directly analogous to a temperature drop in this finite volume. If the earth were made of a linearly elastic, isotropic, and homogeneous material, we could predict rather precisely the displacement of particles at the surface (and elsewhere) due to cooling a portion of it (the volume of the aquifer). We are using the same mechanics to predict surface motion due to pressure drawdown in the aquifer.

But the analysis presented is dimensionally and spatially correct. We know, with reasonable accuracy, the boundaries of certain aquifers along with their depths, thicknesses, and pore pressures. We know or can hypothesize pressure drops. The model should then give the location of the maximum subsidence (not necessarily at the well head) and the relative shape of the subsidence surface. It depends upon but one physical parameter (the product of Cm and $1-\nu$). It should then be possible to evaluate this parameter by precise subsidence measurement (as opposed to a prohibitive amount of coring and testing) and thus have a "global" value of the parameter for application to other Gulf Coast wells. The model is also suspect in that it predicts a quasi-static response to pressure depletion. That is, it predicts subsidence which is effectively instantaneous and does not progress with time. This again is a departure from reality. However, if periodic checks are made on the surface elevation of one or more points above the aquifer, this time dependence, f(t), can be ascertained globally and a single function Cm $(1-\nu)$ f(t), used to model the subsidence spatially and with time.

The Computer Program

The main tool used in this research is a computer program that is capable of taking reservoir geometry information and incorporating this information with the compaction mechanics to estimate subsidence.

This Fortran program uses information on boundary locations and thicknesses of an aquifer to construct a numerical representation of the three-dimensional shape of the aquifer. This is done by segmenting the aquifer into small, finite volumes, all of which have the same top surface area (125 ft x 125 ft in our model). The thickness is determined by linear interpolation from one boundary of the reservoir to the other. This program is flexible enough to describe all types of volumes; however, the more asymmetrical the thicknesses are, the more detailed the input data must be.

Once the aquifer is described, a grid is established at the surface. For each point on the grid, the sum of the drawdown of each of the finite volumes in calculated using Geertsma's formula. This sum represents the maximum amount of subsidence at that point.

Subsidence Prediction for Parcperdue

After this computer modeling technique was developed and checked with simple models, it was applied to predicting the subsidence at the Parcperdue test-well site (Fig. 2).

The Parcperdue well site is located in Vermilion and Lafayette Parishes, approximately eight miles south of Lafayette. The sediments of the aquifer are Middle to Upper Oligocene in age and are contained in the *Cibicides jeffersonensis* sandstone of the Frio formation. Well logs and seismic data provide for extremely accurate subsurface mapping control in this area, which is very important in making calculations of the dimensions of the reservoir.

The aquifer is contained in a relatively small, sealed fault block at a mean depth of 13,400 ft. The block has a top surface of about 939 acres and an average thickness of about 50 ft (varying from 15 ft in the northeast to 105 ft in the south). The sandstone is relatively unconsolidated, with an average porosity of about 29% and an average permeability of about 500 md. Given these values, an estimated 1.06×10^8 bbl of fluid is contained in this aquifer.

Given a compaction coefficient of 4×10^{-7} for the aquifer, our computer model shows that a pressure depletion of 3000 psi in the aquifer will lead to a maximum subsidence of 0.004 ft at the surface. Our estimate of the compaction coefficient is based upon rock mechanics data, and it is possible that with respect to the Gulf Coast, it could be off by a power of 10 or more. However, once the pressure drawdown has been completed and the subsidence has occurred and been measured, we should be able to determine the compaction coefficient for this area fairly accurately.

The results of this study appeared in the proceedings of the Fifth U. S. Gulf Coast Conference on Geopressured-Geothermal Energy under the title, "A Computer Program for Predicting Surface Subsidence Resulting from Pressure Depletion in Geopressured Wells: Subsidence Prediction for the Dow Test Well No. 1, Parcperdue, Louisiana."

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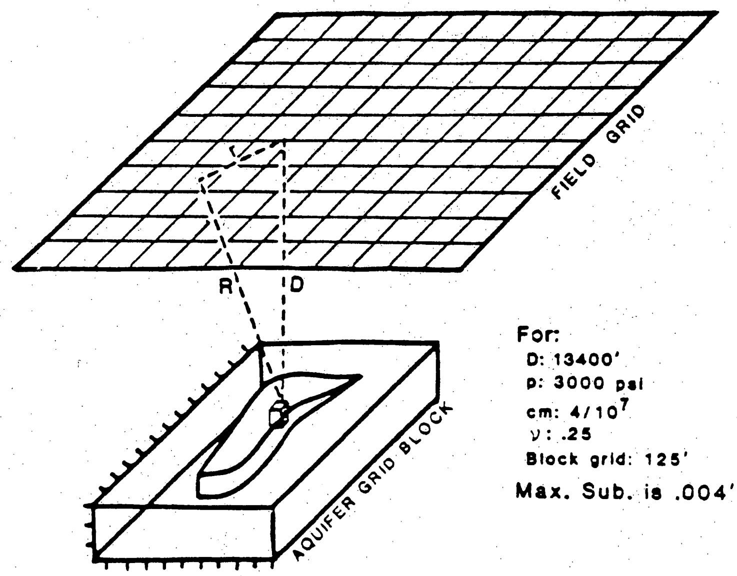

Figure 1. Subsidence program model for the Parcperdue aquifer.

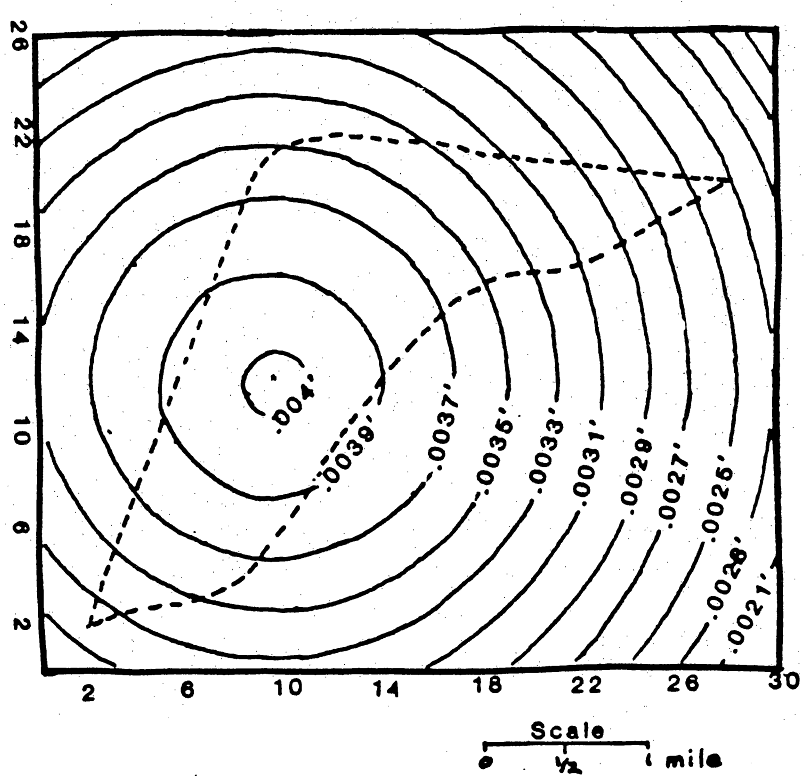

Figure 2. Subsidence contour map at surface over Parcperdue aquifer. Constants equal to those in Figure 1.

RESERVOIR ANALYSIS AND SIMULATION

Z. Bassiouni and P. L. Silva

A New Approach to the Determination of Geopressured Aquifer Salinity from the SP Log

Introduction

The SP log has been extensively used to evaluate formation water salinity. The water resistivity, R_w, is first calculated from the log. The salinity is then obtained using available correlations relating salinity to formation water resistivity. It has been noted in several wells that have been tested in deep, abnormally pressured south Louisiana formations that logging calculations do not appear to give an accurate representation of water salinity. The SP method tends to underestimate salinity.

The amount of gas dissolved in geopressured brines depends on temperature, pressure, and salinity. Figure 1 shows the solubility of methane in water as a function of total dissolved solids at 300°F and 15,000 psia. At these temperature and pressure conditions, an underestimation of the salinity from 100,000 ppm to 50,000 ppm will result in overestimation of the amount of gas in solution by almost 23%. The salinity is also used as screening parameter in the selection of dry holes for the "wells of opportunity" program.

The discrepancy between water salinity values obtained from water samples and those estimated from SP logs could be due to the quality of water samples. Water samples recovered may be diluted and contaminated due to mixing with condensation water or drilling fluids. However, such a discrepancy continues to exist when reliable water samples are available.

The purpose of the study conducted by the Department of Petroleum Engineering at Louisiana State University was to examine the method traditionally used to calculate R_w from the SP log and to develop a new calculation approach yielding more reliable water salinity values.

Traditional Approach

The method traditionally used to calculate R_w from the SP log is based on the well known equation (Wyllie, 1949):

$$SP = -K \log(a_w/a_{mf}) \quad (1)$$

where SP = SP log deflection in millivolts; corrected for bed thickness and other measurement environment,

a_w = activity of the formation water in gr-ion/liter,

a_{mf} = activity of the mud filtrate in gr-ion/liter,

K = coefficient which depends on the formation temperature ($K = 61 + 0.133T$; T in °F).

For pure sodium chloride solutions that are not too concentrated, resistivities are inversely proportional to activities. However, the inverse proportionality does not hold exactly at high concentrations or for all types of waters. Therefore, Goudouin, Texier, and Simard (1957) introduced the concept of equivalent resistivity. The equivalent resistivity, by definition, is inversely proportional to the activity. By this definition, equation (1) becomes:

$$SP = -K \log(R_{mfe}/R_{we}) \quad (2)$$

where R_{mfe} and R_{we} are the mud filtrate equivalent resistivity and the formation water equivalent resistivity, respectively. Graphical relation between true and equivalent resistivities is available in the literature. Equation (2) has been extensively used to estimate R_w from SP values.

Kharaka, Brown, and Carathers (1978) reported detailed chemical analysis of several formation water samples from seven oil and gas fields in the Lafayette, Louisiana, area. These chemical analyses were determined using a new, reliable technique (Presser and Barnes). These waters are predominantly sodium chloride with a concentration of calcium and magnesium less than 5%

by weight. The water resistivity values of these samples were calculated using the technique proposed by Ucok, Ershaghi, and Olhoeft (1980). The comparison of these values and those estimated from the corresponding SP log deflections using equation (2) resulted in Figure 2. The discrepancy between SP-log-calculated values and chemical-analysis-calculated values is evident.

This discrepancy could be the result of one or both of the two assumptions which are implicit in equation (2). These two assumptions are:

1. Both formation water and mud filtrate are pure sodium chloride solutions.
2. The shale is a perfect membrane, i.e., one through which only cations can pass.

The effect of salts other than sodium chloride was investigated (Silva, 1981; Silva and Bassiouni, 1981). This effect was found to be relatively small for brines containing less than 5% by weight of salts other than sodium chloride and can not account for the above significant discrepancies.

Non-Ideal Membrane Behavior of Shales

Equations (2) and (3) assume that shale formations behave ideally as cationic permeable membranes. Laboratory measurements with shale membranes cut from cores commonly show a potential different from that calculated for an ideal membrane (Goudouin and others, 1957; Wyllie and Southwick, 1954; Hill and Milburn, 1956). For the purpose of practical interpretation, K should be related to an available shale electric property which would reflect shale membrane characteristics.

The only shale electric property readily available is the shale electric resistivity, R_{sh}, reported on a resistivity log. Several attempts were made to incorporate R_{sh} in the SP expression. A hypothetical value K_T of the coefficient K was calculated from equation (3) using R_w values from chemical analysis. K_T is the value of coefficient K, which if used in equation (3), will yield a perfect agreement between R_w values from the SP and R_w values from chemical analysis. In Figure 3, the K_T values are plotted against the ratio R_{sh}/R_{mf}. This was done in an attempt to include, in one dimensionless term, two of the parameters which seem to be important. Although no precise relationship can be inferred, two interesting features can be noticed. For a constant R_{sh}/R_{mf} value, K_T tends to increase as the SP reading increases. This is indicated by dotted-line trends. A trend defined by a solid line is also indicated. This trend could be related, according to the high SP values, to clean formations.

Figure 3 shows that coefficient K is a function not only of the temperature, but also of the measurement environment as well. An expression for K would be hard to obtain because of the many unknowns involved. However, a parameter exists that reflects all the possible variables controlling the SP phenomenon. Such a parameter is, of course, the SP reading itself. In fact, when the ratio R_{sh}/R_{mf} is plotted versus R_{mf}/R_w (Fig. 4), a well-defined relationship is obtained for each value of the SP. In order to present the correlation in a more convenient way, interpolated values of Figure 4 are plotted on Figure 5, where R_{mf}/R_w is plotted against the SP reading as a function of several R_{sh}/R_{mf} values.

For comparison, the correlation of Figure 5 was superimposed on the graphical presentation of equation (2) representing the old interpretation approach, Figure 6. The old and new interpretation approaches are close at high SP values. A considerable deviation is noticed at low SP values.

Given the correlation of Figure 5, the R_w values for the samples used in Figure 1 were calculated and plotted in Figure 7 versus the values calculated from the chemical analyses. An excellent agreement is clearly indicated, despite the fact that some of the data points were obtained in shaley formations.

Application of the New Correlation to Geopressured Wells

The new correlation was used to calculate salinity values in six geopressured formations encountered in the wells of opportunity. For comparison, salinities using the traditional approach were calculated as well. Table 1 shows the data and the results of the calculations. Figures 8 and 9 show the comparison between the calculated salinities and the values estimated from chemical analyses. The dotted lines in Figures 9 and 10 represent the calculated standard error.

Table 1. Salinity values

	Chemical Analysis (TDS)	Traditional Technique (TDS)	New Technique (TDS)
1. Pleasant Bayou #2	120,872	101,680	123,380
2. Beulah Simon #2	96,140	66,590	112,570
3. Fairfax-Foster #2	169,193	136,220	144,840
4. E. Delcambre #1a	122,564	44,580	92,560
5. E. Delcambre #1b	105,439	36,750	87,260
6. Praire Canal #1	42,386	24,870	68,360

A qualitative analysis of these figures reveals the advantage of the new correlation to estimate the salinities for the formation under study. This fact is reinforced by mentioning that an average error of 4% and a standard error of +21,500 ppm were obtained when the new correlation was employed. On the other hand, the traditional approach yielded an average error of -39% and a standard error of +47,300 ppm. The statistical parameters have to be carefully considered because of the limited number of data points available.

Conclusions

The traditional SP equation SP = -K log(aw/amf), which assumes ideal membrane behavior of shales where K is only temperature-dependent, yields inaccurate values of R_w. To account for the non-ideal membrane behavior of shales, K should be expressed in terms of R_{sh}, R_{mf}, and R_w. A new relation giving SP as a function of R_{sh}, R_{mf}, and R_w was established (Fig. 5). The use of this new correlation resulted in a significant improvement of the accuracy of R_w and water salinity values, as indicated by their excellent agreement with values obtained from chemical analyses.

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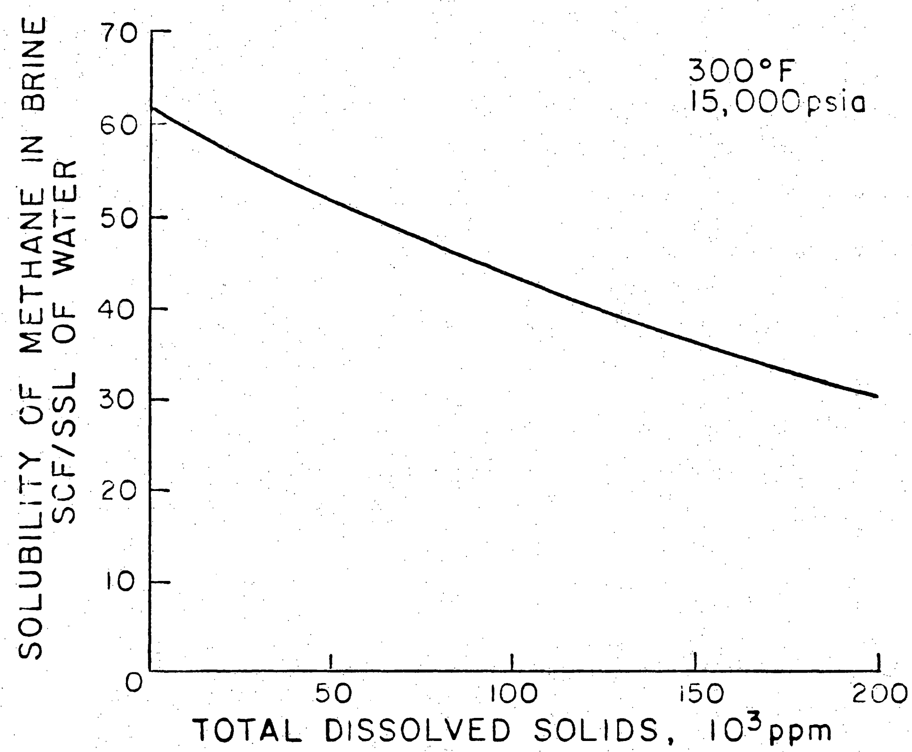

Figure 1. Effect of water salinity on the amount of methane in solution of 300°F and 15,000 psia.

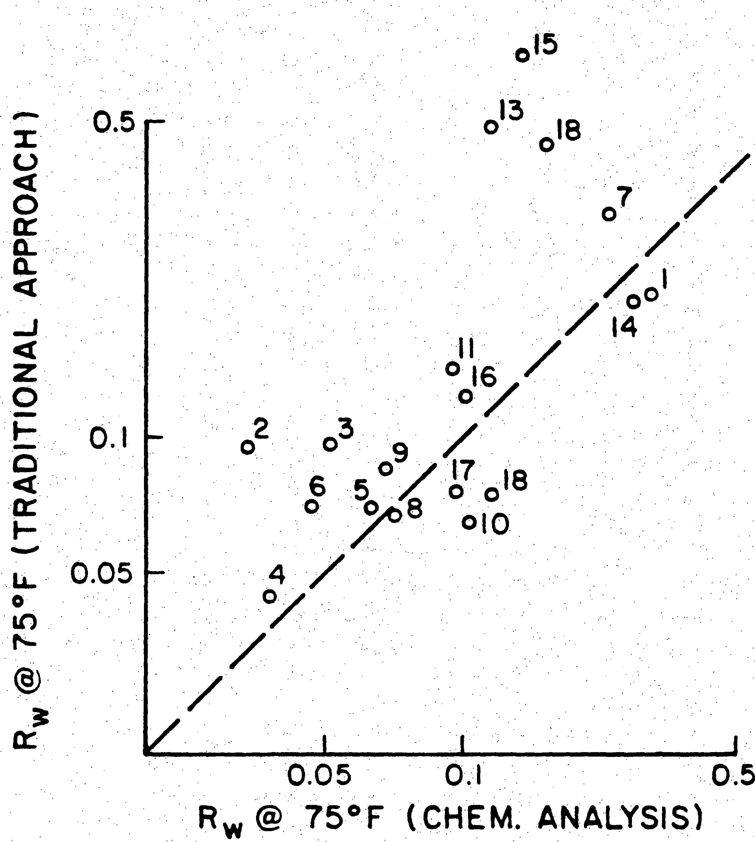

Figure 2. Comparison between R_w from SP log and R_w from chemical analysis.

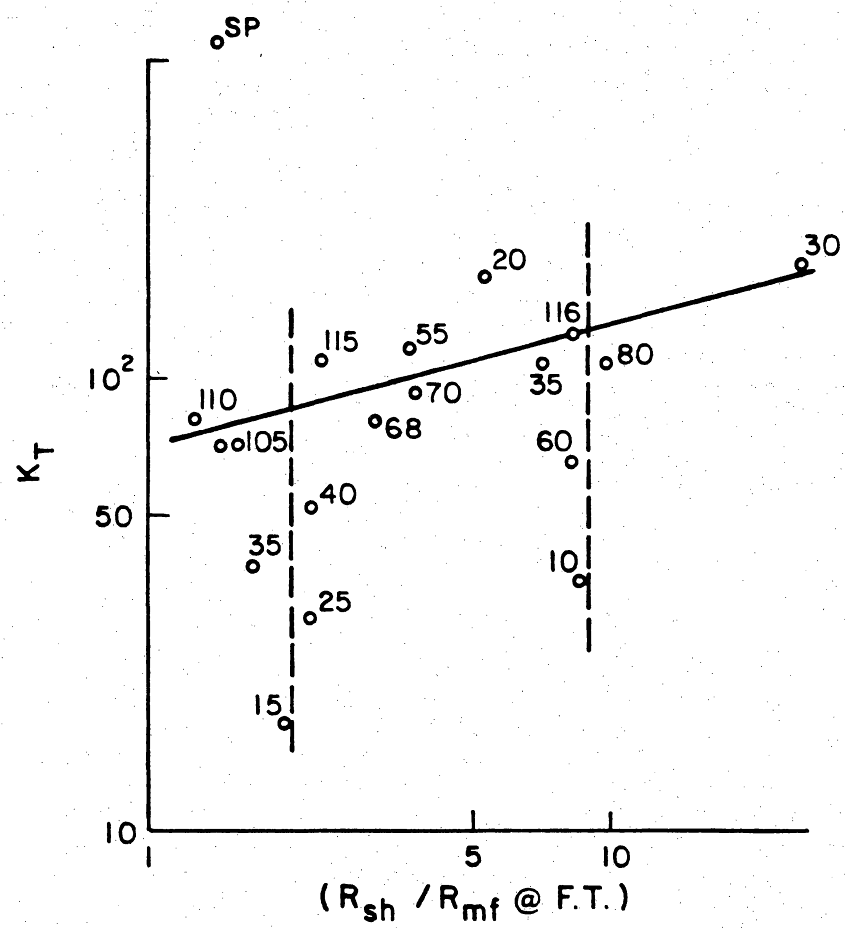

Figure 3. K_T vs. R_{sh}/R_{mf} ratio.

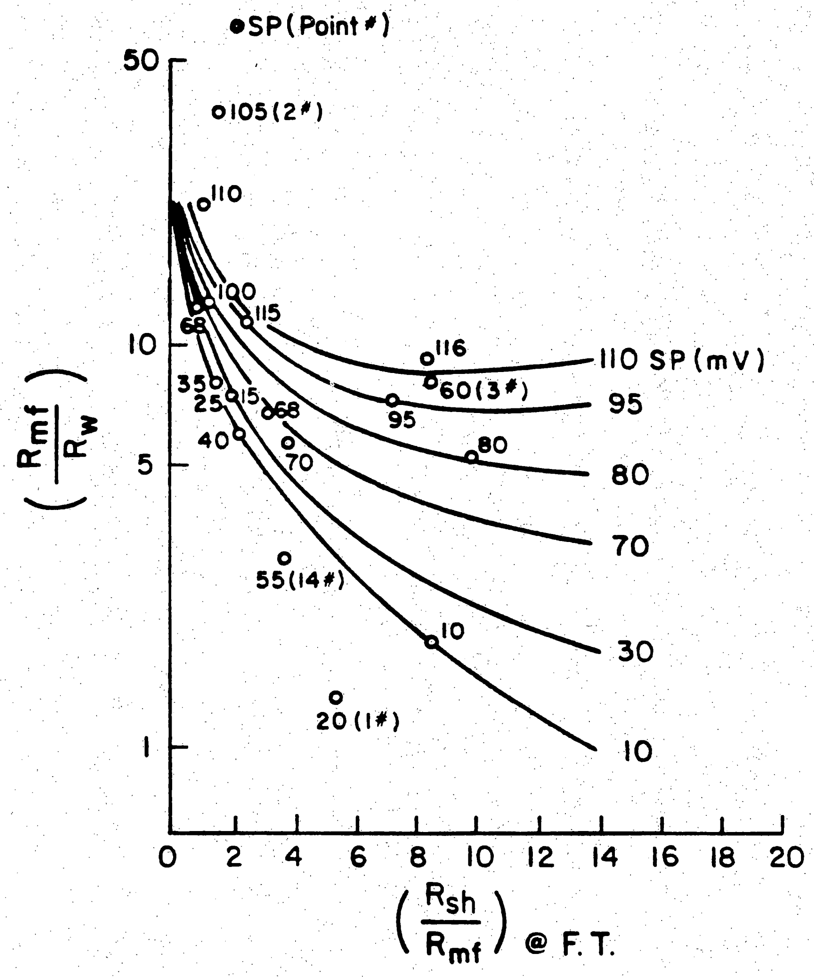

Figure 4. Correlation between R_{mf}/R_w and R_{sh}/R_{mf}.

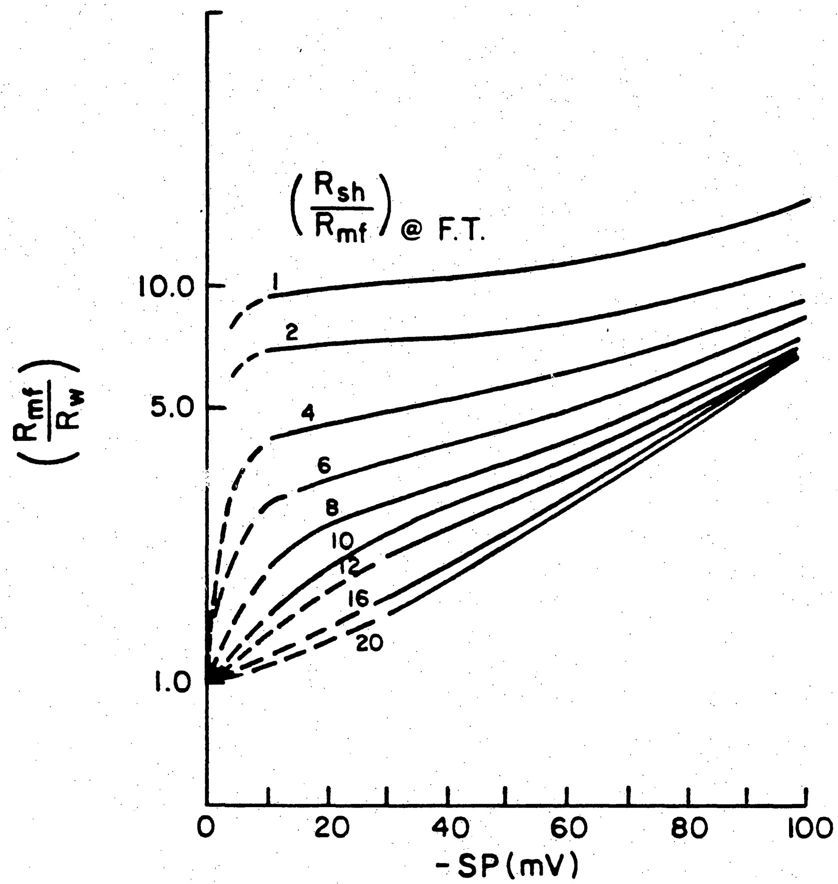

Figure 5. Correlation between R_{mf}/R_w and SP value.

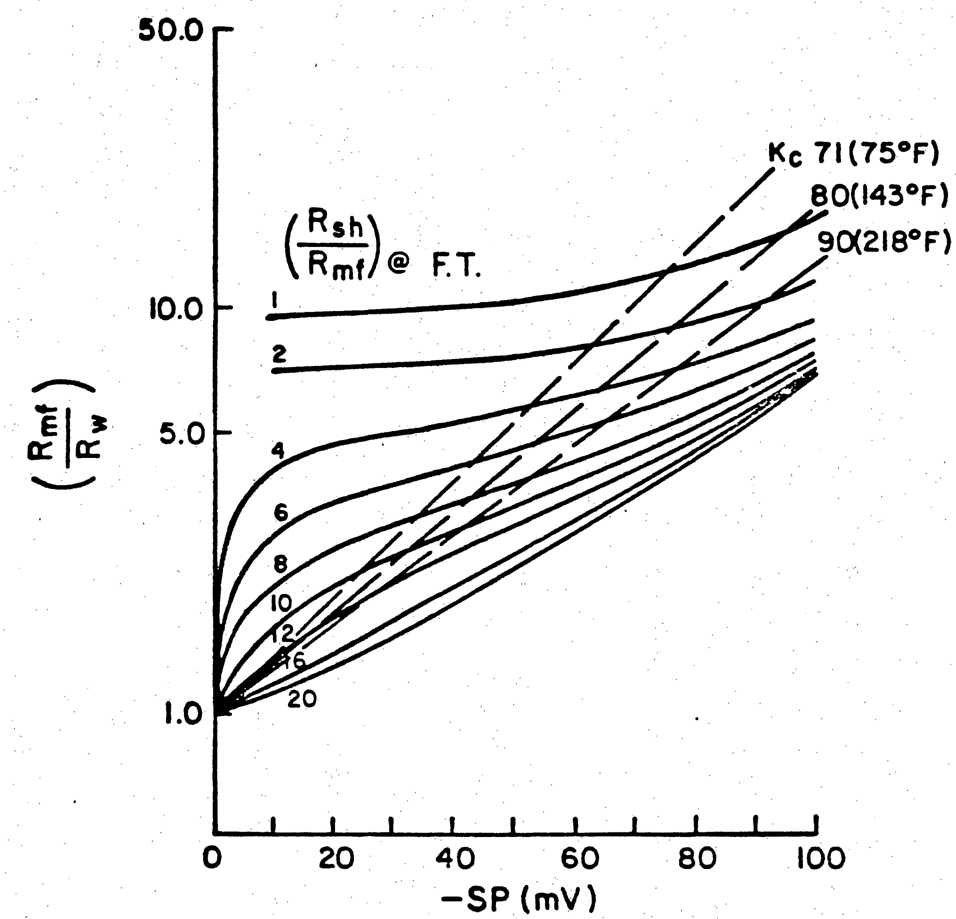

Figure 6. Empirical comparison between old and new approach.

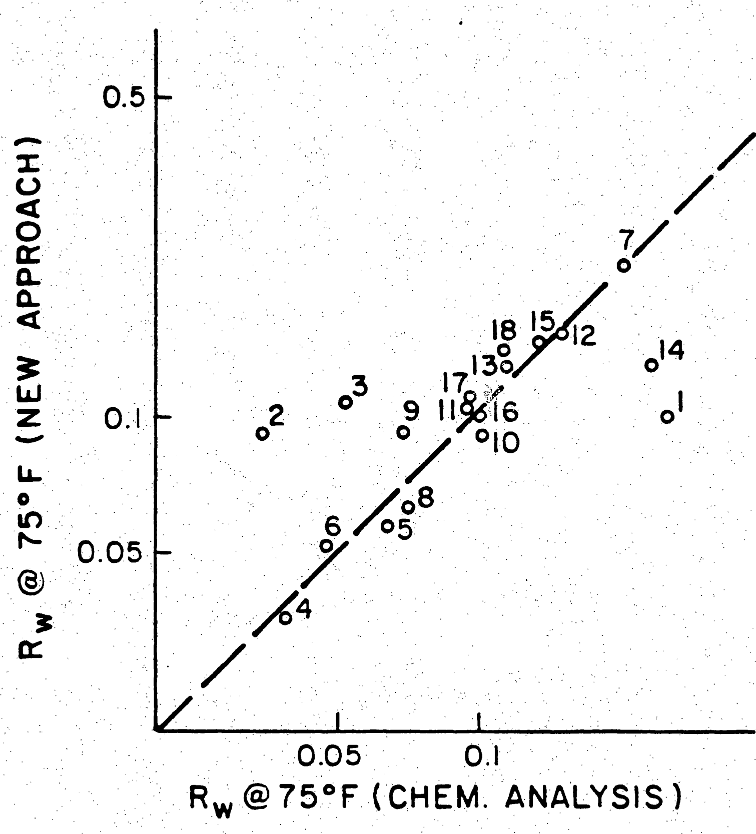

Figure 7. Comparison of the R_w values calculated using the new correlation and those obtained from chemical analysis.

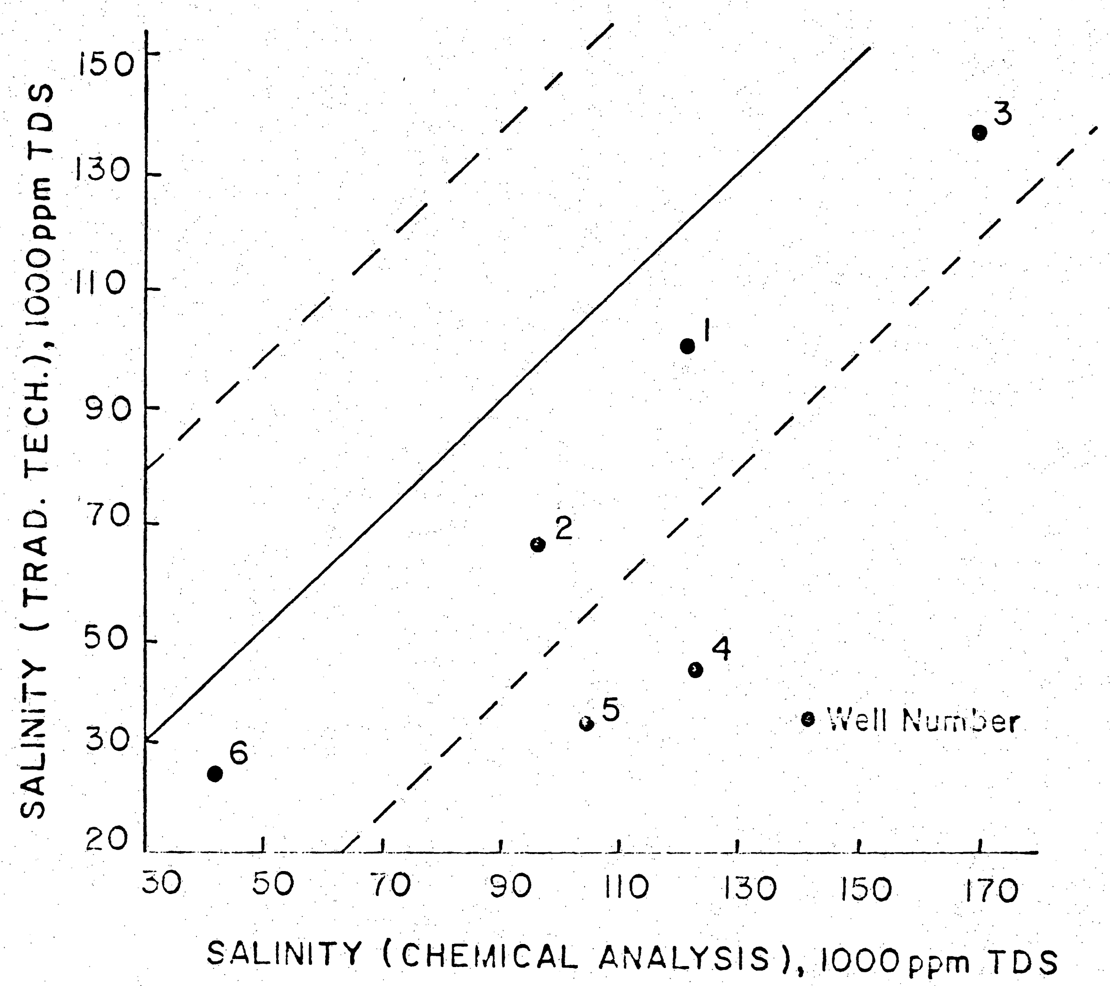

Figure 8. Geopressured brines: Salinity using traditional technique vs. chemical analysis values.

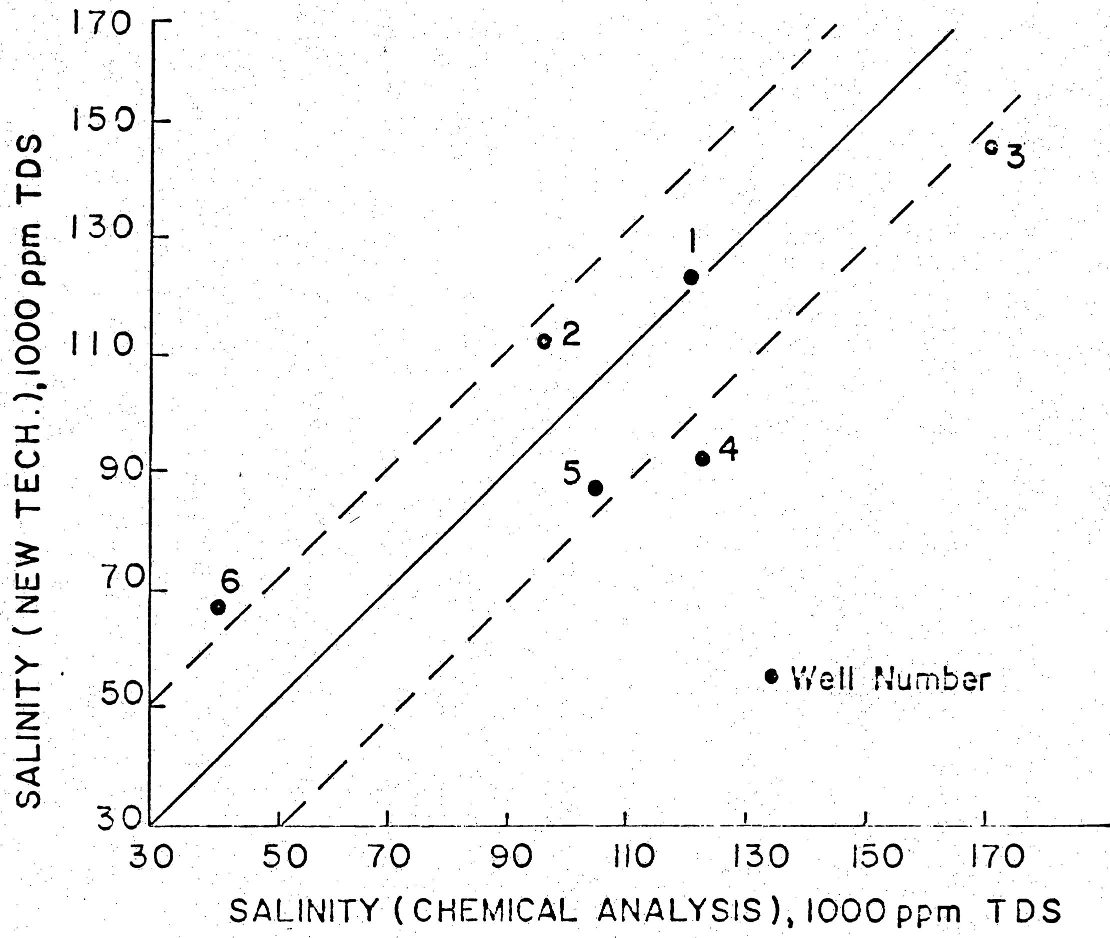

Figure 9. Geopressured brines: salinity using new technique vs. chemical analysis values.

INFORMATION SYSTEMS

F. M. Wrighton and L. K. Veal

Major Project Objective

The Information Center for Geopressured Geothermal (ICGG) was conceived and designed to respond to technical and non-technical users, using the resources and data made available through the past research efforts of Louisiana State University (LSU) researchers, the existing DOE projects, and previous studies on geopressured-geothermal resources. It was anticipated that the principal users would be professors and graduate students involved in geopressured-geothermal research. To meet the needs of in-house project researchers, a traditional research library would be designed and implemented along with acquisition, cataloging, search services, and other such maintenance functions. A computerized data base would be developed, incorporating the results of resource assessments and test-well activities. The LSU project staff would be polled on the inclusion of subject categories relevant to their area of research as well as other library and informational concerns.

To accomplish these objectives the following tasks were done:

1. Information needs were assessed to determine what data and dimensions were required.
2. Similar information systems and data-base managements were reviewed.
3. A review of existing data-base management software packages which would minimize the amount of programming and implementation of the system was conducted.
4. ICGG was then designed to satisfy the needs stated in 1 above.
5. The design was implemented, and information, acquired for the system, converted to machine-readable form whenever appropriate.

6. A mechanism was developed for a periodic update of information and/or revision.
7. A review is being conducted of the system as in place to identify areas for expansion or changes in reporting format.
8. Final revisions are underway based upon the review conducted in 7 above.

Work Performed

LSU has been actively involved in geopressured-geothermal research since the mid 1970's and has produced a substantial amount of information and data on the resource. This system (ICGC) was conceived and designed with the purpose of compiling and making accessible available literature and data of past and existing research. A compilation of all LSU geopressured-geothermal projects was made and copies of all final reports solicited, adding to an existing collection of research literature used by the LSU research staff on previous contracts. From this small collection of literature, task 1 above was initiated.

An information needs assessment was performed by 1) reviewing previous work and literature, and 2) conducting personal interviews with researchers and faculty investigators. Through this assessment, the information system was initiated by the selection and compilation of appropriate subject categories and the design of a classification scheme on geopressured-geothermal energy (App. A). The classification scheme was designed with emphasis on geopressured as the major resource and geothermal as the minor resource. Professional review and opinions were solicited and incorporated in the final draft (App. A), which included additional categories. Upon the completion of this scheme, cataloging procedures were established and implemented.

In the process of assessing information needs, similar information systems and data-base management systems were reviewed (task 2). These systems proved to be unique within the realms of the housing institutions, thereby meeting the specific needs of the home base and its research staff.

An intensive review of existing data-base management software packages along with the information needs assessment of the system resulted in subscription to the DOE Energy Information Data Base and access to the DOE/RECON computerized information retrieval system (task 3). RECON was provided as a search tool for data that was not immediately available within our system, and restricted search services were extended to the university population through ICGG.

Data-Base Management Software Packages

CFAMULUS and the Statistical Analysis System (SAS) software packages were selected as programming tools in ICGG (task 3). The CFAMULUS package provides programming for maintenance of information in a machine-readable form and for subsequent searching of that information with a scan of the entire file. It is a documentation system specifically designed for research workers developed at the Pacific Southwest Forest and Range Experiment Station in Berkeley, California. CFAMULUS offers various information retrieval facilities such as indexing, automatic sorting of files into alphabetical order, and searching in response to specific requests. Because of the ability to collate and extract information, it can also be applied as a tool for research upon the data which it stores. The system is sufficiently general in design to permit various applications, specifically the maintenance of private bibliographies or abstract files.

ICGG used the CFAMULUS software as a programming tool for the Bibliography (GTGPLIB) and Geopressured Researchers Directory Data Bases (App. B).

The bibliography data base is a file consisting of approximately 230 citations, searchable by author, contractor, sponsor, subject, and title, with a Companion Card Catalog File. Each document cited is housed in a traditional research library with assigned call numbers at the Energy Programs Office. All new entries are assessed by the professional staff and entered by supervised students (App. C).

The Geopressured Researchers Directory is a data-base tool also programmed by CFAMULUS for use by professors, graduate students, researchers as well as other professionals. A directory was needed by researchers and other interested individuals on the geopressured resource. With this need for an assessment in mind, an attempt was made to compile a listing of researchers in the geopressured resource and list not only their mailing address but also their affiliation, phone number, and area of expertise or research. (ICGG hopes to expand this file with a listing or bibliography of each researcher's works). This file contains approximately 136 entries, searchable by name, title, affiliation, location, and expertise. The expertise listed coincides with subject categories found in the bibliography (task 5).

The Statistical Analysis System (SAS) is a computer system for data analysis that provides accurate and up-to-date statistical techniques. All tools needed for data analysis are provided by SAS, such as 1) information storage and retrieval, 2) data modification and programming, 3) report writing, 4) statistical analysis, and 5) file handling. This software is used to analyze and plot well data and do other type simulations.

GEOWAT is the ICGG data base utilizing the SAS software; this file contains the sample observations of the water-quality sampling stations at the DOE test well sites in Louisiana. GEOWAT contains the observation sites (Glady's McCall, Parcperdue, and Sweet Lake) and a number of sample locations/stations for each well site. Each site and location is searchable by a number of variables measured in each sample and their values. A user's guide and maintenance manual has been prepared to access and manipulate the GEOWAT data (App. D) and to produce plots and other analytical graphics utilizing collected well data (App. E). This guide is dynamic and will be changed as new sites, variables, and programming expand.

Although the Information Systems Component Professional staff is small (2), graduate and undergraduate students have been hired and trained to assist in the maintenance and periodic updating of the system (task 6). Formats and procedures have been created for the updating and entry of all data into the system. Students have been trained to perform general updating and maintenance with staff supervision.

Work Planned For Next Year

As this project continues into another year (1982), promotion and enhanced utilization of the system will be implemented. Along with continued acquisition of materials for the Geopressured-Geothermal Research Library collection and refinement of the information system. Existing data bases will be expanded and maintained, while newly created data bases will be implemented in support of other project components, such as (1) economic analysis of the test wells and newly identified potential reservoirs, (2) compilation and analysis of gas/water ratios from the test well program and the wells of opportunity program, and (3) a tracking record of economic developments (price, costs, forecasts, etc.) and regulatory developments that affect the commercial outcome of geopressured-geothermal gas as well as the maintenance of the Technoeconomic Simulation Model developed under the Systems Anlysis and Scientific Support component of the current DOE/LSU contract.

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APPENDICES

Information Systems Component

Information Center for Geopressured Geothermal

A. Classification Scheme and Subject Categories: Geopressured Research Library Collection

B. Adaptation of CFAMULUS User's Manual by ICGG: Information Storage and Retrieval with CFAMULUS

C. Bibliographic Citations (Example)

D. GEOWAT User's Guide

E. GEOWAT Graphics and Plots

APPENDIX A

CLASSIFICATION SCHEME AND SUBJECT CATEGORIES: Geopressured Research Library Collection

Energy Research Library Classification Scheme

600 **Geopressured - Geothermal Energy**

610 Geopressured Energy - Louisiana

615 Geopressured Energy - Gulf Coast Region

617

620 Fluid Disposal

621 A. Subsurface

1. Shallow vrs. deep (in producing reservoir)
2. Fluid Compatibility
   - (a) Fluid/Fluid
   - (b) Fluid/Rock
   - (c) Treatment
3. Availability of Aquifers
   - (a) Geologic considerations
   - (b) Competing uses
4. Geohydrology
   - (a) Fluid migration
   - (b) Fault activation
5. Disposal well design and completion
6. Surface equipment and operation
7. Cost analysis

622 B. Surface

1. Feasibility
   - (a) Environmental impacts
   - (b) Regulation
   - (c) Costs vrs. site location
2. Desirability
   - (a) Cost analysis: surface vrs. subsurface

623

624 Resource Assessment

625 A. Reservoir Properties -- Distibution, Prediction

1. Size/geometry
2. Permeability
3. Porosity
4. Temperature
5. Gas content/Equalibrium properties & solubility
6. Physical properties
7. Chemical properties
8. Well Data

626 B. Reservoir Mechanics

1. Rock mechanics
2. Reservoir drive
3. Relative permeability
4. Simulation

627 C. Geophysical Techniques

1. Seismic studies
2. Well logging

628 D. Geologic Studies

1. Regional
2. Diagenaic

629 E. Water Chemistry

630 Geophysical Phenomena

631 A. Subsidence

1. Mechanism
2. Surface impacts
3. Risk to developer
4. Regulation and legal
5. Mitigation and control

632 B. Fault Activation

1. Mechanism
2.
3.
4.
5.

633 C. Induced Seismicity

1. Mechanism
2.
3.
4.
5.

634 D. Impacts on Oil and Gas Reservoirs

1. Mechanism
2.
3.
4.
5.
6. Shale dewatering

635

640 Policy and Analysis (Management)

645

650 Economic Aspects

655

660 Resource Development

661 A. Exploration Strategy

662 B. Development Strategy

1. Resource Utilization

(a) Markets

(b) Institutional barriers

(c) Costs/revenues

2. Organizational arrangements

(a) Institutional

(b) Legal and regulatory context

3. Hand and resource aquisition

(a) Costs

(b) Legal and regulatory context

(c) Hand use conflict

4. Financing

663 C. Environmental Impacts

664 D. Social Impacts

665 Existing Research Programs/Recommendations

A. DOE

B. EPRI

C. GRI

D. IGT (possibly if they are not a contractor)

670 Drilling and Production Technology (Well Testing)

671 A. Drilling Technology

1. Materials

2. Safety

3. Availability

4. Costs

672 B. Completion Technology

1. Materials, practices

2. Safety

3. Availability

4. Costs

673 C. Surface Equipment

1. Volume considerations

2. Sealing, corrosion, erosion

(a) Materials

(b) Treatment

3. Energy utilization

(a) Gas/water separation

(b) Electricity generation

(c) Waste heat utilization

(d) Combinations

4. Availability

5. Safety

6. Costs

674

675 Wells of Opportunity and Design Wells (Field Data)

676 A. Design Wells

677

678

679

680

685

690 Geothermal Research Transfer

691

692 Heat Exchangers

693

694 Geothermal Fluid Resource

-Fluid-cycle

695 Geothermal Power Production (Plants)

APPENDIX B

ADAPTATION OF CFAMULUS USER'S MANUAL BY ICGG:
Information Storage and Retrieval with CFAMULUS

TECHNICAL SUPPORT FOR GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

INFORMATION SYSTEMS COMPONENT

ADAPTATION OF CFAMULUS USER'S MANUAL BY THE INFORMATION CENTER FOR GEOPRESSURED GEOTHERMAL: INFORMATION STORAGE AND RETRIEVAL WITH CFAMULUS

DATA SET: GTGPLIB

JULY 1981

THE LOUISIANA GEOLOGICAL SURVEY
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1. Introduction

In order to store and to retrieve information on geopressure research contract, we have adopted the Famulus package. Famulus is a set of programs developed at the Pacific Southwest Forest and Range Experiment Station in Berkeley, California. It provides for maintenance of information in a machine readable form and for subsequent searching of that information with a scan of the entire file. Famulus handles almost any kind of textual data even various sizes of records. Also, the main library, the law library, and Entomology department use Famulus to store and to retrieve information. For popular and easy usage of searching, we have decided to adopt Famulus.

Each record of geopressure research contract has a regular structure: contractor, file category, subject, sponsor, contact, status, results, holdings, and date of entry. We wish to search the information by contractor, subject, sponsor, and file category. This purpose can be easily achieved by Famulus's 'conversational search.' This documentation illustrates how to store and to retrieve information by Famulus; and each procedure has a complete example. For Famulu's other functions, see Famulus manual. If there are any questions that you can not find either in the Famulus manual or in this documentation, contact Dr. Howand of Library School please.

2. File Organization

A complete collection of information is held by Famulus on magnetic tapes or disks and can be referred to as a file or a data set. A file consists of an unlimited number of records (citations). A record is the basic unit of information and it is broken down into fields. Each field is given a name or label appropriate to its content. Up to ten (10) fields are permitted. The amount of information in a field may vary from record to record or from field to field, subject only to the restriction that records may not exceed 4,000 character in length.

Data set 'EPWRIG.GTGPLIB' is broken down into 6 fields. They are SUBJ (subject), TITL (title) AUTH (author), PUBL (publisher), NOTE (note), and NMBR (number).

3. Data Format

Famulus file may be created from data in a card format or text format. If the data is in card format, the creation of the file may begin immediately. For data in text format, there exists an additional step to translate the date into card format, since the EDIT program expects the input to be in card format. In our work, we use card format.

Card format

Field labels are punched in columns 1-4 of the first card in a field. Continuous cards for the field no not carry labels. Actual text of the record begins in column 6 and continues through column 80. If it is necessary to continue onto another card, punching begins in either column 6 or 7 depending on the last word of the preceding card ended in column 80, one blank is needed to seperate two words; therefore, begin in column 7. If the word is broken in the middle, or if column 80 is blank seperating two words, begin in column 6. In other words, columns 6-80 of successive cards for a field are treated as a continuous string of characters.

The fields in a record must be punched in the correct order, otherwise the record will be rejected. Fields may be omitted, since not every record in a file will require all the allowable fields. In this case, a card containing the field labes is not required.

Each record is followed by a blank card which seperates it from the next record. If the blank card is left out, the second record will be run on to the first and both will be rejected. The last record in the input deck should also be followed by a blank card. The following is an example of a card format.

```
READY
edit 'epwrig.gtgplib' da nonum
EDIT
i
INPUT
subj fluid disposal-subsurface
titl an evaluation of geopressured brine injectibility: department of energy. pl
     easant bayou no.2 well, brazoria county, texas
auth owen, l.b.  et al
publ lawrence livermore laboratory, 10/1980, livermore, ca
note #ucid-18860, 90p.: data
nmbr 611, owe

subj gp-gt conference, resource assessment
titl proceedings second geopressured-geothermal energy conference: vol.3, reserv
     oir research and technology
auth podio, augusto l.  et al
publ center for energy studies. univ. of texas at austin, 2/1976
note contract# e(40-1)4900,  sponsored by u.s. energy research and development
     administration.
nmbr 600,p2 vol.4
```

4. Creating an original Famulus file

The input file 'EPWRIG.GTGPLIB' must be transormed to 'EPWRIG.FAMULUS.DATA' then all the Famulus Functions such as UPDATE, VOCAB, GALLEY, INDEX, SORT, MERGE, INVERT, CSEARCH etc.

can be performed. The following is an example of creating a FAMULUS.DATA file.

```
READY
%create gtgplib
ENTER ID FIELD
gtgp bibliography
FIELD LABELS (COMMAS REQUIRED HERE!)
subj,titl,auth,publ,note,nmbr
DO YOU WANT A DESCRIPTOR FIELD?
n
IS YOUR INPUT DATA IN TEXT FORMAT?
n
STEP: EDIT              TIME = 10:30:18
END OF EDIT             TIME = 10:31:16
DATA SET EPWRIG.FAMULUS.DATA CREATED
DO YOU WANT A HARDCOPY LISTING OF THE FAMULUS FILE?
n
DO YOU WANT A VOCABULARY LIST?
n
READY
```

5. Information Retrieval in CFAMULUS (C: converstional)

Before any retrieval can be down, the user must execute the programs that create the inverted files that are used for the search. This is accomplished by the CLIST's ALLOCIS and INVERT. Only when the inverted files have been generated properly can searching be performed.

5-1 Allocating indexed sequential data sets

ALLOCIS is used to allocate two data sets with indexed sequential organization to be used with CSEARCH. One positional parameter is required: PARM serves to identify the data sets, which are known as &ID.&PAR.CIT.TEST and &ID.PARM.IDX.TEST. &ID.&PARM.CIT.TEXT and &ID.&PARTM.IDX.TEXT must be valid as qualifiers for data sets. In our work, we use 'EPWRIG.ACIT.TEXT' and 'EPWRIG.AIDX.TEXT' as the inverted files, and 'A' is the

&PARM. The other three optional parameters are ID, VOL, and CYL. The default value of ID, VOL, and CYL is user's ID, USER03, and 1 cylinder respectively. Usually the number of the inverted file's tracks is 1/3 greater than that of FAMULUS.DATA. The following es an example of allocating indexed sequential data sets.

```
READY
allocis a
A JOB WILL NOW BE SUBMITTED TO ALLOCATE SPACE FOR THE
INDEXED SEQUENTIAL DATA SETS ENTER JOB NAME CHARACTER ±
(you can give any character you like)
w
JOB EPWRIGW(JOB08617) SUBMITTED
JOBNAME JES# CLASS POS(HELD) FLAG STEPNAME PROCSTEP
EPWRIGW 8617 SETUP 0001(0000)
```

5-2 Creating the inverted files

INVERT takes two positional parameters DSN and PARM. DSN specifies the Famulus file to be inverted, and PARM is the same as we use in ALLOCIS. The follwing is an example of INVERT.

```
%invert famulus.data  a
STEP: TAPE2IS              TIME = 13:06:26
END OF TAPE2IS             TIME = 13:06:58
STEP: WORDS                TIME = 13:07:08
 WER124I  TRK  OVER-ALLOC FACTOR= PRIM/USED=3.3
 WER045C  END SORT PH
 WER246I  FILESIZE 438,480 BYTES
 WER054I  RCD IN     10440, OUT     10440
 WER169I  TPF'S APPLIED 123
 WER052I  END SYNCSORT   OPT= M,  EPWRIG  ,$IKJSPF ,TSO
END OF WORDS               TIME = 13:07:51
STEP: INVERT1              TIME = 13:07:59
END OF INVERT1             TIME = 13:08:15
DO YOU WANT A HARDCOPY OF THE LISTING?
n
```

5-3 Searching the inverted files

A query may contain the following elements:

1. words
2. logic AND operator (&)
3. logic OR operator (:)
4. logic NOT operator (~)
5. left and right parenthesis pair
6. spaces

CSEARCH searches the specified fields of each record word by word according to the query. The following is an example of CSEARCH. The 'sf' stands for 'search field', and 's' stands for 'search'. After the satisfied citations (records) have been found, we use 'ph (print hits) to print out the citations which meet the requirement.

```
■!
READY
%csearch  a
IEC223I IFG0200V,EPWRIG,$IKJSPF,SYSPROC,349,USER02,LSHOWD.FAM.CLIST
CONVERSATIONAL FAMULUS - INITIALIZATION FOR SEARCH
FAMULUS /ID/GTGP BIBLIOGRAPHY
      274 CITATIONS
FIELD LABELS ARE:  SUBJ  TITL  AUTH  PUBL  NOTE  NMBR
? sf(subj)
? s
00001? GEOPHYSICAL&TECHNIQUES
00002?
E? s
       10 CITATIONS SATISFIED THE SEARCH REQUEST
? ph

CIT# 0051
SUBJ  GEOPHYSICAL TECHNIQUES, DRILLING & COMPLETION TECHNOLOGY-WELL TESTING
TITL  TESTING AND SAMPLING PROCEDURES FOR GEOTHERMAL-GEOPRESSURED WELLS - FINAL
      REPORT
AUTH  BOYD, W.E.
PUBL  CENTER FOR ENERGY STUDIES, UNIVERSITY OF TEXAS AT AUSTIN, 1979
NOTE  TASK 1 OF PART 1 "SPECIAL PROJECTS RESEARCH FOR PETROLEUM ENGINEERING
      ASPECTS OF GEOTHERMAL RESEARCH", #UT/CES-GR-2, 2, 152P.: FIGURES
NMBR  623, BOY * C.1-261, C.2-475

CIT# 0052
SUBJ  GEOPHYSICAL TECHNIQUES
TITL  WELL IMAGING AND FAULT DETECTION IN ANISOTROPIC PETROLEUM RESERVOIRS -
      THESIS
AUTH  OVERPECK, ANDREW C.
PUBL  LOUISIANA STATE UNIVERSITY, DEPARTMENT OF PETROLEUM ENGINEERING, BATON
      ROUGE, 5/1969
NOTE  7, 66P.: TABLES, FIGURES
NMBR  623, OVE * C.1-259

CIT# 0054
SUBJ  GEOPHYSICAL TECHNIQUES, RESEARCH PROGRAMS
TITL  BENEFIT/COST ANALYSIS FOR RESEARCH IN GEOTHERMAL LOG INTERPRETATION -
      FINAL REPORT
AUTH  RIGBY, F.A. AND P. REARDON
PUBL  LOS ALAMOS SCIENTIFIC LABORATORY, LOS ALAMOS, NEW MEXICO, 5/1979
NOTE  PREPARED FOR LOS ALAMOS SCIENTIFIC LABORATORY, #LA-7922-MS, 9, 102P.:
      TABLES, FIGURES, APPENDICES A-D
NMBR  623, RIG * C.1-258

CIT# 0055
SUBJ  GEOPHYSICAL TECHNIQUES
TITL  GEOTHERMAL WELL LOG INTERPRETATION - MID-TERM REPORT
AUTH  SANYAL, S.K.; WELLS, L.E.; BICKHAM, R.E.
PUBL  LOS ALAMOS SCIENTIFIC LABORATORY, UNIVERSITY OF CALIFORNIA, LOS ALAMOS,
      CALIFORNIA, 2/1979
NOTE  #LA-7693-MS, 8, 178P.: TABLES, FIGURES, CHARTS
NMBR  623, SAN * C.1-257, C.2-438
```

CIT# 0076
SUBJ GEOPHYSICAL TECHNIQUES, REFERENCE
TITL APPLIED OPENHOLE LOG INTERPRETATION (FOR GEOLOGISTS AND PETROLEUM ENGINEERS)
AUTH HILCHIE, DOUGLAS W.
PUBL GOLDEN, CO: DEPARTMENT OF PETROLEUM ENGINEERING, COLORADO SCHOOL OF MINES, 1978
NOTE COVERS 'HOW TO' OBTAIN DATA FROM WELL LOGS AND 'HOW TO' CALCULATE OIL AND GAS IN-PLACE. TEXT FOR WELL LOGGING COURSE IN GEOLOGY OR PETROLEUM ENGR.
NMBR 623, HIL

CIT# 0078
SUBJ GEOPHYSICAL TECHNIQUES, REFERENCE
TITL OLD ELECTRICAL LOG INTERPRETATION (PRE 1958)
AUTH HILCHIE, DOUGLAS W.
PUBL GOLDEN, CO: DEPARTMENT OF PETROLEUM ENGINEERING, COLORADO SCHOOL OF MINES, 1979
NOTE COVERS THE INTERPRETATION OF OLD ELECTRICAL LOGS (REFERS TO LOGS WHICH ARE COMBINATIONS OF SP/S, NORMALS AND LATERALS.); ALSO MICROLOG, LATERLOGS, MICROLOG, GAMMA RAY NEUTRON LOGS. 164P.: FIGURES, GRAPHS, LOGS, TABLES, SYMBOLS AND SELECTED REFERENCES
NMBR 623, HIO

CIT# 0224
SUBJ GEOPHYSICAL TECHNIQUES
TITL RESEARCH AND DEVELOPMENT OF IMPROVED GT WELL LOGGING TECHNIQUES, TOOLS AND COMPONENTS (CURRENT PROJECTS, GOALS AND STATUS) - FINAL REPORT
AUTH LAMERS, MICHAEL D.
PUBL PALOS VERDES ESTATES, CA, MEASUREMENT ANALYSIS CORP., JAN. 1978
NOTE #SAN/1380-1, 4, 56P.: FIGURES
NMBR 623, LAM

CIT# 0225
SUBJ GEOPHYSICAL TECHNIQUES
TITL IMPROVED GEOTHERMAL WELL LOGGING TOOLS USING NO DOWNHOLE ELECTRONIC - FINAL REPORT
AUTH KRATZ, H. R...ET AL
PUBL SYSTEMS, SCIENCE AND SOFTWARE, LA JOLLA, CA. JULY 1979
NOTE #SAN-1315-1
NMBR 623, KRA

CIT# 0261
SUBJ ECONOMIC STUDIES, GEOPHYSICAL TECHNIQUES
TITL PRODUCTION ECONOMICS OF A GEOPRESSURED GEOTHERMAL PROSPECT
AUTH GOULD, T. L. AND A. SPIVAK
PUBL AMERICAN INSTITUTE OF CHEMICAL ENGINEERS, HOUSTON, 1977
NOTE PAPER NO. 27E, 42P.: TABLES, FIGURES
NMBR 650, GOU

CIT# 0268
SUBJ GEOPHYSICAL TECHNIQUES
TITL OLD ELECTRICAL LOG INTERPRETATION (PRE 1958)
AUTH HILCHIE, DOUGLAS W.
PUBL DEPARTMENT OF PETROLEUM ENGINEERING, COLORADO SCHOOL OF MINES, GOLDEN, CO. 1979
NOTE COVERS THE INTERPRETATION OF OLD ELECTRICAL LOGS (REFERS TO LOGS WHICH ARE COMBINATIONS OF SP/S, NORMAL AND LATERALS.); ALSO MICROLOG, LATERLOGS, MI CORLATEROLOGS, LIMESTONE, & OLD GAMMA RAY NEUTRON LOGS, 164P.: FIGURES, GRAPHS. LOGS, TABLES SYMBOLS AND SELECTED REFERENCES
NMBR 623, H10
?

APPENDIX C

BIBLIOGRAPHIC CITATIONS

DSNAME='EPWRIG.GTGPLIB'
SUBJ THERMAL APPLICATIONS, ENERGY CONVERSION
TITL HELICAL-ROTOR EXPANDER APPLICATIONS FOR GEOTHERMAL ENERGY CONVERSION
AUTH HOUSE, P.A.
PUBL LIVERMORE: LAWRENCE LIVERMORE LABORATORY, UNIV. OF CALIF. 4/1976
NOTE PREPARED FOR U.S. ENERGY RESEARCH AND DEVELOPMENT #UCRL-52043, 3,22P. TABL
ES, FIGURES
NMBR 696, HOU * C.1-115

SUBJ REFERENCE GEOPRESSURED, CONFERENCE GEOPRESSURED, RESOURCE ASSESSMENT
TITL PROCEEDINGS FIRST GP-GT ENERGY CONFERENCE
AUTH DORFMAN, MYRON AND RICHARD DELLER
PUBL CENTER FOR ENERGY STUDIES, UNIV. OF TEXAS AT AUSTIN, 6/1975
NOTE PREPARED BY U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION. 369P.: FI
GURES, TABLES
NMBR 600, P1 * C.1-45, C.2-431

SUBJ REFERENCE GEOPRESSURED, CONFERENCE GEOPRESSURED, RESOURCE ASSESSMENT
TITL PROCEEDINGS SECOND GEOPRESSURED-GEOTHERMAL ENERGY CONFERENCE: VOL. 1, SUMMA
RY AND FUTURES PROJECTIONS
AUTH DORFMAN, MYRON AND RICHARD W. DELLER
PUBL CENTER FOR ENERGY STUDIES, UNIV. OF TEXAS AT AUSTIN, 2/1976
NOTE CONTRACT # E(40-1)4900, SPONSORED BY U.S. ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION
NMBR 600, P2, VOL. 1 * C.1-36

SUBJ REFERENCE GEOPRESSURED, CONFERENCE GEOPRESSURED, RESOURCE ASSESSMENT
TITL PROCEEDINGS SECOND GEOPRESSURED-GEOTHERMAL ENERGY CONFERENCE: VOL.2, RESOUR
CE ASSESSMENT
AUTH BEBOUT, DON
PUBL CENTER FOR ENERGY STUDIES, UNIV. OF TEXAS AT AUSTIN, 2/1976
NOTE CONTRACT # E(40-1)4900, SPONSORED BY U.S. ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION.. 44P.: FIGURES, TABLES
NMBR 600, P2 * C.1-37, VOL.2

SUBJ REFERENCE GEOPRESSURED, RESERVOIR ENGINEERING/RESERVOIR MECHANICS
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ERBERG, IRWIN H.; THOMPSON, THOMAS W.
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AUTH PODIO, AUGUSTO L.; GRAY, KENNETH E.; ISOKRARI, OMBO F.; KANPP, ROY M.; SILB
PUBL CENTER FOR ENERGY STUDIES, UNIV. OF TEXAS AT AUSTIN, 2/1976
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ADMINISTRATION.
NMBR 600, P2, VOL.3 * C.1-38, C.2-122

SUBJ REFERENCE GEOPRESSURED, CONFERENCE GEOPRESSURED, POWER GENERATION, THERMAL
APPLICATIONS
TITL PROCEEDINGS SECOND GEOPRESSURED-GEOTHERMAL CONFERENCE:VOL.4--SURFACE TECHNO
LOGY AND RESOURCE UTILIZATION
AUTH UNDERHILL, GARY K. ..ET.AL.
PUBL CENTER FOR ENERGY STUDIES UNIV. OF TEXAS AT AUSTIN, 2/1976
NOTE CONTRACT # E(40-1)4900, SPONSORED BY U.S. ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION
NMBR 600, P2, VOL.4 * C.1-39, 2-434

APPENDIX D

GEOWAT USER'S GUIDE

DOE/ET/10174

TECHNICAL SUPPORT FOR GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

INFORMATION SYSTEMS COMPONENT

USER'S GUIDE FOR THE INFORMATION SYSTEMS COMPONENT DATA BASE
DATA SET: GEOWAT

NOVEMBER 1981

THE LOUISIANA GEOLOGIAL SURVEY
ENERGY PROGRAMS OFFICE
LOUISIANA STATE UNIVERSITY
BATON ROUGE, LOUISIANA 70803

PREPARED FOR THE
DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE
UNDER CONTRACT NO. DE-AC08-81NV-10174

1. LOGON Procedure

To access the ICGG Data Base and GEOWAT data set, follow the procedure listed below: (Passwords change monthly; for current password please see Ho Chang, Graduate Assisstant, Energy Programs Office, Room 207, Phone - 388-6094)

'EPWRIG.GEOWAT'.

```
logon epwrig
[illegible]004  ACF2, ENTER PASSWORD-
[illegible]
[illegible]G LOGON IN PROGRESS AT 12:32:01 ON NOVEMBER 18, 1981
 You may list  SYS3.MESSAGE  for information about Computer Science Coll
oquia.
ENTERING START CLIST AT 12:32:06
NAME= "WRIGHTON" WAS ASSIGNED
READY
```

2. How To Store Data Into GEOWAT Data Set

GEOWAT analysis data is stored in the data set 'EPWRIG.GEOWAT'. Each member of GEOWAT consists of the data collected from one location. Table 1 shows GEOWAT member and its associated location. The input format is as follows:

```
month 1-2 day 3-4 year 5-6 siteno 7 sitename $ 8-22 wellno 23-24
latitude 25-30 longtude 31-36 smpltype $ 37 fldirect $ 38-39
stafgaug precipt wtempt depth dschargr dschargd tempture ph
conduct turbity orcarbon hardness disoxy sodium potasium ammonia
magnesum sulfate cadium manganse calcium chloride barium lead
arsenic boron mercury chromium;
```

This sequence must be followed exactly, otherwise the correct value(s) will not appear in the assigned column. Table 2 shows the variable definitions. Each variable with column-restriction must be in the same position as the format specifies. For example: MONTH 1-2 DAY 3-4 YEAR 5-6, for 5-21-81. Coding can be entered as '5 2181' or '52181'. Start from column 1 for variables without column-restriction, this will allow the user much flexibility; only follow the sequence and use blank(s) to separate variables. Please follow these rules:

1. Zero before decimal point is omitted to save space.
2. Use '.' to code missing value and variables without exact value. For example: >0.5, >0.004.

Following is an example to input data:

```
READY
edit 'epwrig.geowat(glmcbrdg)' nonum da
DATA SET OR MEMBER NOT FOUND, ASSUMED TO BE NEW
INPUT
```

```
 5 8811gladys mccall   .              s . . . . .8 . . 27.5 6.5 135000 152 5.5 5720
 40 9100 184 1268 3190 . .46 370 16400 .1 . .043 2.98 .0009 .
 6 5811gladys mccall   .              s . . . . 1.4 . . 27 7.59 37000 172 44 4900 6
 8120 120 .21 1222 1660 . .22 13000 .3 . . 2.44 .0009 .03
 7 1811gladys mccall   .              s . . . . 1.2 . . 31 6.8 17700 164 34 3000 6
5120 152 . 616 340 . .98 340 . . .98 208 8700 .1 . .006 1.52 . .
 8 4811gladys mccall   .              s . . . . .5 . . 34 8.5 24000 1020 44 42000
4.2 5560 238 .1 648 2079 .034 .17 255 11200 .4 .2 .042 .57 . .
 9 2811gladys mccall   .              s . . . . .7 . . 29 7.91 19300 1040 20 31000
3.2 4360 140 .16 638 1300 . .13 212 8350 .1 .1 . .73 .0004 .
10 6811gladys mccall   .              s . . . . 7.4 . . 28 8.54 25700 50 15 3800
3.2 6600 239 .06 620 2020 . .09 225 11900 .4 . . 1.92 .0009 .
```

3. How To Access GEOWAT Member for Running SAS Programs

Store your most frequent use programs in GEOWAT(SAS1), GEOWAT(SAS2), and so on for later use. The following is an example of a SAS program to perform:

1. Print all input data.
2. Calculate the means of some variables.
3. Correlation analysis of some variables.
4. Plot.

```
DSNAME='EFWRIG.GEOWAT(SAS1)'
DATA;
INFILE MYDATA;
INPUT MONTH 1-2 DAY 3-4 YEAR 5-6 SITENO 7 SITENAME $ 8-22 WELLNO 23-24
      LATITUDE 25-30 LONGTUDE 31-36 SMPLTYPE $ 37 FLDIRECT $ 38-39
      STAFGAUG PRECIPT WTEMPT DEPTH DSCHARGR DSCHARGD TEMPTURE PH
      CONDUCT TURBITY ORCARBON HARDNESS DISOXY SODIUM POTASIUM AMMONIA
      MAGNESUM SULFATE CADIUM MANGANSE CALCIUM CHLORIDE BARIUM LEAD
      ARSENIC BORON MERCURY CHROMIUM;
PROC PRINT;
PROC MEANS;  VAR PH CONDUCT TURBITY SODIUM POTASIUM;
PROC CORR;  VAR CONDUCT TURBITY POTASIUM;
PROC PLOT;  PLOT POTASIUM * MONTH;
END OF DATA
```

The program is stored on GEOWAT(SAS1). Each time you run a program, you will need to allocate your data set to file (assign a file name). For example, GEOWAT(SAS1) is your SAS program and you want GEOWAT(BPP) as your input data. Give the following commands.

```
READY
alloc file(mydata) ds(geowat(bpp)) shr
READY
alloc file(mypgm) ds(geowat(sas1)) shr
READY
%sasdd
READY
%sas options(sysin=mypgm)
```

Note: File name 'mydata' must match the file name in INFILE statement.
File name 'mypgm' must match the file name in SYSIN= statement.

```
READY
alloc file(mydata) ds(geowat(bpp)) shr
READY
alloc file(mypgm) ds(geowat(sas1)) shr
READY
%sasdd
READY
%sas options(sysin=mypgm)
```

Note: File name 'mydata' must match the file name in SAS program INFILE statement.
File name 'mypgm' must match the file name in command %sas options(sysin=)

If you want GEOWAT(DOW130) as input data to run the same program, free file(mydata) first, then allocate it to GEOWAT(DOW130). The following is an example of these commands:

```
READY
free file(mydata)
READY
alloc file(mydata) ds(geowat(dow130)) shr
READY
%sasdd
READY
%sas options(sysin=mypgm)
```

By using FREE and ALLOCATE commands, you can use different data set as input data without changing the program.

To create a new file, use GEOWAT(DOW130) as input data to run the same program. Free file (mydata) first, then allocate it to GEOWAT(DOW130). The following is an example of these commands:

```
READY
free file(mydata)
READY
alloc fi(mydata) ds(geowat(dow130)) shr
READY
READY
%sasdd
READY
%sas options(sysin=mypgm)
```

Table 1. Members of GEOWAT and its associated site name and location name.

MEMBER	SITE	LOCATION
BPP	Parc Perdu	Bayou Parc Perdu
DI30	Parc Perdu	Dow's 130 foot well
LEBLANCC	Parc Perdu	Leblanch ditch near church
LEBLANCR	Parc Perdu	Leblanch ditch near Vermilion river
NEW180	Parc Perdu	New 180 foot well
SWEZY50	Parc Perdu	Mr. Sweezy's 50 foot well
SWEZY100	Parc Perdu	Mr. Sweezy's 100 foot well
GLMCBRDG	Glady's McCall	Bridge
GLMCHOG3	Glady's McCall	Hog Bayou #3
GLMCLAKE	Glady's McCall	Lake
GLMCWEL1	Glady's McCall	Well #1
GLMCWEL2	Glady's McCall	Well #2
SWLKBRDG	Sweet Lake	Bridge
SWLKSQRE	Sweet Lake	Square
SWLKSWLK	Sweet Lake	Sweet Lake
SWLKWEL1	Sweet Lake	Well #1
SWLKWEL2	Sweet Lake	Well #2
SWLKWEL3	Sweet Lake	Well #3

Table 2. Variable definitions.

VARIABLE	MEANING
MONTH	month
DAY	day
YEAR	year
SITENO	site number
SITENAME	site name
WELLNO	well number
LATITUDE	latitude
LONGTUDE	longtitude
SMPLTYPE	sample type
FLDIRECT	flow direction
STAFGAUG	staff gauge
PRECIPT	precipitant
WTEMP	weather temperature (^oC)
DEPTH	depth (ft.)
DSCHARGR	discharge rate (gal/min)
DSCHARGD	discahrge duration (min)
TEMPTURE	sample temperature (^oC)
PH	pH value
CONDUCT	specific conductance (umhos at 25^oC)
TURBITY	turbidity (N.T.U.)
ORCARBON	total organic carbon (mg/l)
HARDNESS	total hardness (mg/l)
DISOXY	dissolved oxygen (mg/l)
SODIUM	sodium (mg/l)
POTASIUM	potassium (mg/l)
AMMONIA	ammonium (mg/l)
MAGNESUM	magensium (mg/l)
SULFATE	sulfate (mg/l)
CADIUM	cadium (mg/l)
MANGANSE	manganese (mg/l)
CALCIUM	calcium (mg/l)
CHLORIDE	chloride (mg/l)
LEAD	lead (mg/l)
ARSENIC	arsenic (mg/l)
MERCURY	mercury (mg/l)
CHROMIUM	chromium (mg/l)
BARIUM	barium (mg/l)
BORON	boron (mg/l)

APPENDIX E

GEOWAT GRAPHICS AND PLOTS

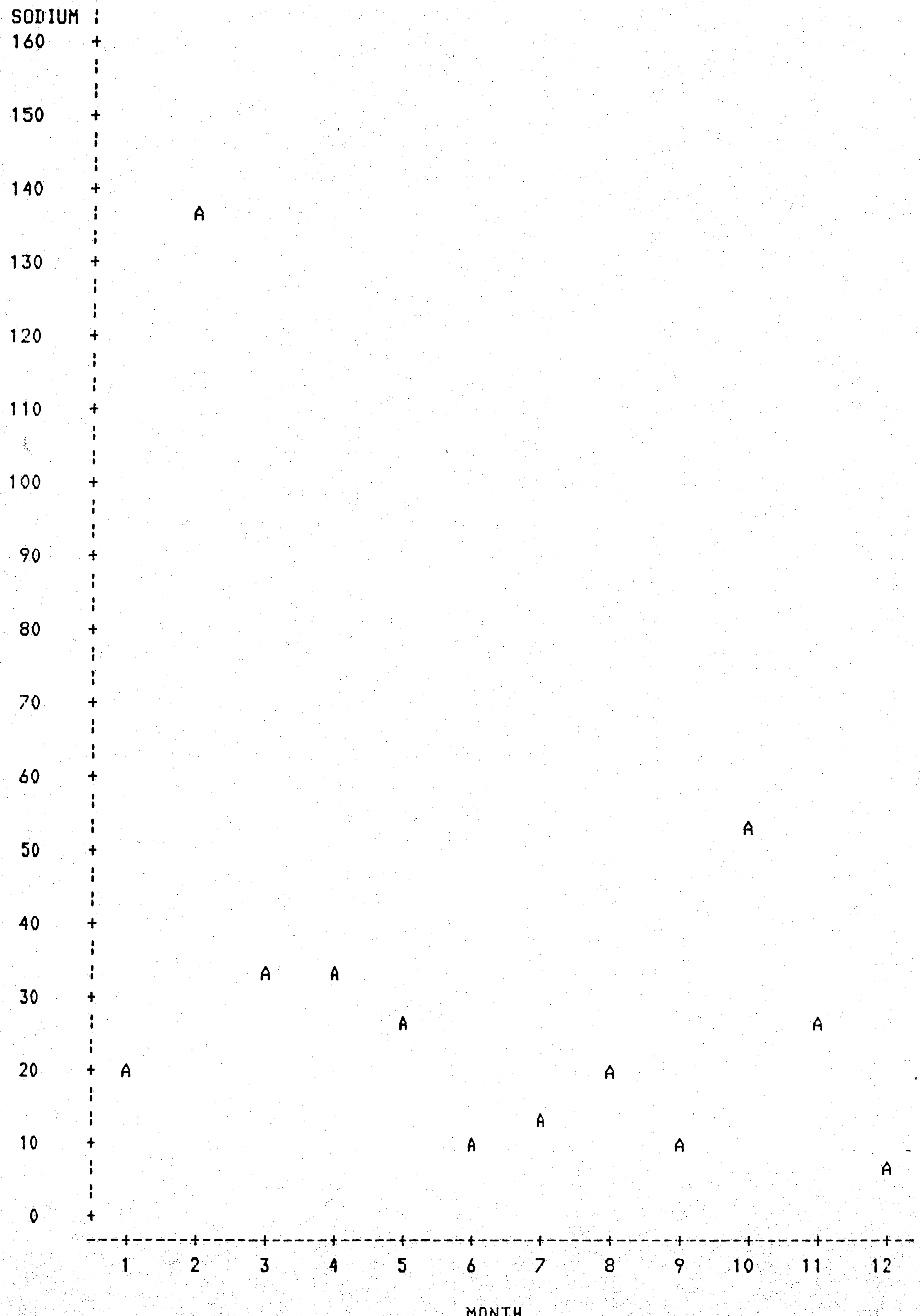
```
READY
%sasdd
READY
%sas options(sysin=pgm)
NOTE: SAS RELEASE 79.5 AT LOUISIANA STATE UNIVERSITY (00327).


NOTE: INFILE MYDATA(TEMP) IS:
      DSNAME=EPWRIG.GEOWAT(TEMP),
      UNIT=DISK,VOL=SER=USER04,DISP=SHR,
      DCB=(BLKSIZE=3600,LRECL=80,RECFM=FB)
NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
      REACHED PAST THE END OF A LINE.
NOTE: 24 LINES WERE READ FROM INFILE MYDATA(TEMP).
NOTE: DATA SET WORK.DATA1 HAS 12 OBSERVATIONS AND 38 VARIABLES. 54 OBS/TRK.
```

SITE: PARC PERDU FIELD
LOCATION: BAYOU PARC PERDU 1981, UNIT: MG/L

OBS	MONTH	SODIUM	CHLORIDE	SULFATE	BORON	HARDNESS
1	1	20.5	21.55	12.0	0.010	55.7
2	2	138.0	88.00	5.0	0.600	138.2
3	3	32.0	67.80	30.0	0.250	99.9
4	4	32.0	19.00	.	0.150	108.5
5	5	28.1	19.00	4.0	0.025	95.6
6	6	11.3	14.50	3.0	0.100	64.0
7	7	12.2	10.20	2.0	0.140	32.7
8	8	20.3	17.50	7.0	0.100	59.3
9	9	10.5	11.50	12.0	0.030	49.7
10	10	53.2	25.40	8.0	0.030	69.5
11	11	27.0	31.25	13.5	0.030	69.9
12	12	7.4	15.00	8.0	0.030	28.9

SITE: PARC PERDU FIELD
LOCATION: BAYOU PARC PERDU 1981, UNIT: MG/L

PLOT OF SODIUM*MONTH   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



ENVIRONMENTAL MONITORING

C. G. Groat, V. R. Van Sickle, D. Trahan, and L. T. Gorman

Introduction

Under a previous contract (DE-AS05-78ET27160), environmental monitoring programs were established at the Sweet Lake and Parcperdue geopressured-geothermal prospects. In addition to the continuation of monitoring at these two sites, the current contract authorized environmental monitoring for geopressured well testing in the Rockefeller Refuge prospect. The results of monitoring in the three prospects during calendar year 1981 are described in the following sections.

Rockefeller Refuge

The Rockefeller Refuge geothermal prospect area is in the chenier plain of southwest Louisiana, a physiographic region characterized by relict beach ridges and low-lying coastal marsh. The DOE Gladys McCall test well was drilled near the western border of Rockefeller Refuge in an area of impounded brackish marsh. The well is located in the East Crab Lake field approximately 2.3 miles south of Grand Chenier Ridge. Land use in the immediate vicinity of the test site is extractive; surface hydrology of the area has been modified by levees and canals excavated for oil and gas development.

During December 1980, Louisiana State University (LSU) investigators conducted several site visits and a low-altitude aerial survey to determine drainage patterns and land use/land cover within the prospect. A review of available published and unpublished data collected in the vicinity of the prospect was also conducted. Considering both site characteristics and the potential impacts of resources testing, an environmental monitoring plan was prepared for the Gladys McCall test well. In accordance with this plan, field stations were established to monitor 1) surface- and ground-water quality, 2) subsidence, 3) land loss and shoreline erosion, and 4) seismicity. Historical data were collected and interpreted to establish base-line conditions, wherever possible. The results of the first year of environmental monitoring studies in the Rockefeller Refuge prospect are provided below.

1. Water Quality Monitoring

a. Surface Water: The Gladys McCall test site is located in the coastal marshlands of southwestern Louisiana. The marsh surrounding the test site has very low relief, is at or near sea level, and is bounded to the north by Grand Chenier Ridge, to the south by a migrating beach, and to the east and west by roads and levees. The tide-dominated drainage is, therefore, restricted to breaches in the road and levee systems. In addition, the area immediately surrounding the test site is completely encircled by a large levee. Water flow is controlled through a culvert in the southeastern corner of the levee into Second Lake and subsequently into Hog Bayou, which travels southwesterly to a single outlet (Beach Prong) that empties into the Gulf of Mexico.

Three surface-water sampling stations were established for representative sampling of this system (Fig. 1). The first station is located 1000 ft north-northeast of the test site in a shallow pond within the large levee. A second station was placed outside of the southeastern corner of the levee near the drainage access point. These two stations were installed and initially sampled in May 1981. Sampling commenced in August 1981 at a third station installed in Hog Bayou approximately 1 mile southwest of the test site.

Monthly changes in the surface-water parameters reflect seasonal patterns and cannot, at this time, be attributed to test well operations (App. A, Sec. 1). The concentration of constituents vs. time profiles for the surface-water stations are parallel and indicate very little water-quality variability between stations.

Drilling fluids and/or local drainage from the test site were observed flowing through a break in the ring levee during June 1980. A mud pit sample was taken and analyzed in July 1980 to determine potential effects on ambient surface-water quality. In most cases, pollutant quantity in surface-water drainage from the site and in the mud pit sample was less than or equal to that in the natural environment. Therefore, no adverse effects on water quality have been attributed to the June discharge.

b. Ground Water: Wells located within a 10-mile radius of the test site are used mainly for oil and gas exploration/production and observation. Only a few are used for domestic and industrial water supply; these are shallow (200 to 1200 ft deep) and produce from depths of 200 to 600 ft. Oil and gas wells, on the other hand, are from 10,000 to 17,000 ft deep.

A typical electric log (Fig. 2) illustrates the following vertical stratigraphic sequence:

ft (msl*)	lithology
-200	fresh water sand down
	to -340 ft msl,
-400	shale to -420 ft msl,
	sand, fresh at top,
-600	grading to saline near
	-800 ft msl,
-800	shale from -800 ft to
-1000	-1150 ft msl,
-1200	salt-water sand to -1240 ft
	msl, then salt-water sand with
-1400	small shale stringers to -1600
	ft msl, another shale to -1670
-1600	ft msl, a salt-water sand to
-1800	-1900 ft msl, on top of lower-
-2000	most shale.

*msl: mean sea level

The stratigraphy of the area is represented by a cross section (Fig. 3) which transects the test site from northeast to southwest. In general, the upper 2000 ft of section in the area contains three to four main clay units separated by three to four main bodies of sand. Data are lacking for the upper 200 ft of the section. The uppermost sand averages approximately 150 ft in thickness. The base of the sand is between -100 and -400 ft msl. Below the upper sand is a shale 100 to 300 ft thick which contains a few thin (less than 100 ft thick) fresh-water sand lenses. The base of clay occurs at relatively consistent depths between -500 and -600 ft msl. The sand below this clay has an average thickness of 400 ft, with no observable clay lenses or tongues, and contains the lower limit of fresh water in the area. The next clay in the sequence is approximately 200 ft thick. A moderately thick sand (200 ft thick on the average) separates the second clay from the third clay, which is the lowermost unit of interest in this study.

The freshness of the water in the upper sand and in the sand lens in the upper shale can be confirmed with an analysis of water quality (Table 1). Water sampled from wells Cn-127 and Cn-126 (which produce from these sands, respectively) has a low concentration of chloride and total dissolved solids. These factors are much higher in all the other wells which produce from the lower sands.

The above information was used to install two ground-water quality observation wells in May 1981. The first well, located within 200 feet north-northwest of the Gladys McCall test well, was drilled to a depth of 660 ft. An electric log of this well revealed the following lithologies:

Table 1. Water-quality data for selected observation wells in the Rockefeller Refuge prospect.

Well No.	Depth	Date	Water Level	SC	pH	$CaCO_3$	TDS	SiO_2	HCO_3	SO_4	NO_3	PO_4	CO_3	CO_2	Fe	Ca	Mg	Na	K	Cl	F	Mn	B	Br
Cn-20	--	6-09-49	----	2280	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	432	--	--	--	--
Cn-41	460	2-02-55	----	2270	7.5	193	1230	30	416	2.1	0.2	0.19	0	--	0.04	48	19	408	4.5	547	0.1	0.01	0.05	--
Cn-42	460	2-02-55	----	1840	7.4	181	1000	28	360	0.5	4.5	0.36	0	--	0.01	44	17	317	3.6	416	0.1	0.02	0.11	--
Cn-111	590	11-13-75	----	6770	7.6	410	3950	23	288	4.8	0.08	--	0	--	0.87	90	45	1400	8.0	2100	0.2	0.16	--	--
Cn-118	637	9-07-74	----	2800	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	920	--	--	--	--
Cn-126	336	12-03-75	23.24 GL	1120	7.9	80	656	17	412	0	0.42	--	0	--	0.14	18	8.5	240	2.9	170	0.2	0.04	--	--
Cn-127	204	12-03-75	----	1020	7.1	85	601	24	377	22.0	0.43	--	0	--	0.19	18	9.7	210	4.2	160	0.2	0.06	--	--

feet	lithology
0 - 20	black clay
20 - 43	yellow-white clay
43 - 95	gray clay
95 - 290	fine to coarse, glauconitic sand with pea gravels
295 - 625	gray clay
625 - 680	sand

The first observation well was screened in the lowermost sand at 670 ft. A second observation well, located 2000 ft north-northwest of the test site, was drilled to and screened at a depth of 310 ft in the uppermost sand of the section. Sampling began at both wells in June 1981. A total of 22 parameters was analyzed in the laboratory. The results of ground-water quality analyses for a selected group of parameters through December 1981 are presented in Appendix A, Section 2. No changes can be attributed to test well operations thus far, although some seasonal changes were obvious. The quantity vs. time profiles for sodium, magnesium, chloride, specific conductance, hardness, temperature, and sulfates illustrate the relative depths of the observation wells. Values for these parameters are higher and more variable in the deeper well.

2. Subsidence Monitoring

In order to assess the subsidence impacts of resource testing, a field monitoring program was designed to 1) determine base-line subsidence rates in the prospect prior to well testing and 2) to monitor changes in land-surface elevation during and after the test period.

Base-line subsidence, or subsidence existing in the prospect area prior to flow testing, was determined by comparing successive years of elevation surveys in the region of the designed well. In addition, a network of new benchmarks was installed in the immediate vicinity of the test well. This network was designed to intersect each of the faults which define the geothermal reservoir and was connected to a vertical control line established in 1965 by the National Geodetic Survey (NGS). This historical line extends from west to east along state Highway 82, subparallel to the coastline (Fig. 5a).

During the fall of 1980, LSU subcontractors surveyed both the historical NGS line and the new benchmarks in the immediate vicinity of the test well. In order to determine trends, the 1980 survey data was compared with the 1965 data, which was used as a base line. Two spatial reference marks were selected for reference. When the westernmost benchmark (P 213) was used for reference, the survey profile indicated slight uplift in the eastern portion of the prospect (Fig. 5b). When the easternmost benchmark (Y 213 - not shown) was used, the profile indicated subsidence along the entire length of the line (Fig. 5b). For this reason, no conclusion regarding historical subsidence will be drawn until the line is resurveyed during February 1982 by the National Geodetic Survey.

To assist in interpreting subsidence data, a study of growth faults and surface lineations within the prospect was conducted. Growth faults are a major structural element of the Gulf Coast geosyncline and provide the mechanism by which fluids in the geo-pressured zones are trapped. These faults are usually quite steep at shallow depths and become more horizontal with increases in fluid pressure. Growth faults that define the geopresured-geothermal reservoir were extrapolated to the land surface using the Law of Tangents and a range of faults angles between 45° and 60° (Fig. 6).

Fault planes that intersect the land surface are likely to produce fault traces or lineations. Lineations were mapped from high altitude (1:65,000) NASA U-2 photography and available 1:24,000 black-and-white prints. Dates of the black-and-white and U-2 photography were 1955 and 1978, respectively. Lineations were visible due to tonal variations, usually a result of soil moisture differences and geomorphic irregularities, such as angular drainage diversions and landform boundaries. Care was taken not to confuse possible fault traces with man-made features, such as canals and political boundaries. Soil boundaries were also delineated.

On the NASA imagery, abandoned beach ridges, or cheniers, were evident due to tonal variations, vegetation differences, and drainage anomalies. These cheniers are indicated on the map (Fig. 6) as soil boundaries. There are no cheniers which could be confused with fault trace lineations south of Highway 82.

Two lineations in Figure 6 are parallel with extrapolated fault zones A' and B'. Lineations which are subparallel to the fault zones may be surface expressions of shallower faults. Other lineations strike parallel and subparallel to the existing shoreline and cheniers, thus probably depositional or erosional in origin.

3. Land Loss and Shoreline Erosion

Several recent studies have documented dramatic rates of shoreline erosion and land loss in coastal Louisiana. One study published in 1981 by the U.S. Fish and Wildlife Service estimates that 39.4 mi^2 miles of Louisiana's coastal wetlands are converted to open water each year. Minute changes in the elevation of near-sea-level marsh environments can result in land loss. In order to determine the rates of land loss and shoreline retreat within the two coastal prospects prior to well testing, an analysis of historical changes in land/water interface was performed.

A study of land loss during 1955 to 1978 was completed for the Rockefeller Refuge prospect. Land and water features were mapped within an area south of Grand Chenier Ridge and between Price Lake road on the east and Club Canal on the west (Fig. 1). Brackish marshes occur in the northern portion of the study area and are dominated by Spartina patens (wire grass) and Distichlis spicata (salt grass). More saline environments dominate the southern half of the study area. Saline marshes within the region have a greater vegetation diversity and include the following forms:

SCIENTIFIC NAME	COMMON NAME
Spartina alterniflora	oyster grass
Batis maritima	saltwort
Spartina patens	wire grass
Scirpus robustus	saltmarsh bulrush
Borrchia frutescens	sea ox-eye

Major land features such as roads, canals, open water, and impounded marsh were delineated from 1955 (Fig. 7) and 1978 (Fig. 8) aerial photographs. Calculations for area were then computed with an electronic digital planimeter. Changes in land/water ratio were determined for the total study area, the shoreline zone, and the inland marsh. Total lengths of canals and roads during 1955 and 1978 were also calculated. Linear shoreline erosion was then determined at several points along the 7-mile coastline.

The study revealed a significant amount of marshland loss--1240 acres over the 23-year period (Table 2). The immediate coastline below the test site receded at an average rate of 47.5 ft per year between 1955 and 1978, accounting for a total loss of 872 acres (Table 3). Since the early 1950's, a large amount of marshland has reverted to open water due to expanding oil and gas development in the immediate area. Roads and canals increased 52% and 35%, respectively, over the 23-year period. Within the impounded area, water is constantly being trapped, increasing open water by 72%. Standing water and storm surges within the impounded marsh caused the disappearance of some halophyte vegetation. Coincidental with land loss, vegetation patterns have been altered within the study area.

4. Microseismic Monitoring

On April 1, 1981, a subcontract was awarded to Woodward-Clyde Consultants to perform microseismic monitoring in the Rockefeller Refuge prospect. This contract provides for the installation and operation of an eight-station array of continuous recording seismometers. During May and June 1981, the design and installation of six of the eight monitoring stations were completed. These seismometers are located within a 5-km radius of the Gladys McCall test site, as shown in Figure 1. Station coordinates, seismometer depths, and installation dates are presented in Table 4.

The field stations consist of a seismometer and a standard amplifier/voltage-controlled oscillator unit and power supply. The signal is transmitted by high-frequency radio telemetry to the equipment shed at the Gladys McCall well entrance. The sensors are Mark Products L28LV 4.5 Hz seismometers that were placed in boreholes at depths ranging from 35 to 50 ft below ground surface.

Table 2. Land-loss results - Rockefeller Refuge

	1955-1978	Net Change (%)
Total land loss	1240 acres	9% - loss
Shoreline Area	872 acres	5% - loss
Roads	17 mi	52% - gain
Canals	17 mi	35% - gain

Table 3. Linear shoreline erosion

Location	Shoreline Retreat (ft/23 yrs)	Shoreline Retreat (average ft/ yr)
Club Canal	1060	46
East boundary line of study area	1122	49

Table 4. Description of the Rockefeller Refuge microseismic monitoring array.

Station Code	Station Name	North Latitude	West Longitude	Seismometer Depth (ft)	Data Seims. Installed	Date on Line to B.R. Office	Date First Recorded on Mag. Tape
BCH 680 Hz	Beach	29°40'38"	92°53'19"	35	6/24/81	7/9/81	7/20/81
LEV 1020 Hz	Levee	29°42'43"	92°52'54"	50	6/25/81	7/9/81	7/20/81
SHR 1360 Hz	Sohio Rd.	29°42'25"	92°50'31"	50	6/25/81	7/9/81	7/20/81
PLR 1700 Hz	Price Lake Rd.	29°41'14"	92°50'00"	50	6/25/81	7/9/81	8/22/81
ALP 2040 Hz	Alligator Ponds	29°43'13"	92°48'32"	50	6/26/81	7/9/81	7/20/81
GCS 2380 Hz	Grand Chenier School Property	29°44'05.3" (Tentative)	92°53'54" Not yet installed				
--- 2720 Hz		Not yet installed					
HQS 3060 Hz	Equipment Shed	29°44'31"	92°52'27"	35	6/23/81	7/9/81	7/20/81

Note: Problems with telephone telemetry to Baton Rouge office prevented recording station signals until 20 July 1981.

Stations PLR and HQS had noise interference until maintenance field trip on 21 August 1981 revealed defective batteries, which were replaced. PLR first recorded beginning 8/22/81.

The standard seismic electronics packages which are manufactured by Sprengnether, Inc., consist of an amplifier and voltage-controlled oscillator (VOC) that provides continuous data transmission via radio. The radio transmitters are Monitron 100 mW transmitters coupled to Scala Yaga transmit-and-receive antennas. Each field station is transmitted on a different carrier frequency to the equipment shed, near the testing manager's trailer, where the signals are multiplexed and transmitted to the central recording facilities on standard, voice-grade telephone lines. The VCO frequencies used for data transmission are 680 Hz, 1360 Hz, 1700 Hz, 2040 Hz, 2380 Hz, 2720 Hz, and 3060 Hz. Field telemetry packages are powered by 12-volt DC air-cell batteries.

The central recording facilities include the following: one recording and one playback 1/2-in magnetic tape recorders (Honeywell 101) that record 24 hours of incoming data on a single tape pass; signal discriminators for each telemetered data frequency (from the multiplexed incoming signal); three dual-pen drum recorders (Sprengnether VR-60) that provide visible monitoring of selected incoming data (station) signals; and oscillograph playback facilities for hard-copy recovery of all data recorded on magnetic tape.

Appurtenant facilities include a time-code generator and time code reader for recording and playing back of station data on a common time base. Recorded time is the basis for analysis of seismic data and hypocentral (location and depth) determination of all events.

Incoming data is recorded on magnetic tape in multiplexed format and simultaneously sent through signal discriminators and recorded on visible drum recorders. Seismic data can be played back when the multiplex signal from magnetic tape is fed through discriminators onto a multichannel oscillograph (paper) recorder. Recorded time-code is then simultaneously played back off the magnetic tape and is the basis for scaling the arrival of various incoming seismic waves.

Recording of base-line data began in late May 1981. Data was collected using a portable micro-earthquake monitoring device (Sprengnether, Inc., MEQ-800). Data recovery was intermittent and of poor quality due to the high background noise level found at the surface in the Refuge area. Several sites were selected for monitoring with the portable unit, but no satisfactory site could be found that was quite enough to observe anomalous ground motion caused by natural or man-made events. The portable seismometers were placed in hand-augered boreholes at a depth between one and two feet. Analysis of the data collected with the portable instrument indicated a high surface-noise level over a wide area surrounding the well site. No features other than the high noise level were detected during this early period of data collection.

Review of data collected since the installation of the permanent network indicates that the noise level has been significantly reduced by placing the seismometers in deeper boreholes. Background noise at the borehole stations is low, comparable to that of the Sweet Lake seismic monitoring network; however, a variety of seismic signals has been detected from nearby cultural activities and geophysical operations.

All signals received during the period through August 31, 1981, have been classified as man-induced events. Many of the geophysical blasts detected during this time period at the Refuge network have also been recorded at the Sweet Lake network.

During September 1981, one local natural event was recorded. This event occurred on September 14 at 14.23 UTC (Universal Time Coordinated), 9:23 local time, and was recorded by all the seismometers in the network. The event was also detected at the Sweet Lake network. Assuming a P-wave to S-wave velocity ratio of 1.66 for the Rockefeller Refuge area, the location of the September 14 event is lat 29°42'14" N and long 92°49'33" W along Wildlife and Fisheries Union Canal at an unconstrained depth of 6.56 km (Fig. 9). The given depth of 6.56 km (21,500 ft) is an approximation because focal depth is the least accurate earthquake parameter. Richter magnitude of this event was approximated at 1.5 or less, a calculation based on the duration of the event at each station.

Seven events were recorded during October and probably have a local natural origin. These seven events, as listed in the October event log, occurred offshore in the Gulf of Mexico approximately 0.25 miles north and 3 miles southeast of the beach station (Fig. 10). Magnitudes of about 1.5 were calculated based on the duration of the seismic wave at each station. The most likely explanation of the occurrence of the September and October events is slippage along the subsurface fault system.

Four series of events, which were recorded November 13, 14, 15, and 18, have been tentatively classified as man-induced due to their frequency of occurrence and time of day. These events occurred two to three minutes apart during daylight hours, similar to previously recorded geophysical blasting associated with oil exploration on land. The shape of the signals differ from those of the earlier blasts in that the arrival times at each station are more erratic. All four events were detected at the beach station (BCH). The computed location of these seismic events indicates that the signals are associated with nearby offshore geophysical exploration.

Parcperdue

During October 1979, LSU began designing an environmental monitoring program at the Dow Chemical test site in the north Parcperdue oil and gas field. Base-line studies of air quality, water quality, subsidence, and microseismicity were established during the first two quarters of 1980 and continued through calendar year 1980. These studies were described in detail in the final report which was prepared for the previous Technical Support contract (DE-AS05-78ET27160). Rather than repeat all of the details of these programs, a summary of work performed during January-December 1981 is presented below:

1. Air Quality

An ambient air quality and meteorological monitoring station was operated by KEMRON Environmental Services, under subcontract to LSU, during January-October 1981. The station was located approximately 1600 ft northwest of the production well (Fig. 11) and provided continuous records of hydrogen sulfide, sulfur dioxide, and non-methane and total hydrocarbons. Meteorological data from continuous recorders included wind speed, wind direction, temperature, and precipitation.

Sulfur dioxide (SO_2) and non-methane hydrocarbons were the only pollutants monitored for which National Ambient Air Quality Standards (NAAQS) have been established by EPA. The following are standards for integrated values of sulfur dioxide and non-methane hydrocarbon concentrations in ambient air:

<u>Sulfur Dioxide</u>

Primary:	Annual arithmetic mean	80 $\mu g/m^3$
	Max. 24-hr concentration	365 $\mu g/m^3$
Secondary:	Max. 24-hr concentration	260 $\mu g/m^3$

Non-Methane Hydrocarbons

Primary:	Max. 3-hr concentration (6 a.m. - 9 p.m.)	160 $\mu g/m^3$
Secondary:	Same as primary	

μg = microgram

Neither primary nor secondary NAAQS for sulfur dioxide were exceeded during the ten-month period. The highest 24-hour average concentration was 17 $\mu g/m^3$ reported on March 3 and March 7, 1981. The wind direction was generally 330°-80° (north to northeast) during periods that sulfur dioxide was reported. The Baton Rouge metropolitan area is located approximately 55 miles northeast (62°) of the site; New Orleans is located 110 miles almost due east (90°) of the site. There was no apparent trend in the time of day that sulfur dioxide was recorded during the ten-month period.

Standards for non-methane hydrocarbons were exceeded on an average of 11 days each month at the Parcperdue site. The highest concentration of non-methane hydrocarbons reported during the NAAQS period (6:00 am to 9:00 pm) was 3339 $\mu g/m^3$ on October 4, 1981. It should be noted here that hydrocarbons, at levels reported at the Parcperdue site, may have no direct effect on human health. Standards have been established for these compounds because they contribute to the formation of ozone by reacting with nitrogen oxides in sunlight. In Louisiana, 19 parishes have been designated by EPA as "non-attainment" regions for ozone.

Total hydrocarbons were recorded each day at the site and averaged between 42 and 698 $\mu g/m^3$ over a 24-hour period. The time of day when both methane and non-methane hydrocarbons were reported was basically the same each day, from 5:00 pm to 8:00 am, including weekends. The wind direction from which hydrocarbons came varied; however, most methane and non-methane hydrocarbons were reported when wind speeds were very low, between 0 and 1 mph.

Hydrogen sulfide (H_2S) was reported daily in minor concentrations at the Parcperdue site during January-October 1981. The average 24-hour concentration was between 5 and 23 ug/m^3 each month. There were no apparent relationships between hydrogen sulfide concentrations and wind direction or time of day.

2. Water Quality Monitoring

a. Surface Water: Sampling continued at all original surface-water sampling stations (Fig. 11) throughout calendar year 1981. Sampling was impossible for two of the stations during "dry" months. Leblanc ditch near the church was dry in April and July. Likewise, Leblanc ditch near Vermilion River was dry in July and also in November. In the latter instance, the only noticeable effluent was a small puddle of oil, presumably from nearby drilling activities.

Selected graphs of monthly surface-water quality observations are listed in Appendix B, Section 1. Monthly changes between stations are predominantly parallel and seasonal. Values for sodium, chloride, conductivity, and hardness are higher during spring and early winter. As would be expected, temperature is lowest during early spring and midwinter. The range between seasonal lows and highs is 30°C. Values for magnesium and boron are highest during the early part of the year and lowest during late winter. Turbidity was fairly constant throughout the year, with the exception of anomalously high values which occurred in Bayou Parcperdue during the early spring. Values for sodium, magnesium, chloride, conductivity, boron, sulfate, and pH were also exceptionally high during this period in Bayou Parcperdue. The high turbidity may have led to increased suspension of particulates and an increase in solutes. Values for pH fluctuate more than those for other parameters throughout the year. In general, pH was highest during the early part of the year and gradually tapered down to a low in early winter.

b. Ground Water: Sampling which had originated at the land-owner's 100-ft domestic well in 1980 was discontinued in January 1981 and replaced by Dow Chemical's drilling supply well. This well is located approximately 100 ft northwest of the test site and produces from a depth of 130 ft (#3 in Fig. 11). Sampling continued at this well until July 1981 when it was capped due to completion of the geopressured well. It was replaced in the sampling program in December 1981 by a 90-ft well that supplies potable water to on-site facilities. The 90-ft well is located about 500 ft northwest of the test site (#2 in Fig. 11). Sampling continued at the LSU observation well (180 ft) until September 1981 when sand accumulation in the bottom of the well delayed further sampling. The well was not cleaned out until December 1981, at which time sampling resumed.

Monthly observations of selected ground-water quality parameters for calendar year 1981 are listed in Appendix B, Section 2. Values for sodium and chloride were higher in the shallower (130 ft) well, but values for magnesium, conductivity, hardness, and pH are consistently lower in the shallow well. Seasonal extremes coincide more between wells for temperature, turbidity, and boron content while those for pH are opposite. The variation between wells could be due to the influence of recharge and dilution from nearby Vermilion River. Chloride was at its highest value during late spring in both ground-water observation wells. Plots for temperature, turbidity, and boron content are essentially the same for both wells.

3. Subsidence Monitoring

Subcontractors were sent to the site during August 1981 to relevel the benchmarks surrounding the test site (Fig. 11). The subcontractors successfully releveled all designated marks except one (LSU-P2) which had been covered over with cement. The benchmark was subsequently cleaned. The leveling crew re-entered the site and completed the job in December 1981. Tables 5 and 6 provide a comparison of 1981 work and the 1980 leveling data. Up to 4 mm of movement occurred at the site in the year's time since November 1980. The benchmark indicating the greatest downward movement is that which is located nearest the test well (P2).

4. Microseismic Monitoring

During October 1981, a technical paper was presented at the Fifth U.S. Gulf Coast Conference on geopressured-geothermal energy describing the results of subsidence and microseismic monitoring at the Parcperdue test site. The paper was entitled "Subsidence and Induced Faulting: Key Environmental Issues in Geopressured-Geothermal Resources Development" and was published in the Proceedings of the Fifth Conference, pages 325-330.

This paper should be consulted for a detailed description of the microseismic monitoring network and the results of studies conducted during calendar year 1981.

Sweet Lake

Environmental monitoring studies at the Magma Gulf/Technadril site near Sweet Lake began during the spring and summer of 1980. An environmental monitoring plan and a detailed description of work performed at the Sweet

Table 5. Comparison of 1981 with 1980 leveling: Parcperdue geopressured-geothermal test site. Data listed "as received."

MARK	11-80	8-81	12-81
LSUP11	6.436	6.436	
28V25	6.804	6.802	
LSUP6	7.093	7.092	
LSUP5	6.125	6.124	
LSUP12	6.989	6.987	
LSUP1	5.679	5.677	5.677
LSUP2	6.400		6.397
LSUP3	5.730	5.727	5.729
LSUP4	6.341	6.339	6.342

Table 6. Comparison of 1981 with 1980 leveling: Parcperdue geopressured-geothermal test site. Data is normalized to benchmark LSUP4;11-80.

MARK	11-80	CHANGE	8-81	CHANGE	12-81
LSUP11	6.436	+.002	6.438		
28V25	6.804	-0-	6.804		
LSUP6	7.093	+.001	7.094		
LSUP5	6.125	+.001	6.126		
LSUP12	6.989	-0-	6.989		
LSUP1	5.679	-0-	5.679	-.003	5.676
LSUP2	6.400	________	-.004	________	6.396
LSUP3	5.730	-.001	5.729	-.001	5.728
LSUP4	6.341	-0-	6.341	-0-	6.341

Lake site during calendar year 1980 were provided in the final report, which was prepared for the previous Technadril Support contract (DE-AS05-78ET27160). Rather than repeat the details of the field monitoring program, a summary of work performed during January-December 1981 is presented in the following sections.

1. Air Quality

An ambient air quality and meteorological monitoring station was operated by Core Labs, under subcontract to LSU, during January-December 1981. The station is located approximately 1 mile northwest of the production well site (Fig. 12). The station provides continuous records of hydrogen sulfide, sulfur dioxide, non-methane hydrocarbons, and total hydrocarbons in accordance with U.S. Environmental Protection Agency guidelines. Meteorological data collected at this site include wind speed, wind direction, temperature, and precipitation.

Sulfur dioxide and non-methane hydrocarbons were the only pollutants monitored for which National Ambient Air Quality Standards (NAAQS) have been established (See Parcperdue - Air Quality). Neither primary nor secondary NAAQS for sulfur dioxide were exceeded during the 12-month period. The highest 24-hour average concentration was 23 $\mu g/m^3$ reported on March 12, 1981. The wind direction was frequently from 270°-300° (west to northwest) during periods that sulfur dioxide was reported. Lake Charles, the nearest metropolitan area, is located 12 miles north-northwest (337°) of the site. Sulfur, a smaller industrial center, is located 18 miles northwest (315°) of the site.

Standards for non-methane hydrocarbons were exceeded on an average of 23 days each month of the Sweet Lake site. The highest concentration of non-methane hydrocarbons during the time of day when the standards are effective (6:00 am to 9:00 pm) was 10,933 $\mu g/m^3$ on February 3, 1981. Highest levels of non-methane hydrocarbons were reported when wind directions were easterly. However, standards violations were also recorded during calm periods. A similar trend was observed for total hydrocarbons. For example, the average 24-hour concentration of total hydrocarbons during calm periods during the month of October was 926 $\mu g/m^3$. The time of day when both methane and non-methane hydrocarbons were reported was during the evening and early morning hours (5:00 p.m. to 8:00 a.m.).

Hydrogen sulfide was reported in trace amounts (1-6 $\mu g/m^3$) during March, April, May, June, November, and December. The average concentration was less than 1 $\mu g/m^3$ during calendar year 1981. There was no relationship between hydrogen sulfide occurrence and wind direction, wind speed, or time of day.

2. Water Quality Monitoring

a. Surface Water: Sampling continued at the original surface- water sampling stations (Fig. 12) during calendar year 1981. At the time of this report, data for December 1981 had not been received.

Seasonal highs occurred during mid-spring and mid-winter for sodium, magnesium chloride, conductivity, and hardness (App. C, Sec. 1). For most sampling periods, values for samples taken at the bridge were consistently lower than those taken near the lakes. Values for turbidity were highest during the late winter, but were much lower during mid-summer, probably due to an increase in runoff. Values for boron and sulfate were highest during late winter and mid-spring, declining gradually during the year to a low in early winter. Again, there is a marked difference between values obtained at the bridge compared with those obtained from the lakes. Values for lead were below detection limits for most of the year in the lakes. High values for lead content were reported during February, July, and September at the bridge and during September at Sweet Lake. Highest mercury values also occurred during February, July, and September. Values for pH are lowest during spring and summer and highest during early winter.

b. Ground Water: Sampling continued through calendar year 1981 at the three original ground-water observation wells (Fig. 12).

Unlike the graphs of surface-water quality, the graphs of ground-water quality indicate that seasonal trends for each parameter are consistently parallel (App. C, Sec. 2). Sodium content was highest during spring, with a low during early fall. Magnesium was high in January and May, but was very low during all other months. Chloride was fairly constant in the shallower wells (#1 and #2, 280 ft), but fluctuated more in the deeper well (#3, 435 ft). Graphs for conductivity roughly parallel those for sodium, with highs during spring, early summer, and winter and a low during September. Values for water hardness declined from a high in January to a low in April, but were fairly constant during the latter half of the year. Ground-water temperature fluctuated more than surface-water temperature, although the range was small. Temperatures in the deeper well (#3) were lower during some months. Turbidity was almost non-existent for most of the year, but was reported during a few fall and winter months. Boron values were highest during mid to late winter and early summer. Graphs for lead and mercury are roughly parallel with highs during mid-spring, mid-summer, and early fall. Sulfate values were higher during April and for deeper wells. Values for pH were lowest during late winter and rose gradually to a high in late summer.

The Sweet Lake test site began flowing geopressured brines during June and July 1981. Thus far, the water-quality data indicates no contamination from the geothermal well.

3. Subsidence Monitoring

No additional leveling was performed using the original subsidence monitoring network installed in September 1980 and initially surveyed in December 1980. One benchmark, LSU-S1, was damaged during the installation of geopressured-geothermal surface testing equipment. This benchmark was replaced in December 1981 by the National Geodetic Survey. New benchmarks were also established in conjunction with tilt-meter surveys by Woodward-Clyde Consultants of Baton Rouge. These benchmarks were installed in early March 1981 and were surveyed monthly beginning in April 1981 (Table 7). The ten benchmarks were located northwest and west of the test site along Highway 384 and Precht Road, respectively, and are spaced about 150 m apart. Total movement of these benchmarks is primarily downward, although three have shown some upward movement. Vertical movement ranges from a maximum upward component of 0.9 to a maximum downward component of 2 mm.

Table 7. Leveling data corresponding to those benchmarks installed by tilt-meter contractors.

	LSU-S3	WC-1	WC-2	WC-3	WC-4	WC-5
December 1980	2.98597					
April 1981	2.98597	3.00502	3.28330	3.35558	3.78551	4.20729
May	2.98597	3.00492	3.28230	3.35238	3.78288	4.20463
June	2.98597	3.00515	3.28281	3.35379	3.78505	4.20686
July	2.98597	3.00517	3.28252	3.35312	3.78567	4.20772
August	2.98597	3.00552	3.28315	3.35410	3.78623	4.20783
September	2.98597	3.00537	3.28287	3.35287	3.78602	4.20682
October	2.98597	3.00542	3.28262	3.35335	3.78568	4.20758
November	2.98597	3.00520	3.28275	3.35352	3.78644	4.20759
Total change	0.0000	+.00018	-.00055	-.00206	+.00093	+.00030

	LSU-S4	WC-6	WC-7	WC-8	WC-9	LSU-S5
December 1980	2.50475					2.67070
April 1981	2.50431	3.29861	3.09781	2.55956	3.12749	2.67076
May	2.50123	3.29708	3.09648	2.55738	3.12503	2.66768
June	2.50293	3.29807	3.09725	2.55804	3.12609	2.66919
July	2.50302	3.29842	3.09747	2.55767	3.12552	2.66892
August	2.50318	3.29820	3.09725	2.55755	3.12632	2.66940
September	2.50167	3.29752	3.09657	2.55597	3.12432	2.66707
October	2.50323	3.29833	3.09688	2.55738	3.12638	2.66988
November	2.50319	3.29844	3.09719	2.55794	3.12639	2.66994
Total change	-.00156	-.00017	-.00062	-.00162	-.00110	-.00076

4. Microseismic Monitoring

A microseismic monitoring array at the Sweet Lake test site has been operative since August 1980. The array consists of eight permanent field stations at locations shown in Figure 12.

A review of base-line data recorded during the second year of network operation revealed a variety of seismic noise sources ranging from routine cultural noise to nearby geophysical survey activities. Occasional large, distant earthquakes, or teleseisms, have been recorded from Alaska, Mexico, and Italy.

A regional event occurred on the night of February 12, 1981. The location of this event was placed off the coast in the Gulf of Mexico near the Texas-Louisiana border. This event is probably not a true earthquake; however, since the arrival times were not sharp but appeared as slow, harmonic surface waves, the computer program placed the origin at the surface in the Gulf of Mexico. Therefore, this event may have been produced by some large aerial phenomena.

Several events which were detected in June 1981 appear to be possible local earthquakes. Since these events occurred several miles beyond the network aperture and the velocity model used to locate events is only an approximation of P-wave velocity for the Sweet Lake area, the locations of these events were given low confidence. During the second half of the year, July through December, the Sweet Lake seismic network recorded geophysical blasts and several possible regional earthquakes. No naturally occurring or artificially induced local microseismic events were recorded at the Sweet Lake site during January-December 1981.

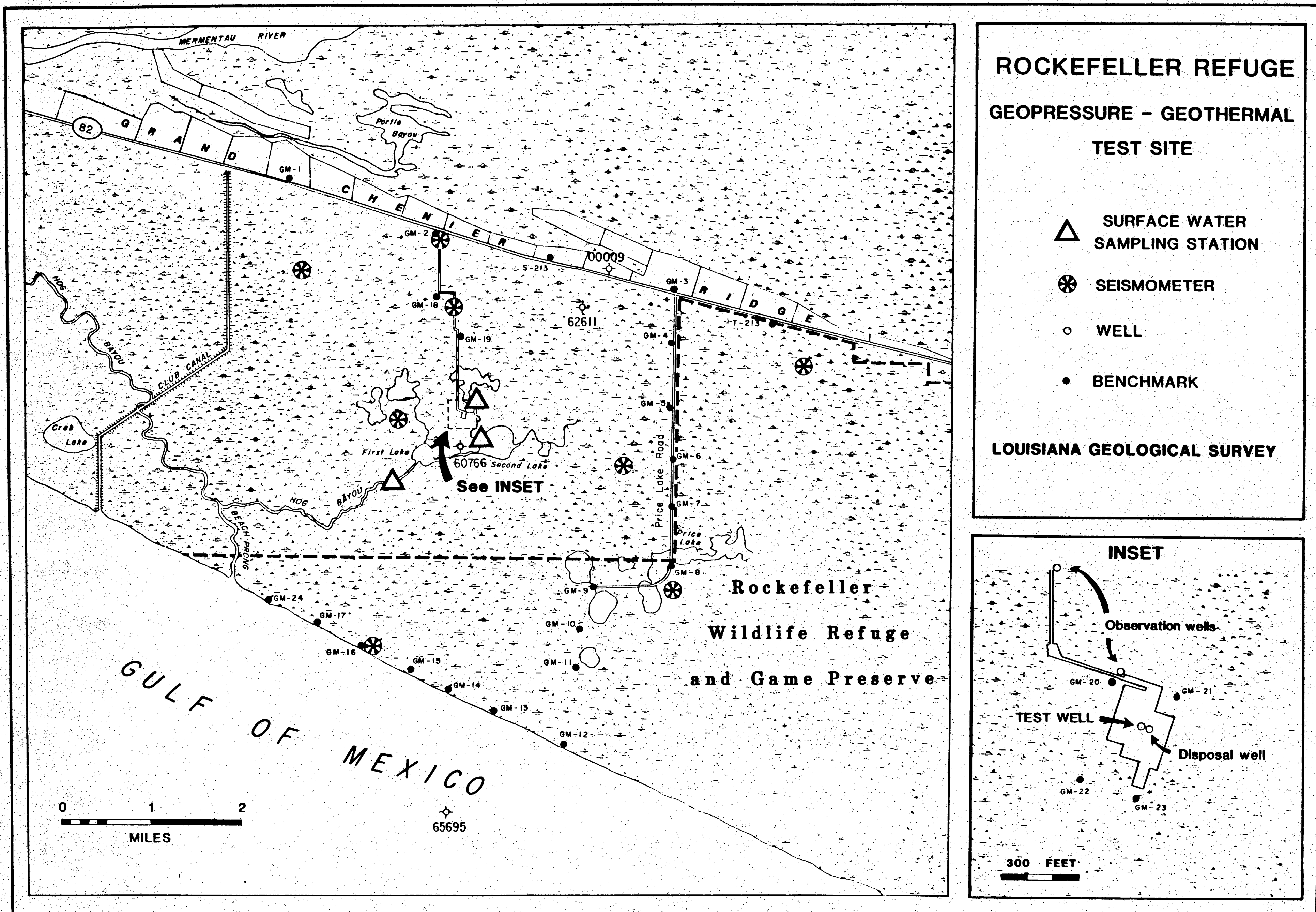


Figure 1. Environmental monitoring field stations in the Rockefeller Refuge geopressured-geothermal prospect.

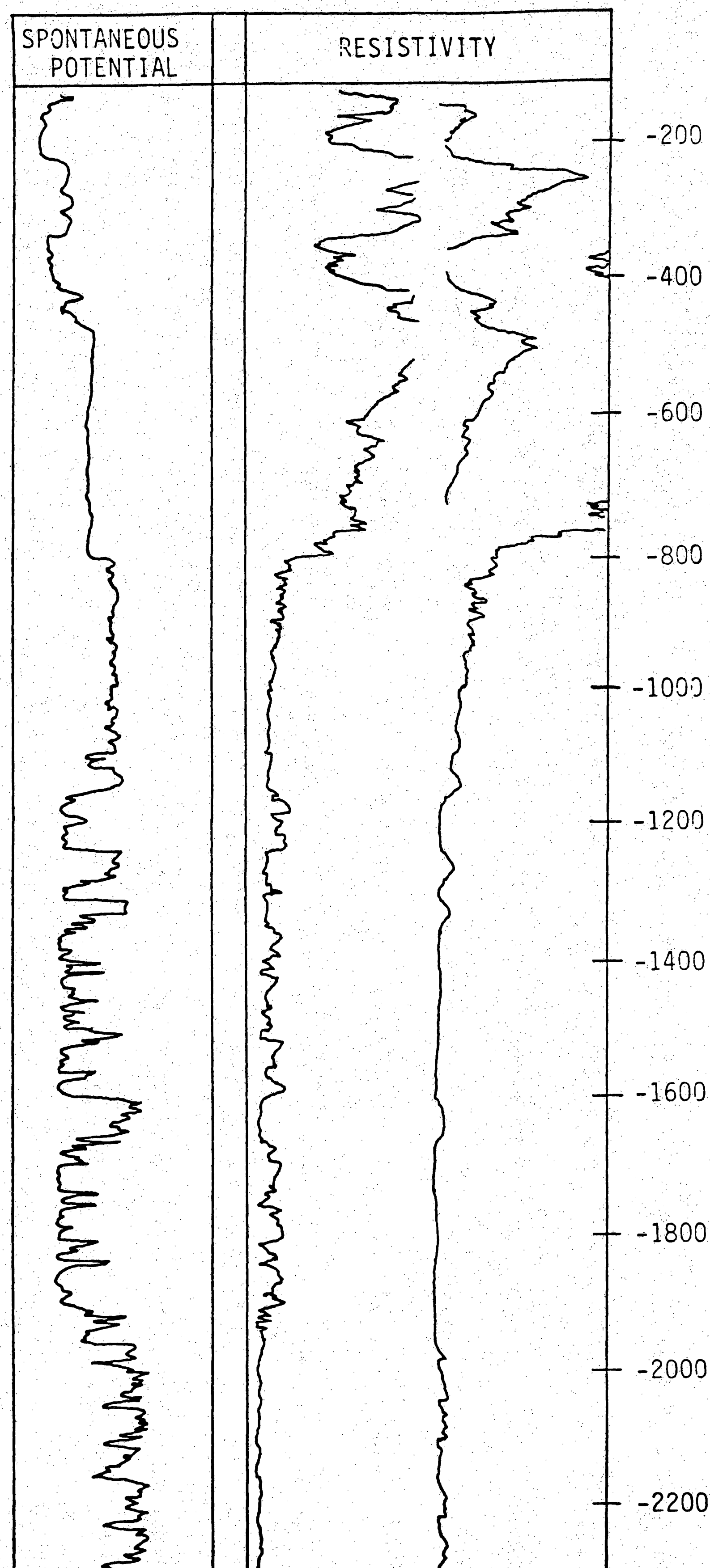


Figure 2. Typical electric log for wells in the Gladys McCall area. (Texas Crude Oil and Union Oil of California; Mermentau Mineral Land Company, #1)

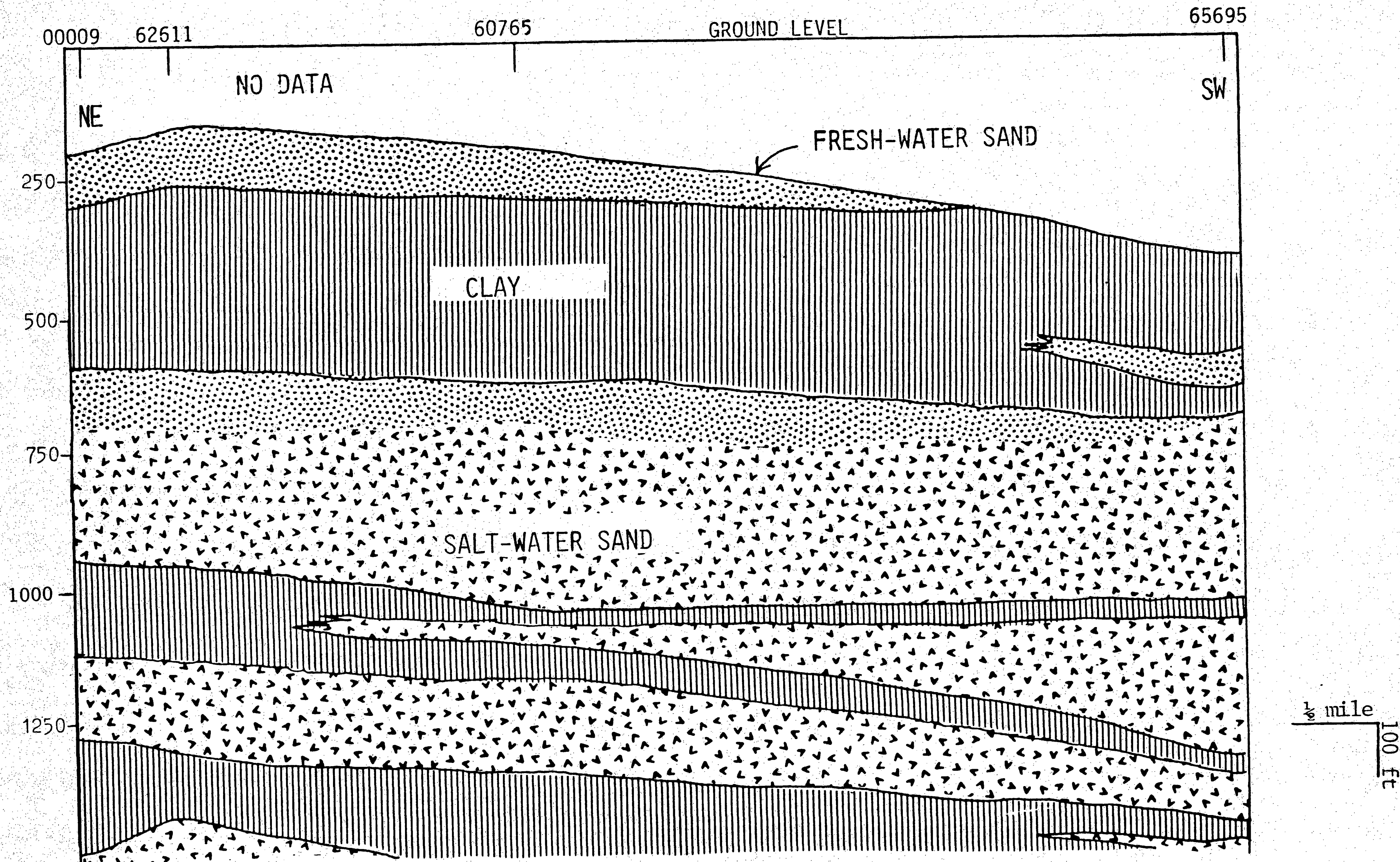


Figure 3. Characteristic stratigraphic cross section through the Gladys McCall test site (see Fig. 1 for well locations).

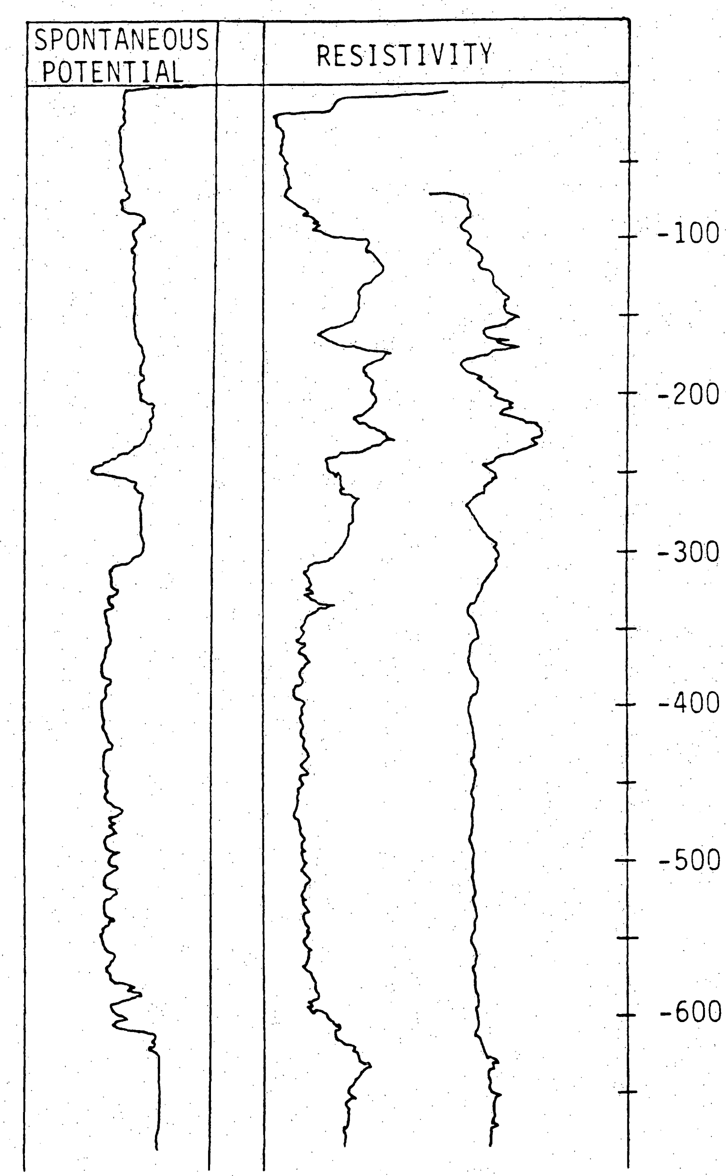


Figure 4. Electric log for deep ground-water well. (Louisiana State University; Gladys McCall Observation Well #1)

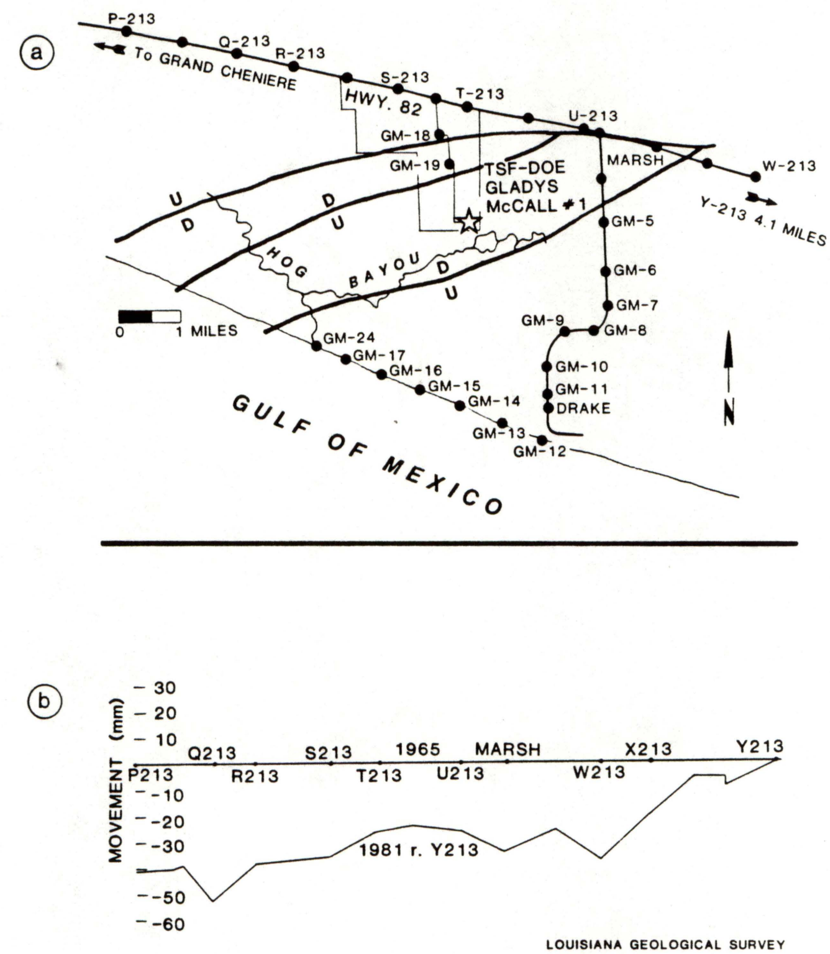


Figure 5. a) Network of first-order elevation benchmarks in the Rockefeller Refuge prospect; b) comparison of 1965 and 1981 elevation data using P213 (top) and Y213 (bottom) as reference.

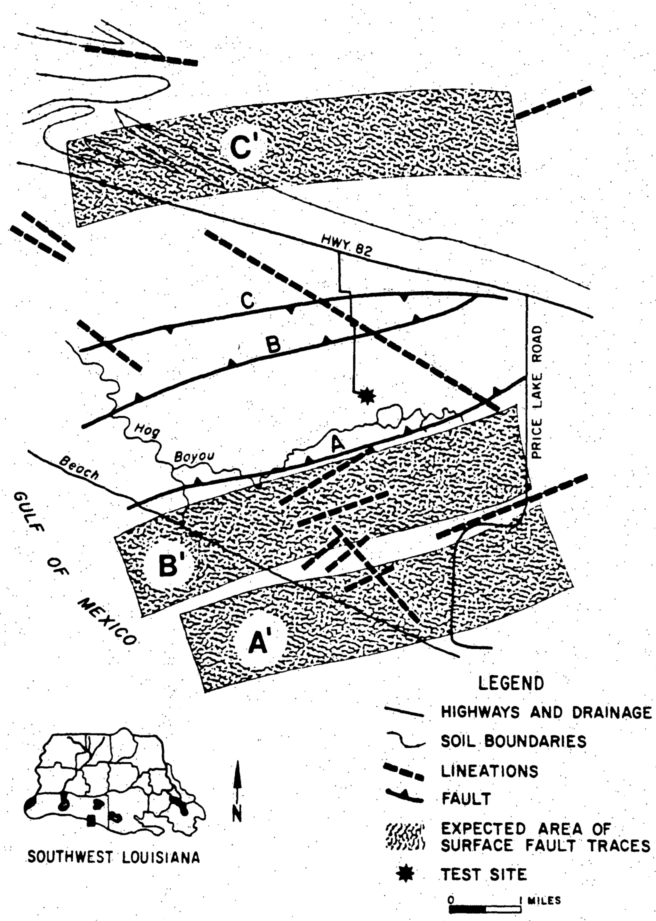


Figure 6. Subsurface faults, extrapolated fault zones, and mapped lineations in the Rockefeller Refuge prospect.

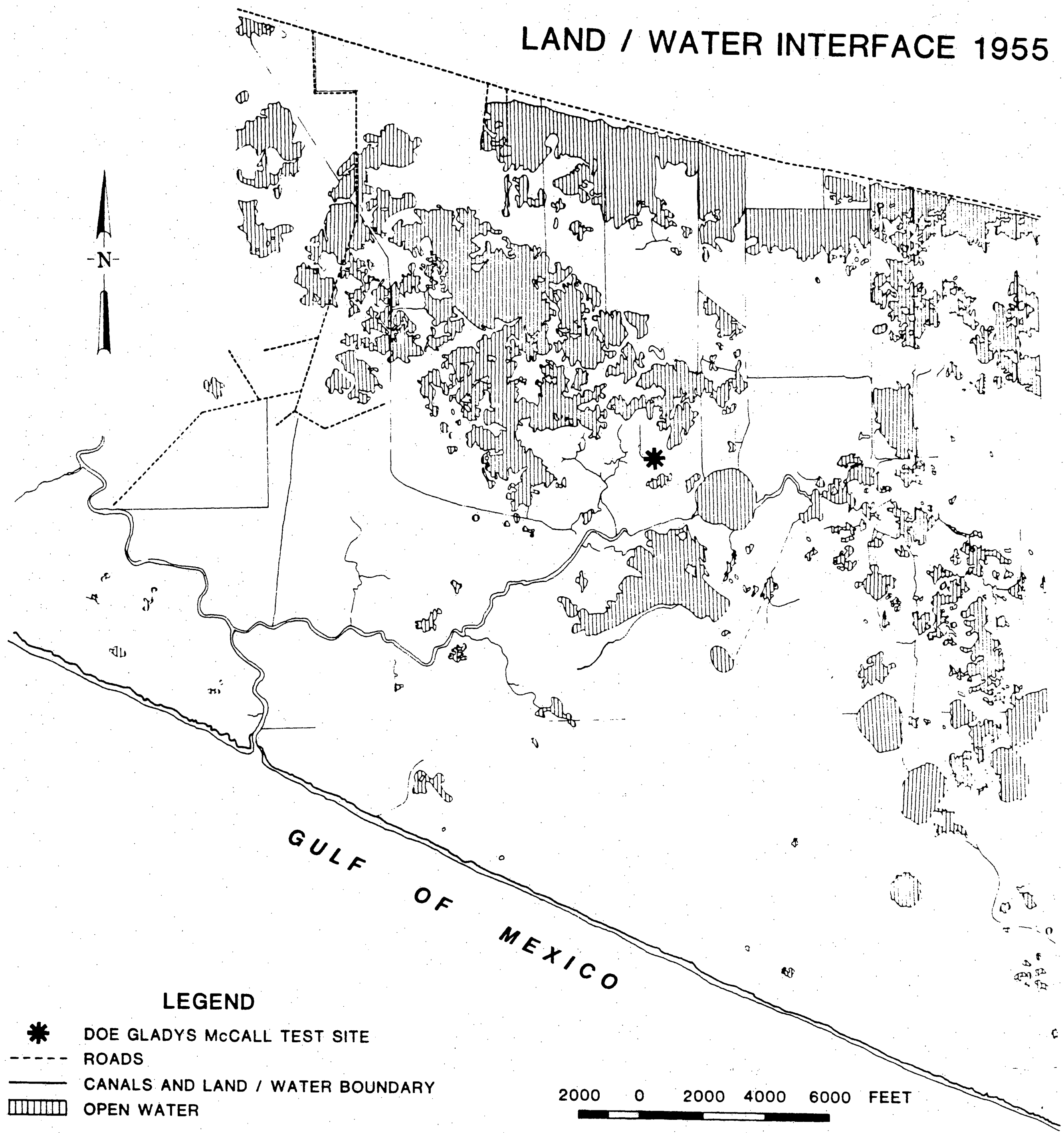


Figure 7. 1955 map of land and water features in the Rockefeller Refuge study area.

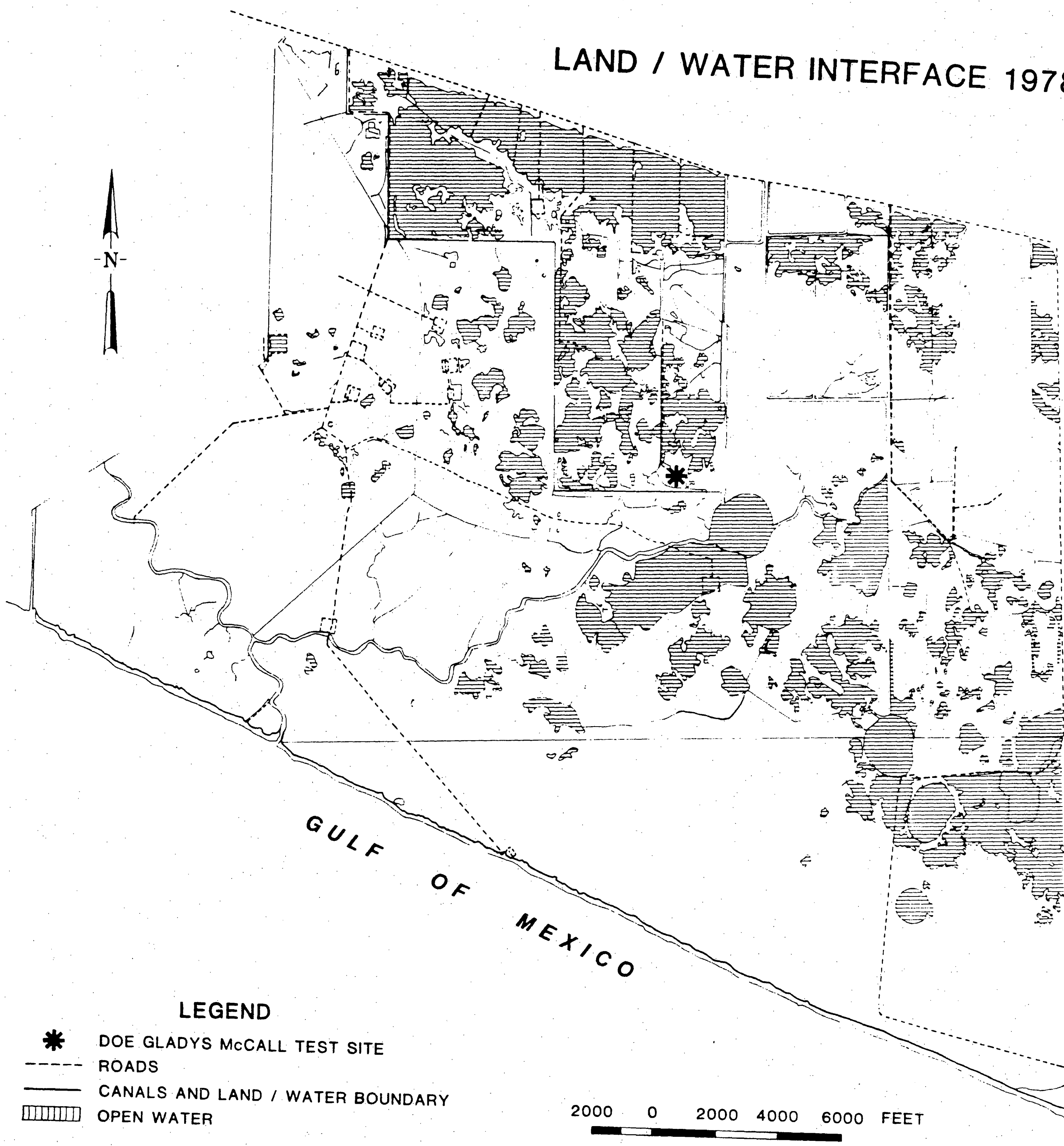


Figure 8. 1978 map of land and water features in the Rockefeller Refuge study area.

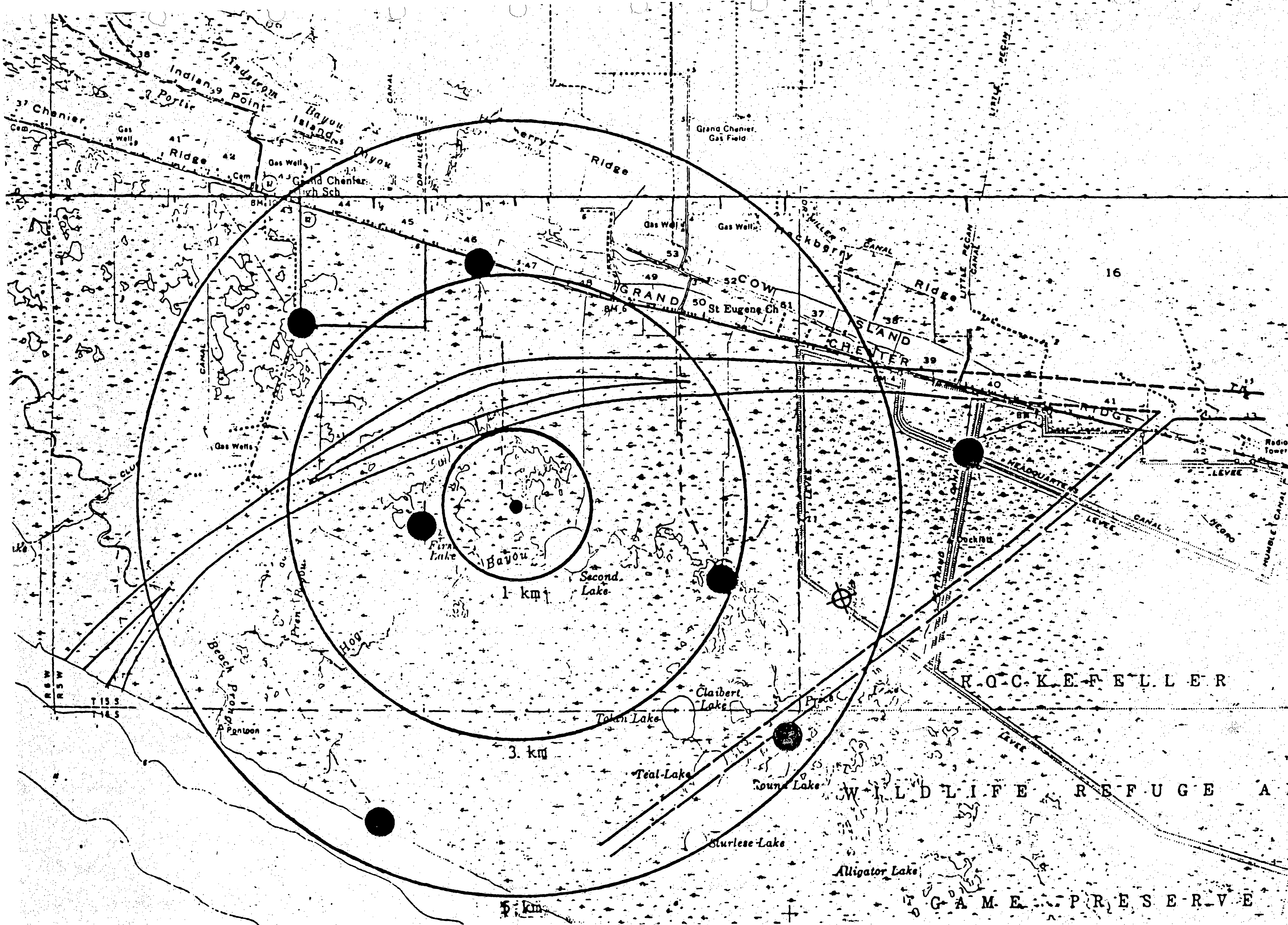


Figure 9. Location of September 14 event, marked with ⊕ oriented along axis of error ellipse.

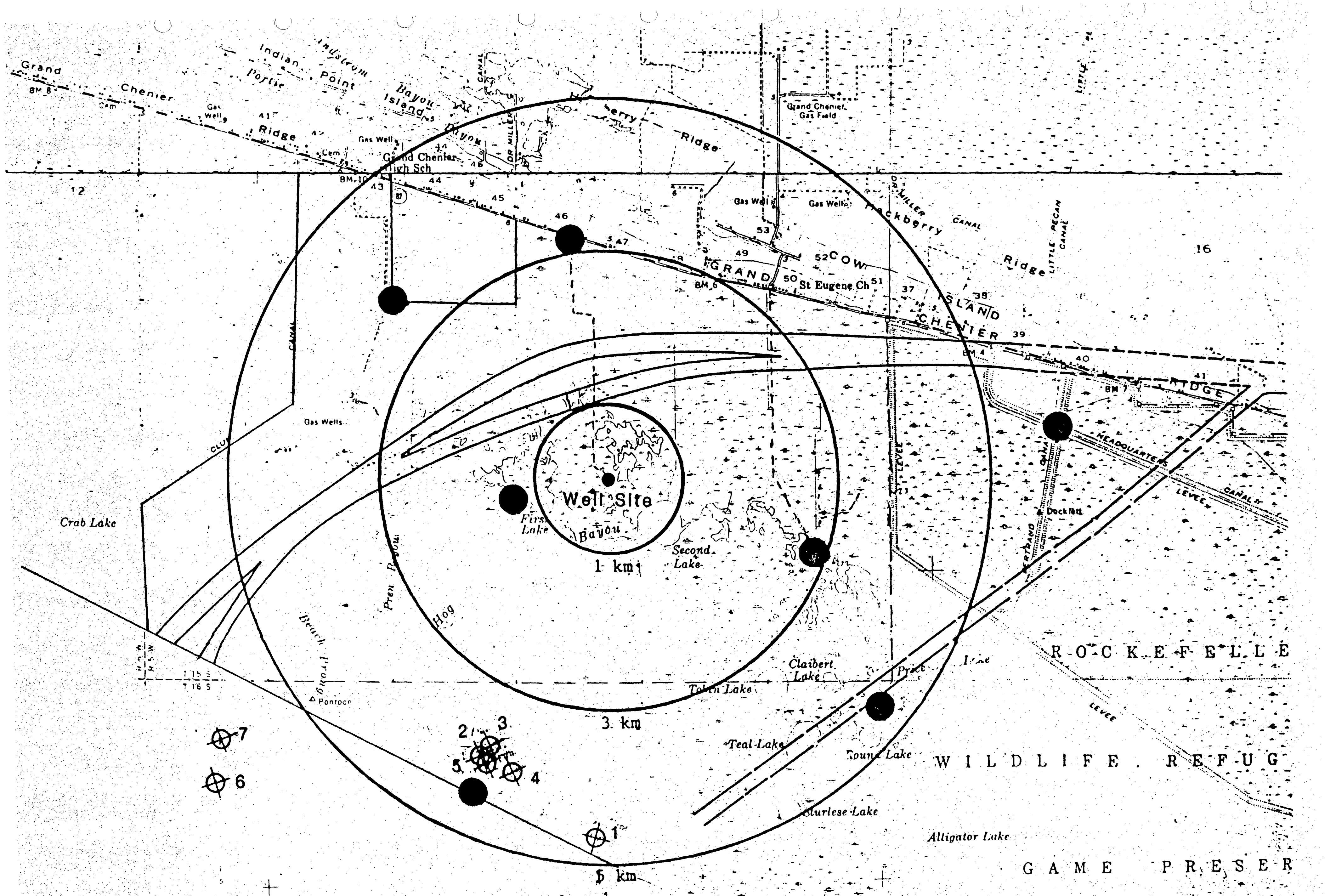


Figure 10. Location of the seven natural seismic events during October 1981 shown by ⊕ oriented along respective error ellipse axes.

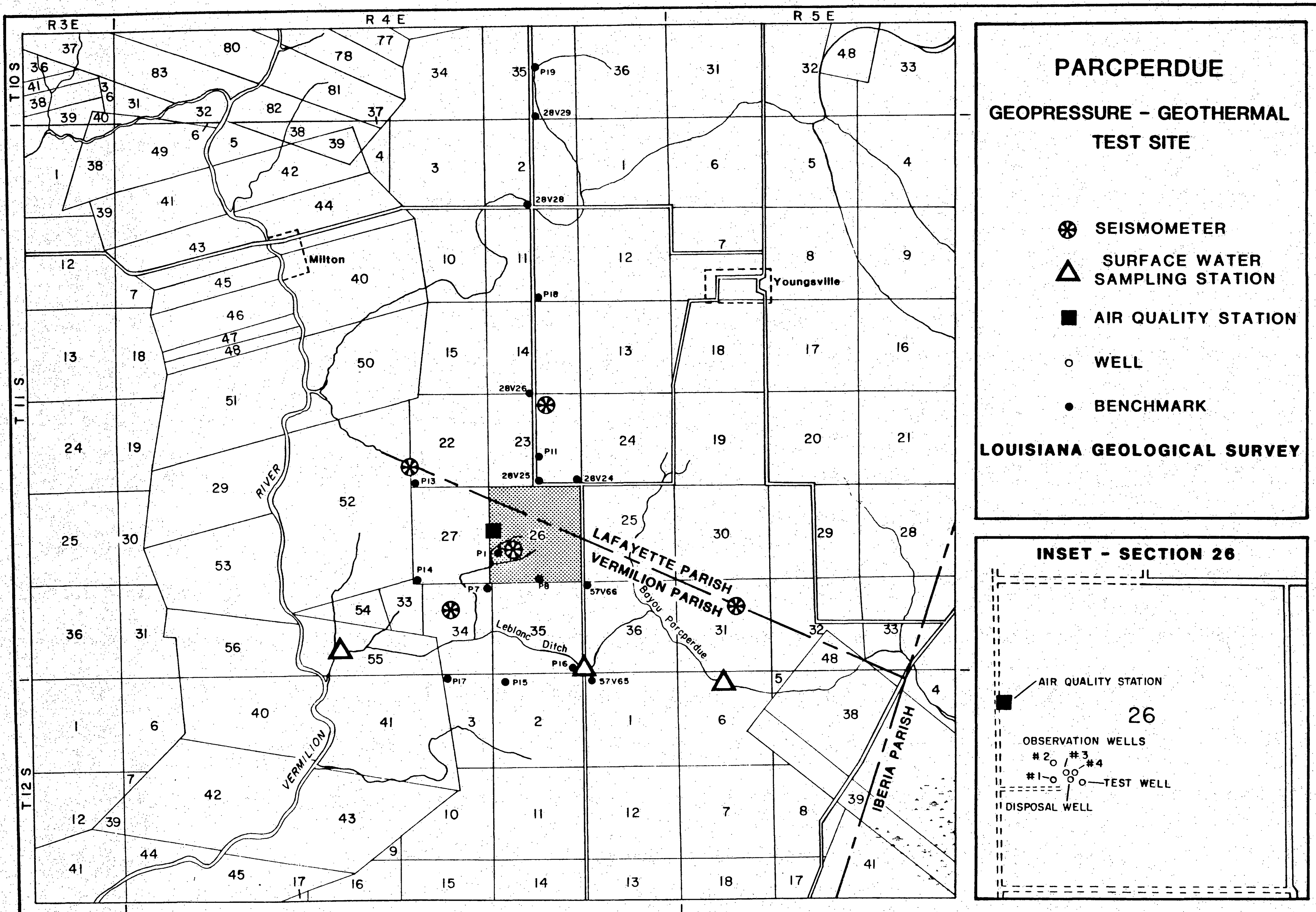


Figure 11. Environmental monitoring field stations in the Parcperdue geopressured-geothermal prospect.

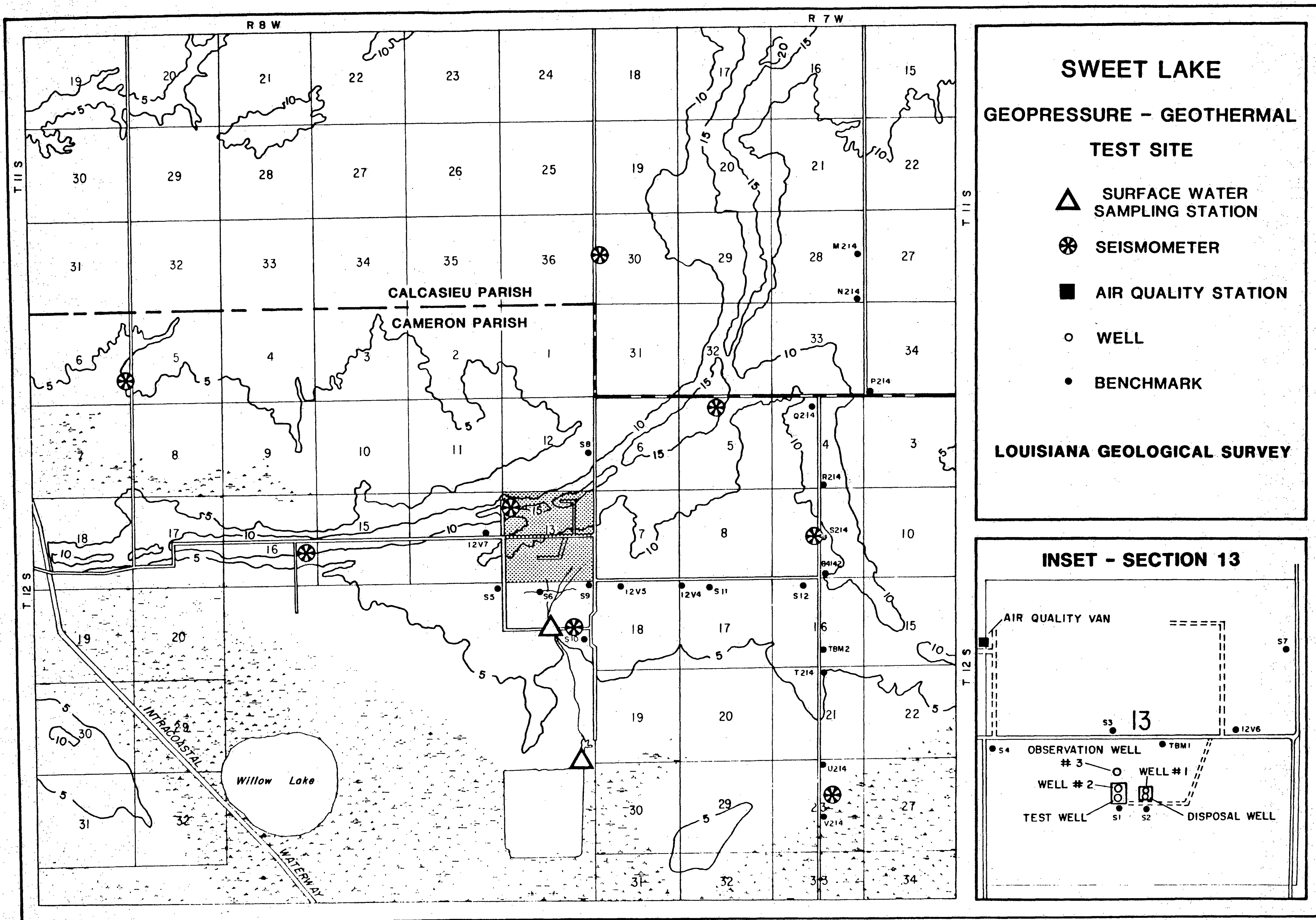


Figure 12. Environmental monitoring field stations in the Sweet Lake geopressured-geothermal prospect.

APPENDIX A

Rockefeller Refuge

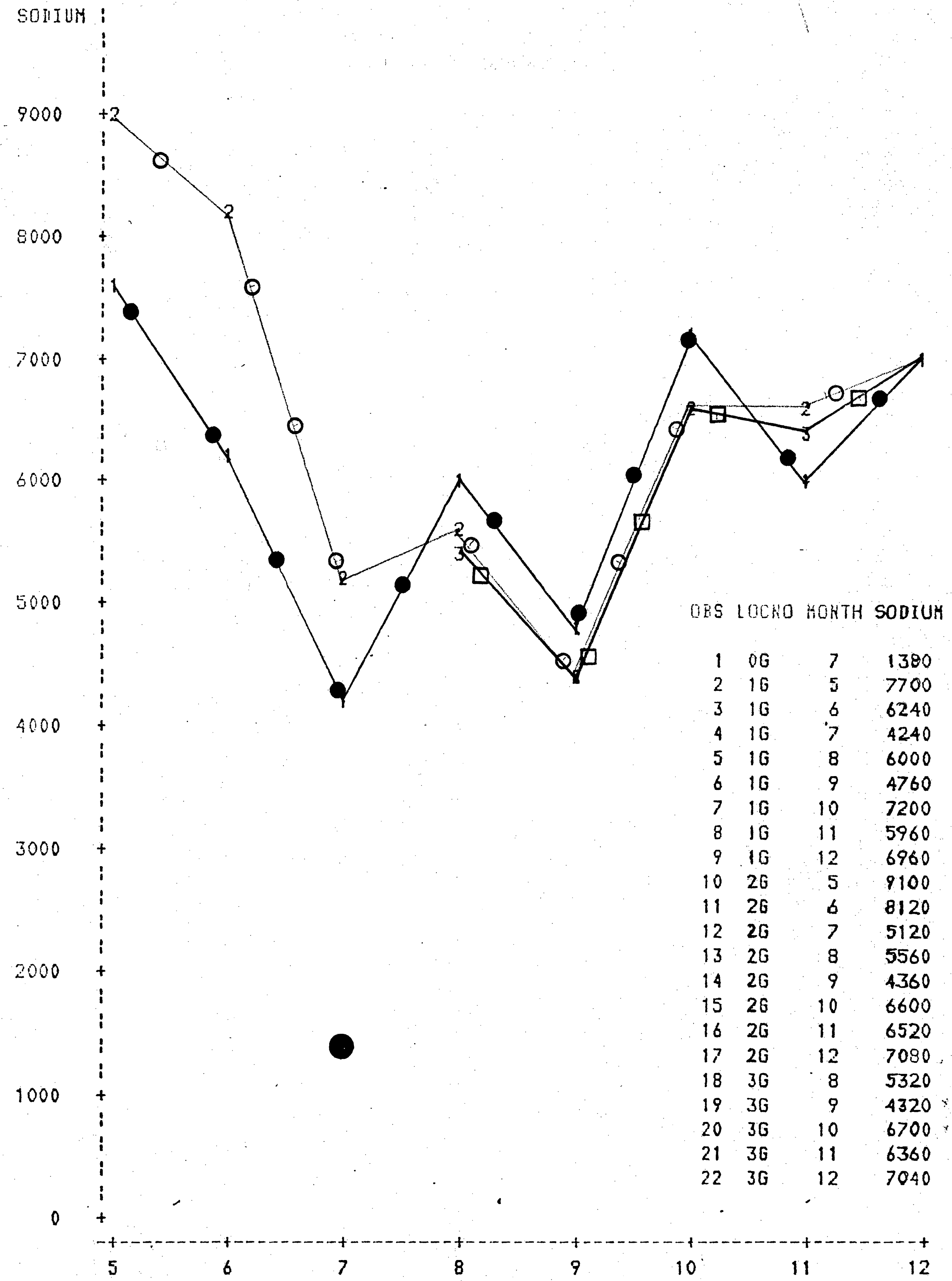
Section 1
Surface-Water Quality

Constituent vs. Time Profiles

Constituent	Concentration Units
Sodium	μg/ml Na
Magnesium	μg/ml Mg
Chloride	μg/ml Cl^-
Conductivity	μmho/cm
Hardness	μg/ml $CaCO_3$
Temperature	°C
Turbidity	turbidity units
Boron	μg/ml B
Lead	μg/ml Pb
Mercury	μg/ml Hg
Sulfate	μg/ml SO_4
pH	pH units

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF SODIUM*MONTH SYMBOL IS VALUE OF LOCNO

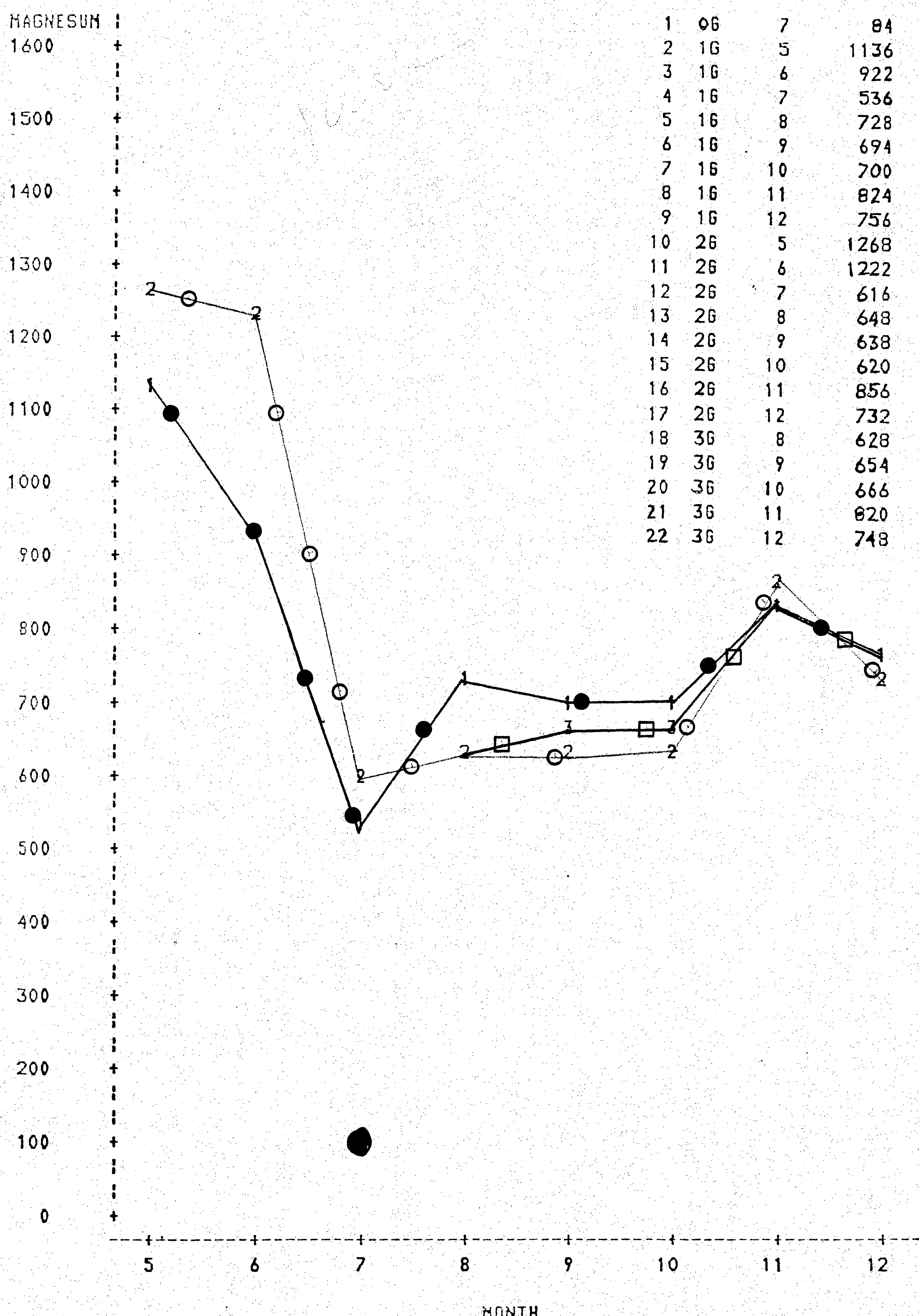


OBS	LOCNO	MONTH	SODIUM
1	0G	7	1380
2	1G	5	7700
3	1G	6	6240
4	1G	7	4240
5	1G	8	6000
6	1G	9	4760
7	1G	10	7200
8	1G	11	5960
9	1G	12	6960
10	2G	5	9100
11	2G	6	8120
12	2G	7	5120
13	2G	8	5560
14	2G	9	4360
15	2G	10	6600
16	2G	11	6520
17	2G	12	7080
18	3G	8	5320
19	3G	9	4320
20	3G	10	6700
21	3G	11	6360
22	3G	12	7040

NOTE: 4 OBS HIDDEN

0 - MUD PIT ● 1 - LAKE —●— 2 - BRIDGE —○— 3 - HOG BAYOU —□—

PLOT OF MAGNESUM*MONTH SYMBOL IS VALUE OF LOCNO

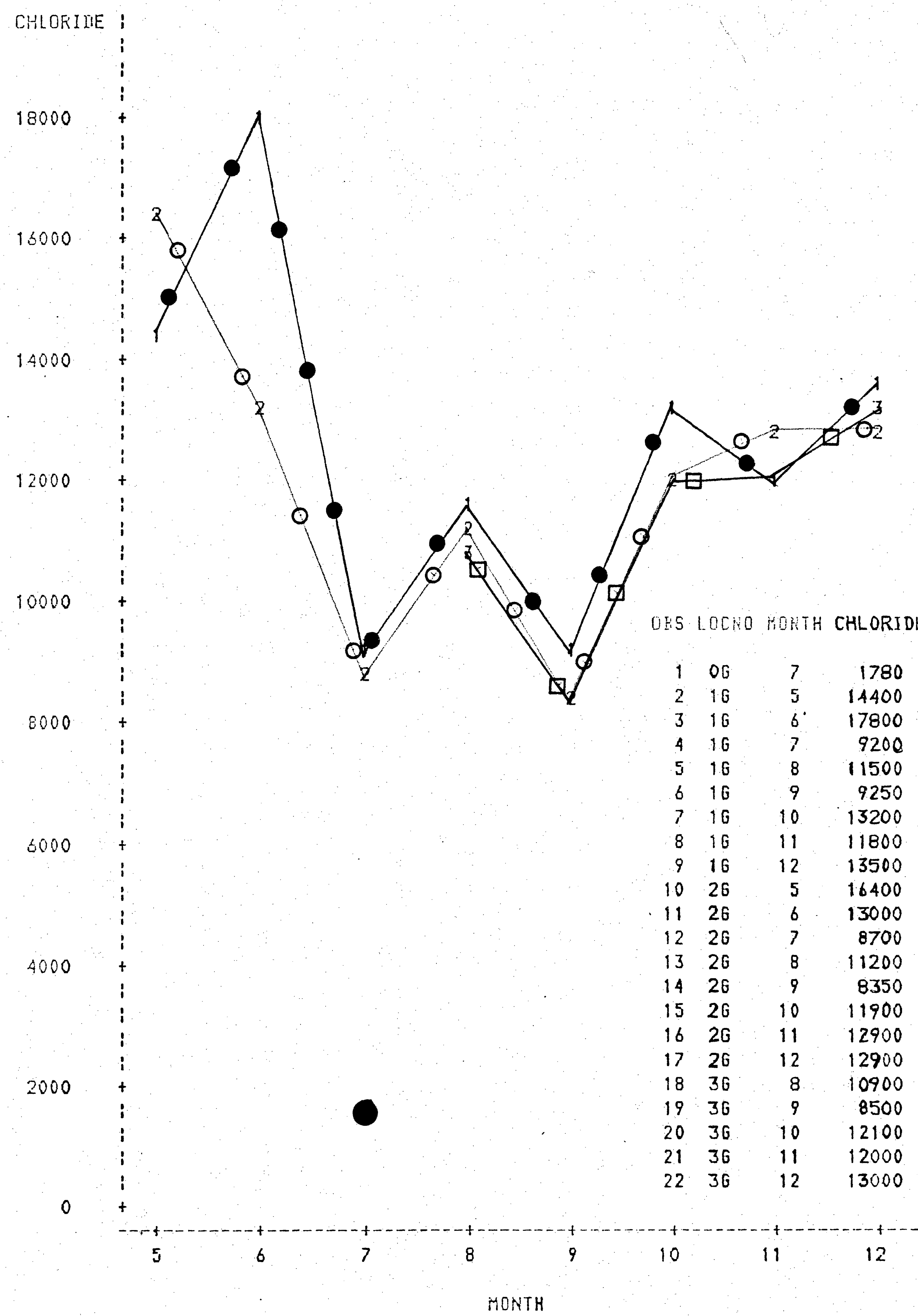


OBS	LOCNO	MONTH	MAGNESUM
1	0G	7	84
2	1G	5	1136
3	1G	6	922
4	1G	7	536
5	1G	8	728
6	1G	9	694
7	1G	10	700
8	1G	11	824
9	1G	12	756
10	2G	5	1268
11	2G	6	1222
12	2G	7	616
13	2G	8	648
14	2G	9	638
15	2G	10	620
16	2G	11	856
17	2G	12	732
18	3G	8	628
19	3G	9	654
20	3G	10	666
21	3G	11	820
22	3G	12	748

NOTE: 3 OBS HIDDEN

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF CHLORIDE*MONTH   SYMBOL IS VALUE OF LOCNO

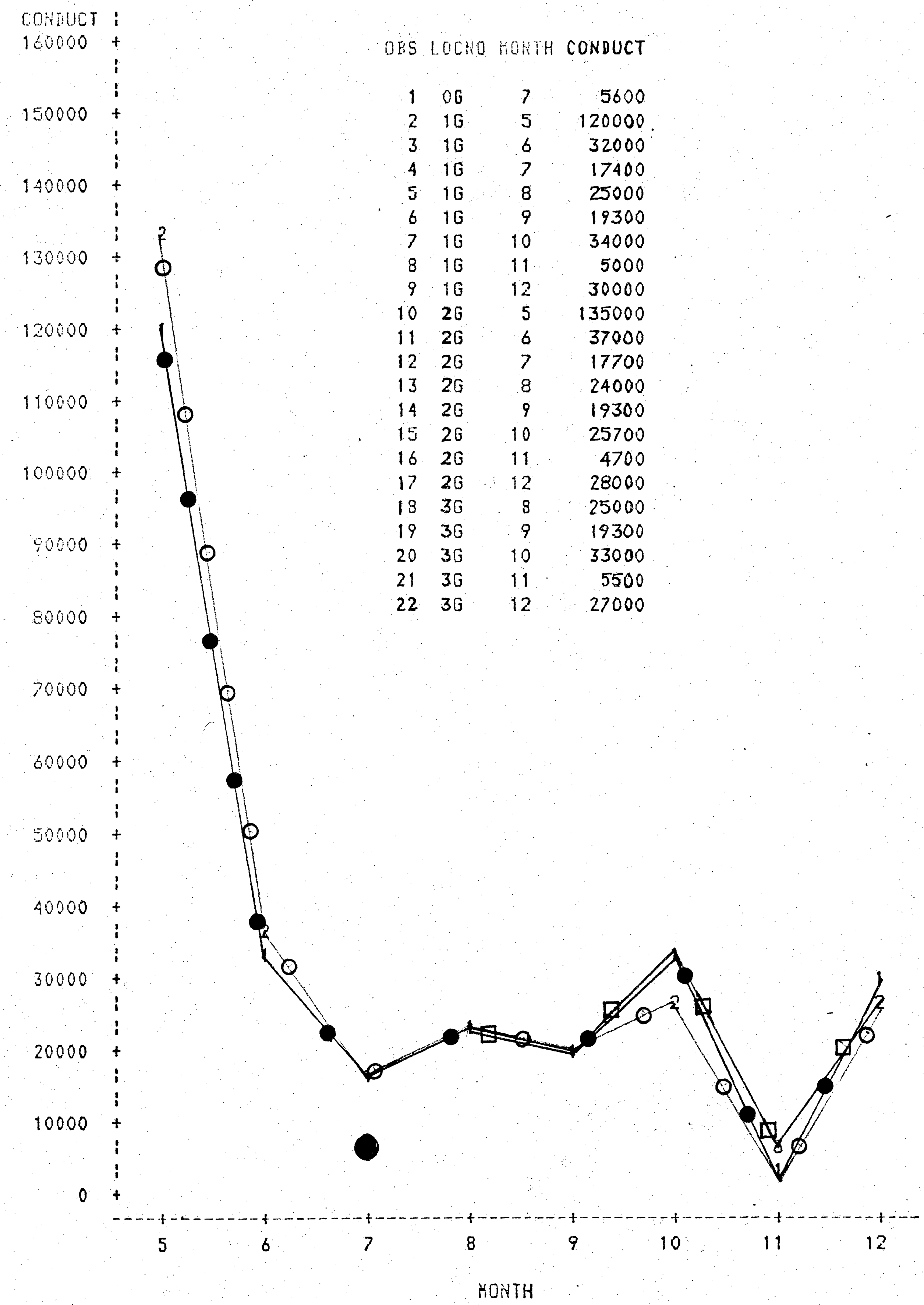


OBS	LOCNO	MONTH	CHLORIDE
1	0G	7	1780
2	1G	5	14400
3	1G	6	17800
4	1G	7	9200
5	1G	8	11500
6	1G	9	9250
7	1G	10	13200
8	1G	11	11800
9	1G	12	13500
10	2G	5	16400
11	2G	6	13000
12	2G	7	8700
13	2G	8	11200
14	2G	9	8350
15	2G	10	11900
16	2G	11	12900
17	2G	12	12900
18	3G	8	10900
19	3G	9	8500
20	3G	10	12100
21	3G	11	12000
22	3G	12	13000

NOTE: 3 OBS HIDDEN

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF CONDUCT*MONTH   SYMBOL IS VALUE OF LOCNO



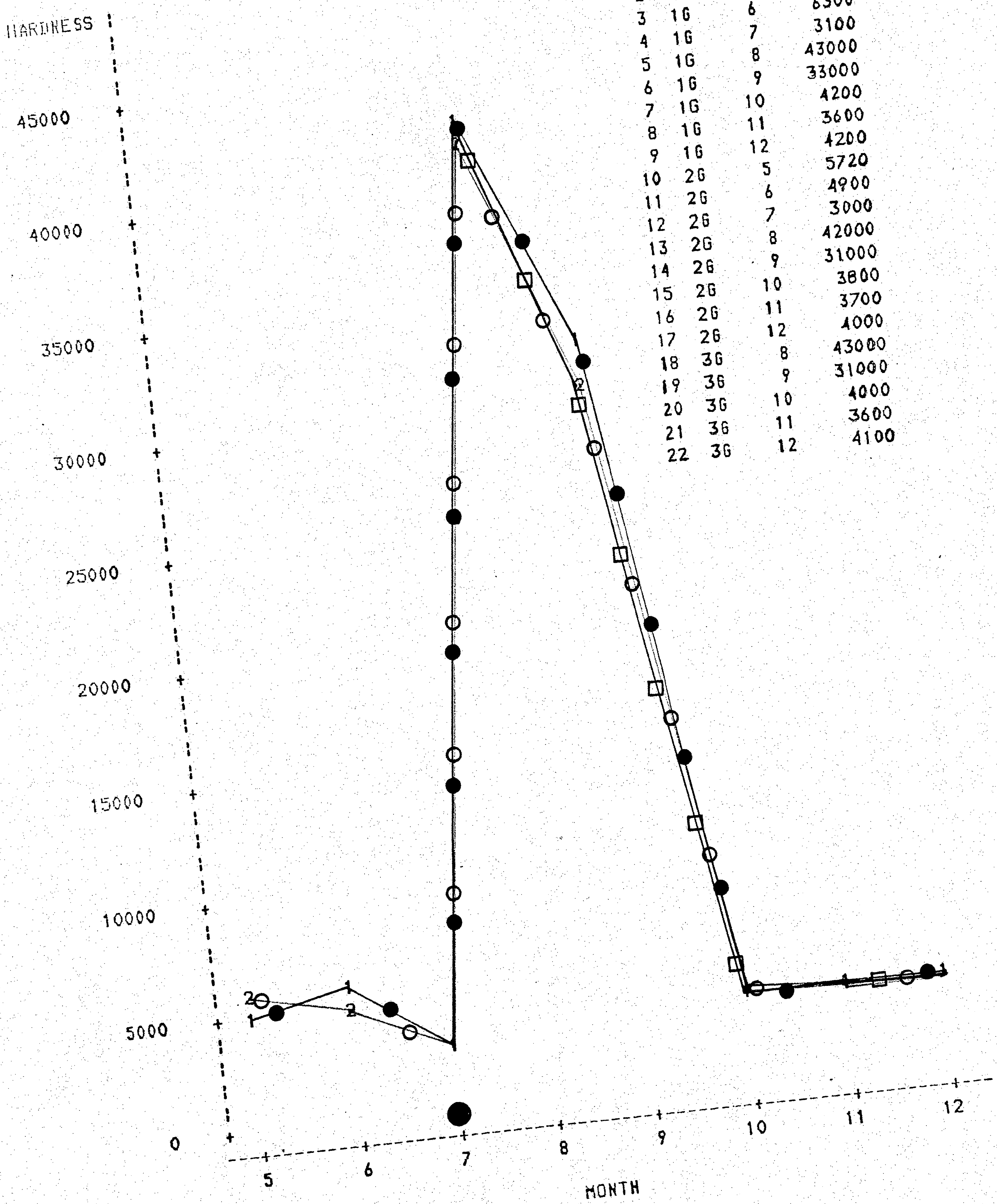
OBS	LOCNO	MONTH	CONDUCT
1	0G	7	5600
2	1G	5	120000
3	1G	6	32000
4	1G	7	17400
5	1G	8	25000
6	1G	9	19300
7	1G	10	34000
8	1G	11	5000
9	1G	12	30000
10	2G	5	135000
11	2G	6	37000
12	2G	7	17700
13	2G	8	24000
14	2G	9	19300
15	2G	10	25700
16	2G	11	4700
17	2G	12	28000
18	3G	8	25000
19	3G	9	19300
20	3G	10	33000
21	3G	11	5500
22	3G	12	27000

NOTE: 8 OBS HIDDEN

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF HARDNESS*MONTH SYMBOL IS VALUE OF LOCNO

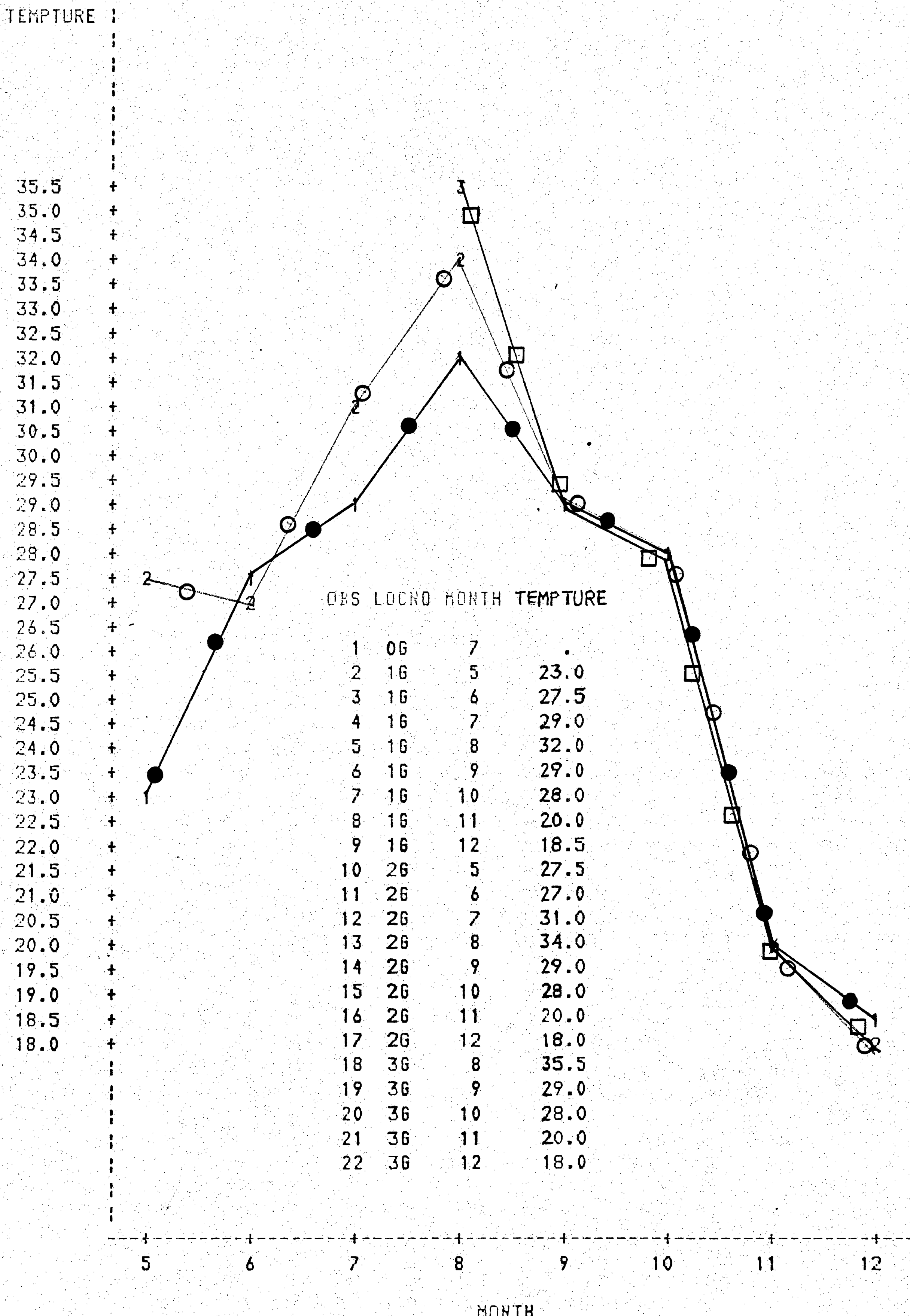
OBS	LOCNO	MONTH	HARDNESS
1	0G	7	310
2	1G	5	5150
3	1G	6	6300
4	1G	7	3100
5	1G	8	43000
6	1G	9	33000
7	1G	10	4200
8	1G	11	3600
9	1G	12	4200
10	2G	5	5720
11	2G	6	4900
12	2G	7	3000
13	2G	8	42000
14	2G	9	31000
15	2G	10	3800
16	2G	11	3700
17	2G	12	4000
18	3G	8	43000
19	3G	9	31000
20	3G	10	4000
21	3G	11	3600
22	3G	12	4100



NOTE: 9 OBS HIDDEN

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF TEMPTURE*MONTH SYMBOL IS VALUE OF LOCNO

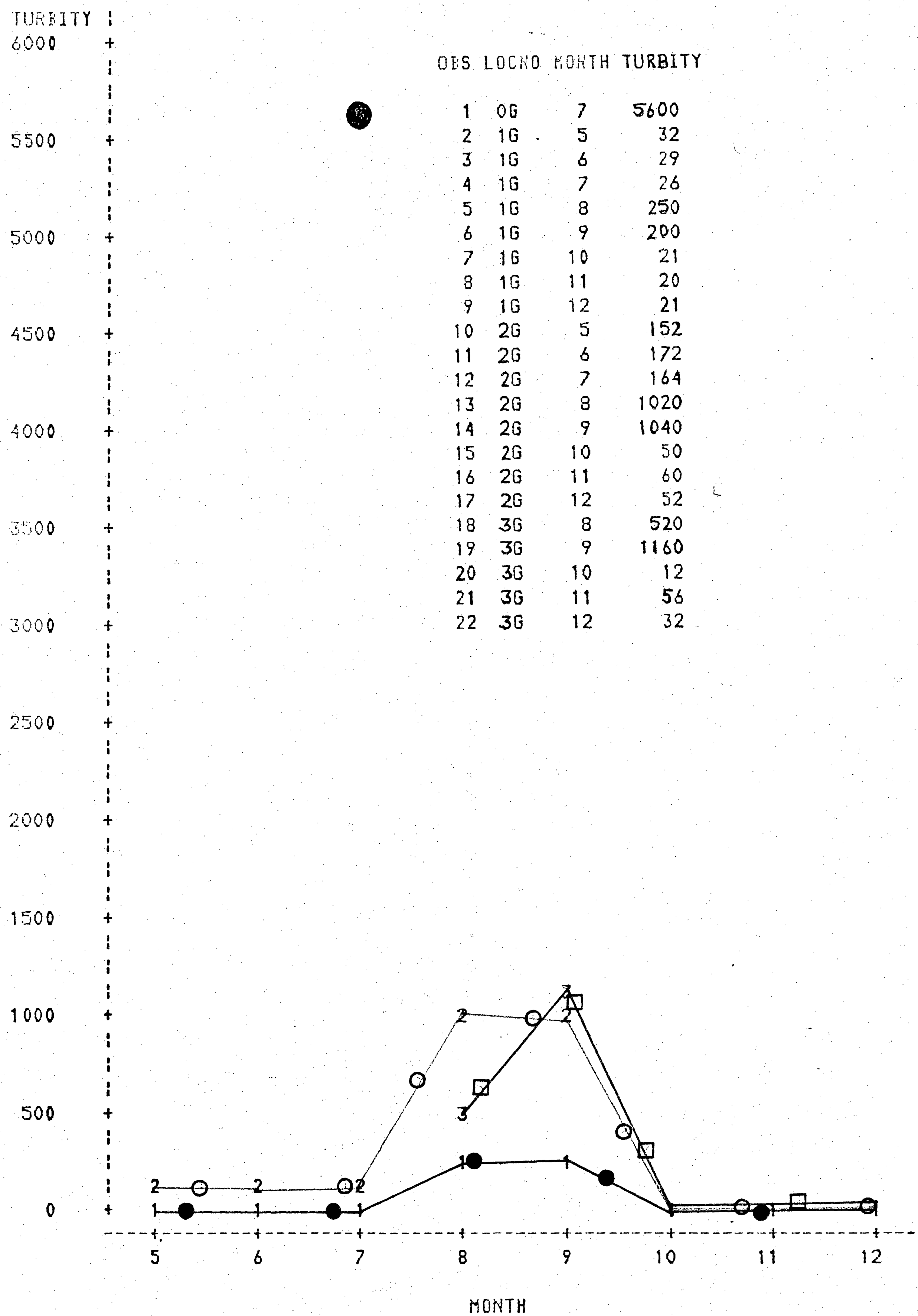


OBS	LOCNO	MONTH	TEMPTURE
1	0G	7	.
2	1G	5	23.0
3	1G	6	27.5
4	1G	7	29.0
5	1G	8	32.0
6	1G	9	29.0
7	1G	10	28.0
8	1G	11	20.0
9	1G	12	18.5
10	2G	5	27.5
11	2G	6	27.0
12	2G	7	31.0
13	2G	8	34.0
14	2G	9	29.0
15	2G	10	28.0
16	2G	11	20.0
17	2G	12	18.0
18	3G	8	35.5
19	3G	9	29.0
20	3G	10	28.0
21	3G	11	20.0
22	3G	12	18.0

NOTE: 1 OBS HAD MISSING VALUES 7 OBS HIDDEN

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF TURBITY*MONTH SYMBOL IS VALUE OF LOCNO

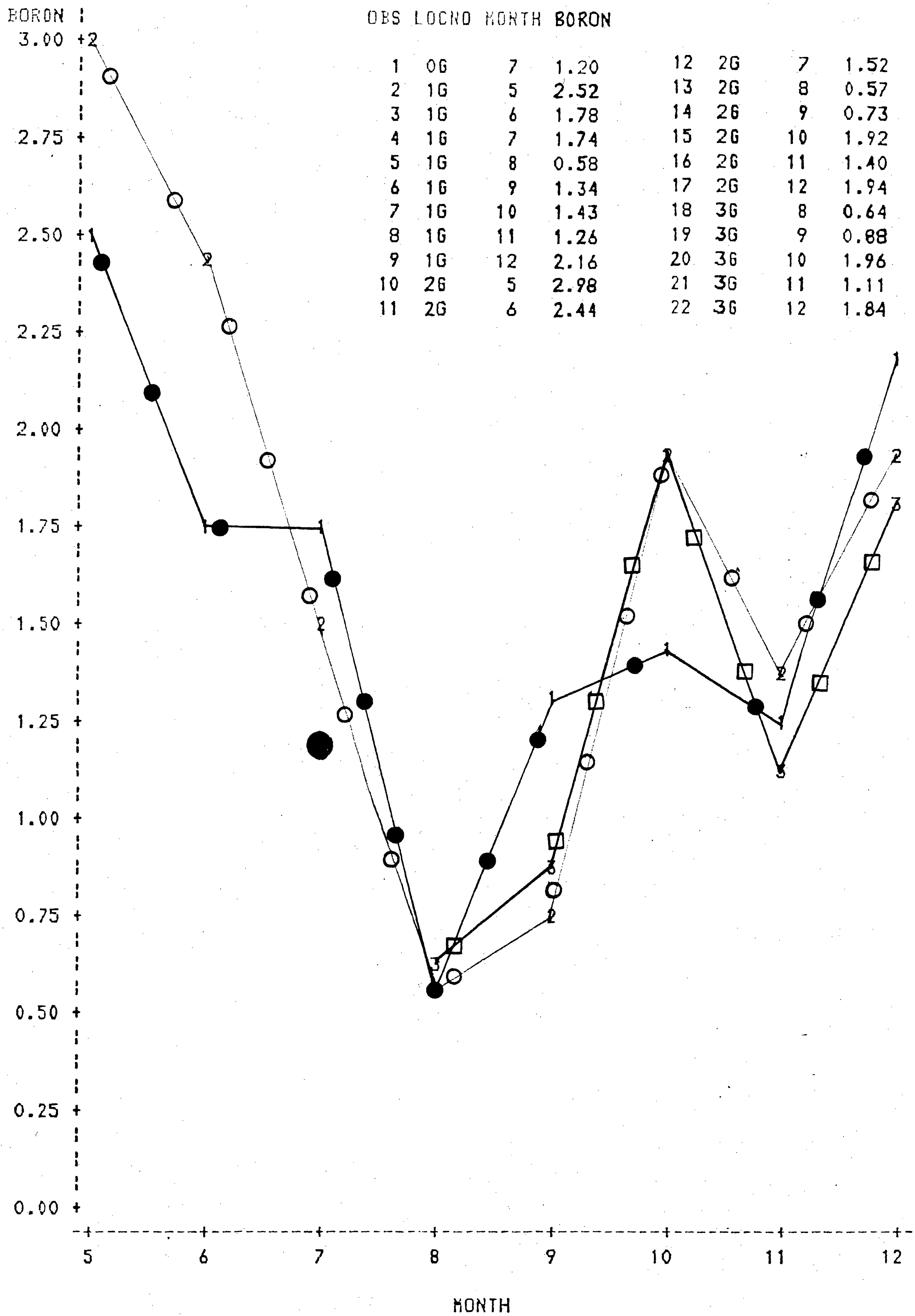


OBS	LOCNO	MONTH	TURBITY
1	0G	7	5600
2	1G	5	32
3	1G	6	29
4	1G	7	26
5	1G	8	250
6	1G	9	200
7	1G	10	21
8	1G	11	20
9	1G	12	21
10	2G	5	152
11	2G	6	172
12	2G	7	164
13	2G	8	1020
14	2G	9	1040
15	2G	10	50
16	2G	11	60
17	2G	12	52
18	3G	8	520
19	3G	9	1160
20	3G	10	12
21	3G	11	56
22	3G	12	32

NOTE: 6 OBS HIDDEN

0 - MUD PIT ● 1 - LAKE -○- 2 - BRIDGE -○- 3 - HOG BAYOU -□-

PLOT OF BORON*MONTH SYMBOL IS VALUE OF LOCNO

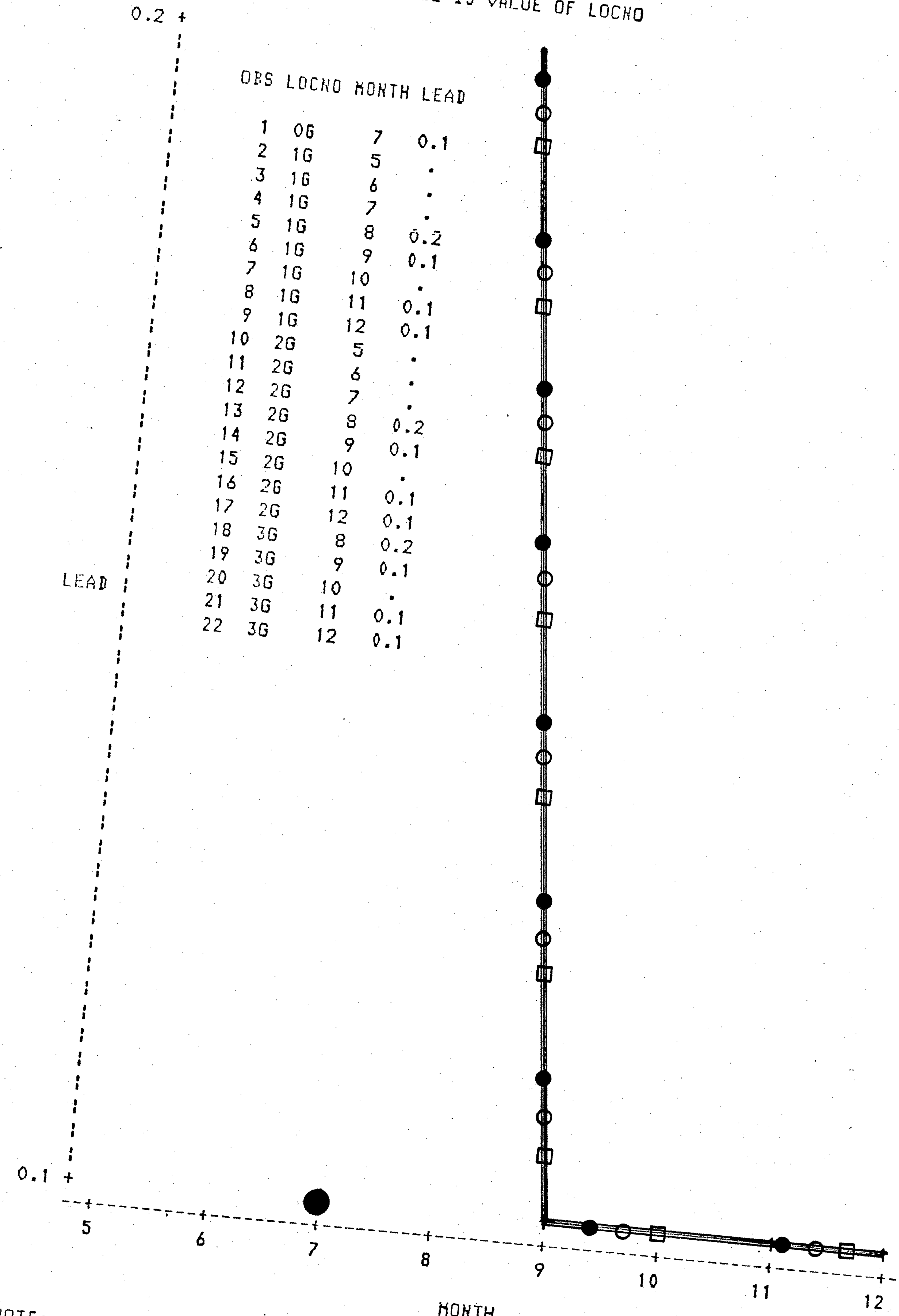


OBS	LOCNO	MONTH	BORON
1	0G	7	1.20
2	1G	5	2.52
3	1G	6	1.78
4	1G	7	1.74
5	1G	8	0.58
6	1G	9	1.34
7	1G	10	1.43
8	1G	11	1.26
9	1G	12	2.16
10	2G	5	2.98
11	2G	6	2.44
12	2G	7	1.52
13	2G	8	0.57
14	2G	9	0.73
15	2G	10	1.92
16	2G	11	1.40
17	2G	12	1.94
18	3G	8	0.64
19	3G	9	0.88
20	3G	10	1.96
21	3G	11	1.11
22	3G	12	1.84

NOTE: 2 OBS HIDDEN

0 - MUD PIT ● 1 - LAKE ● 2 - BRIDGE ○ 3 - HOG BAYOU □

PLOT OF LEAD*MONTH SYMBOL IS VALUE OF LOCNO

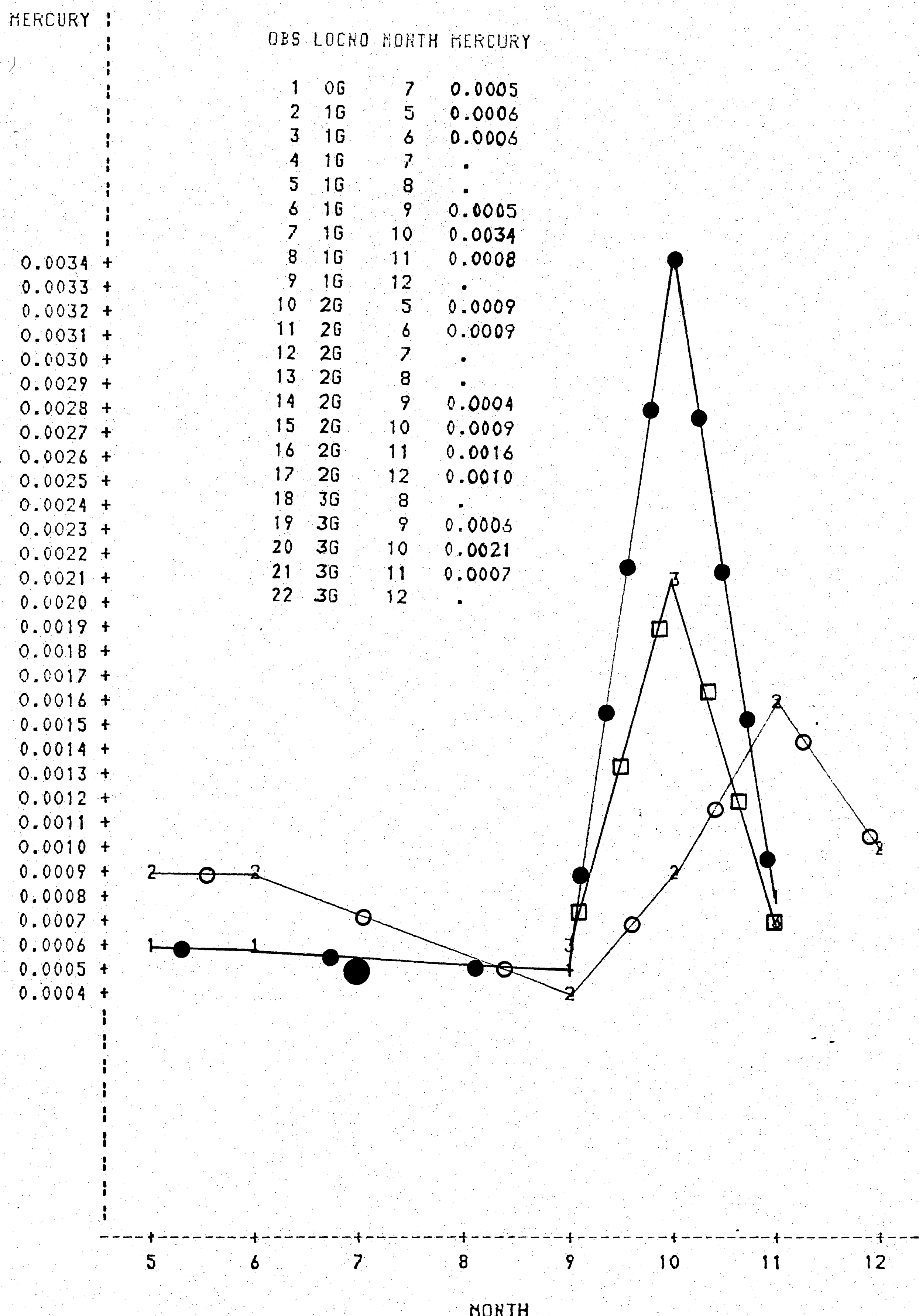


OBS	LOCNO	MONTH	LEAD
1	0G	7	0.1
2	1G	5	.
3	1G	6	.
4	1G	7	.
5	1G	8	0.2
6	1G	9	0.1
7	1G	10	.
8	1G	11	0.1
9	1G	12	0.1
10	2G	5	.
11	2G	6	.
12	2G	7	.
13	2G	8	0.2
14	2G	9	0.1
15	2G	10	.
16	2G	11	0.1
17	2G	12	0.1
18	3G	8	0.2
19	3G	9	0.1
20	3G	10	.
21	3G	11	0.1
22	3G	12	0.1

NOTE: 9 OBS HAD MISSING VALUES 8 OBS HIDDEN

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF MERCURY*MONTH   SYMBOL IS VALUE OF LOCNO

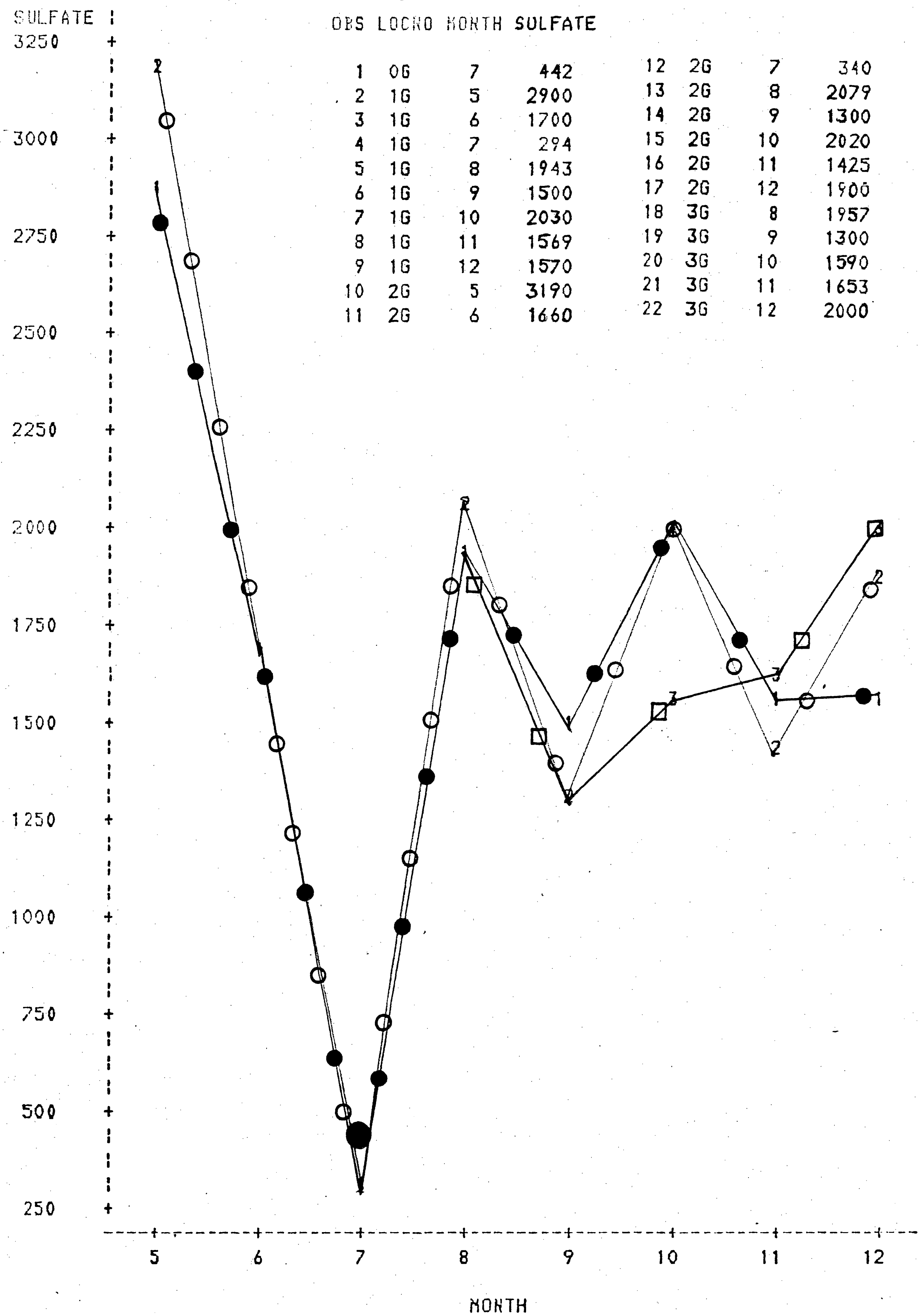


OBS	LOCNO	MONTH	MERCURY
1	0G	7	0.0005
2	1G	5	0.0006
3	1G	6	0.0006
4	1G	7	.
5	1G	8	.
6	1G	9	0.0005
7	1G	10	0.0034
8	1G	11	0.0008
9	1G	12	.
10	2G	5	0.0009
11	2G	6	0.0009
12	2G	7	.
13	2G	8	.
14	2G	9	0.0004
15	2G	10	0.0009
16	2G	11	0.0016
17	2G	12	0.0010
18	3G	8	.
19	3G	9	0.0006
20	3G	10	0.0021
21	3G	11	0.0007
22	3G	12	.

NOTE: 7 OBS HAD MISSING VALUES

0 - MUD PIT 1 - LAKE 2 - BRIDGE 3 - HOG BAYOU

PLOT OF SULFATE*MONTH   SYMBOL IS VALUE OF LOCNO

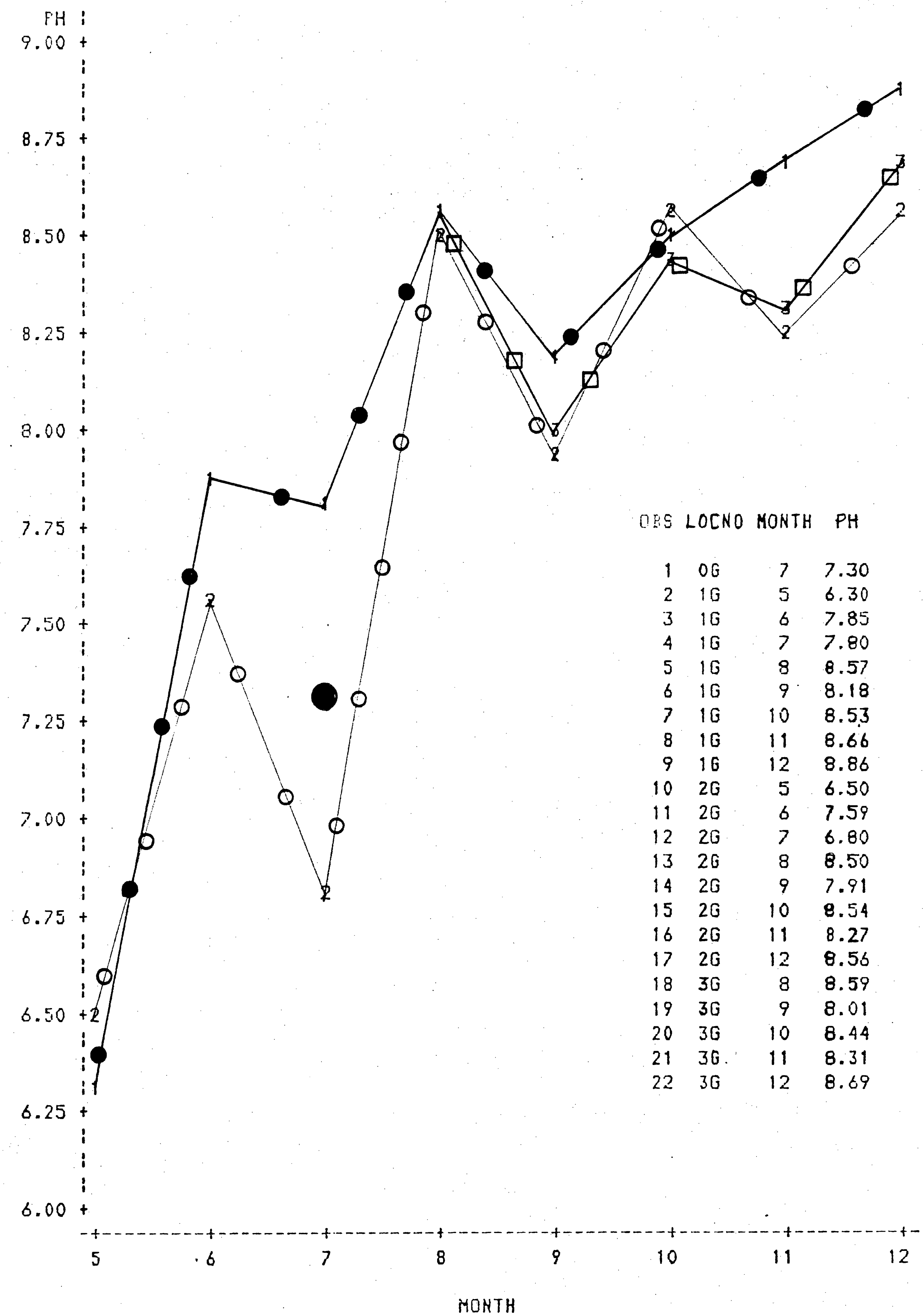


OBS	LOCNO	MONTH	SULFATE
1	0G	7	442
2	1G	5	2900
3	1G	6	1700
4	1G	7	294
5	1G	8	1943
6	1G	9	1500
7	1G	10	2030
8	1G	11	1569
9	1G	12	1570
10	2G	5	3190
11	2G	6	1660
12	2G	7	340
13	2G	8	2079
14	2G	9	1300
15	2G	10	2020
16	2G	11	1425
17	2G	12	1900
18	3G	8	1957
19	3G	9	1300
20	3G	10	1590
21	3G	11	1653
22	3G	12	2000

NOTE: 5 OBS HIDDEN

0 - MUD PIT ● 1 - LAKE -●- 2 - BRIDGE -○- 3 - HOG BAYOU -□-

PLOT OF PH*MONTH SYMBOL IS VALUE OF LOCNO



OBS	LOCNO	MONTH	PH
1	0G	7	7.30
2	1G	5	6.30
3	1G	6	7.85
4	1G	7	7.80
5	1G	8	8.57
6	1G	9	8.18
7	1G	10	8.53
8	1G	11	8.66
9	1G	12	8.86
10	2G	5	6.50
11	2G	6	7.59
12	2G	7	6.80
13	2G	8	8.50
14	2G	9	7.91
15	2G	10	8.54
16	2G	11	8.27
17	2G	12	8.56
18	3G	8	8.59
19	3G	9	8.01
20	3G	10	8.44
21	3G	11	8.31
22	3G	12	8.69

NOTE: 1 OBS HIDDEN

APPENDIX A

Rockefeller Refuge

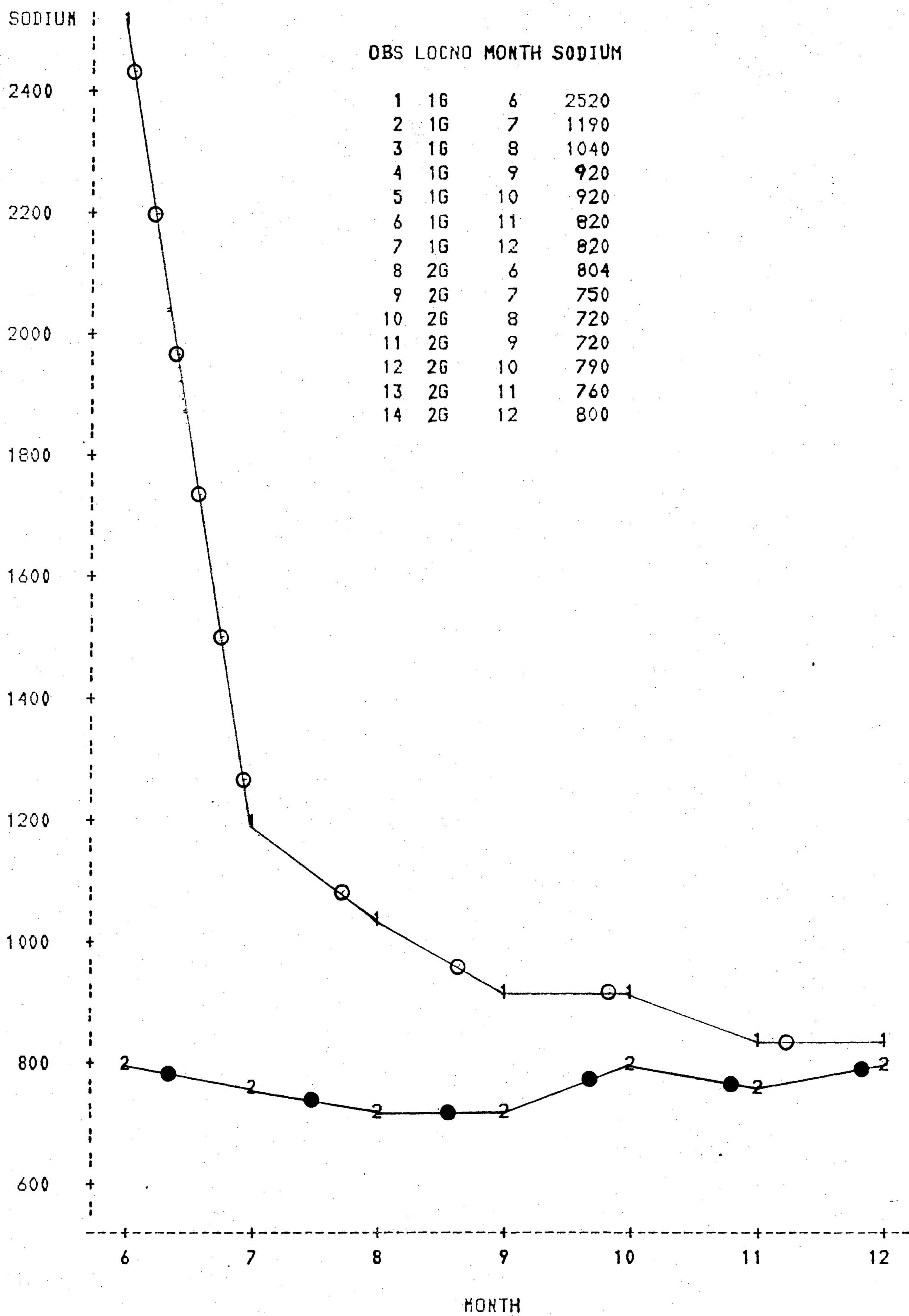
Section 2
Ground-Water Quality

Constituent vs. Time Profiles

Constituent	Concentration Units
Sodium	µg/ml Na
Magnesium	µg/ml Mg
Chloride	µg/ml Cl^-
Conductivity	µmho/cm
Hardness	µg/ml $CaCO_3$
Temperature	°C
Turbidity	turbidity units
Boron	µg/ml B
Lead	µg/ml Pb
Mercury	µg/ml Hg
Sulfate	µg/ml SO_4
pH	pH units

1 - WELL 1 —O—   2 - WELL 2 —●—

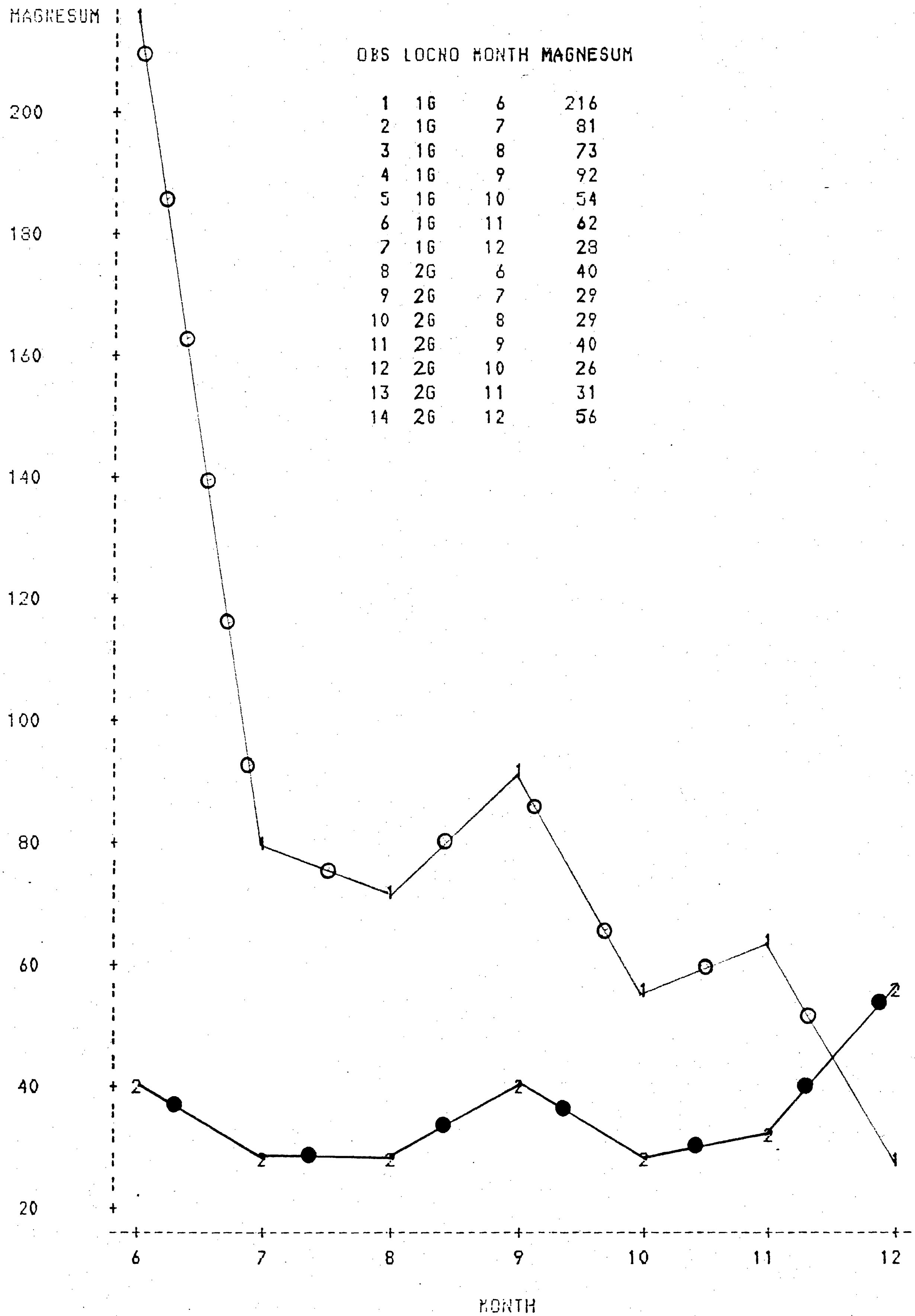
PLOT OF SODIUM*MONTH   SYMBOL IS VALUE OF LOCNO



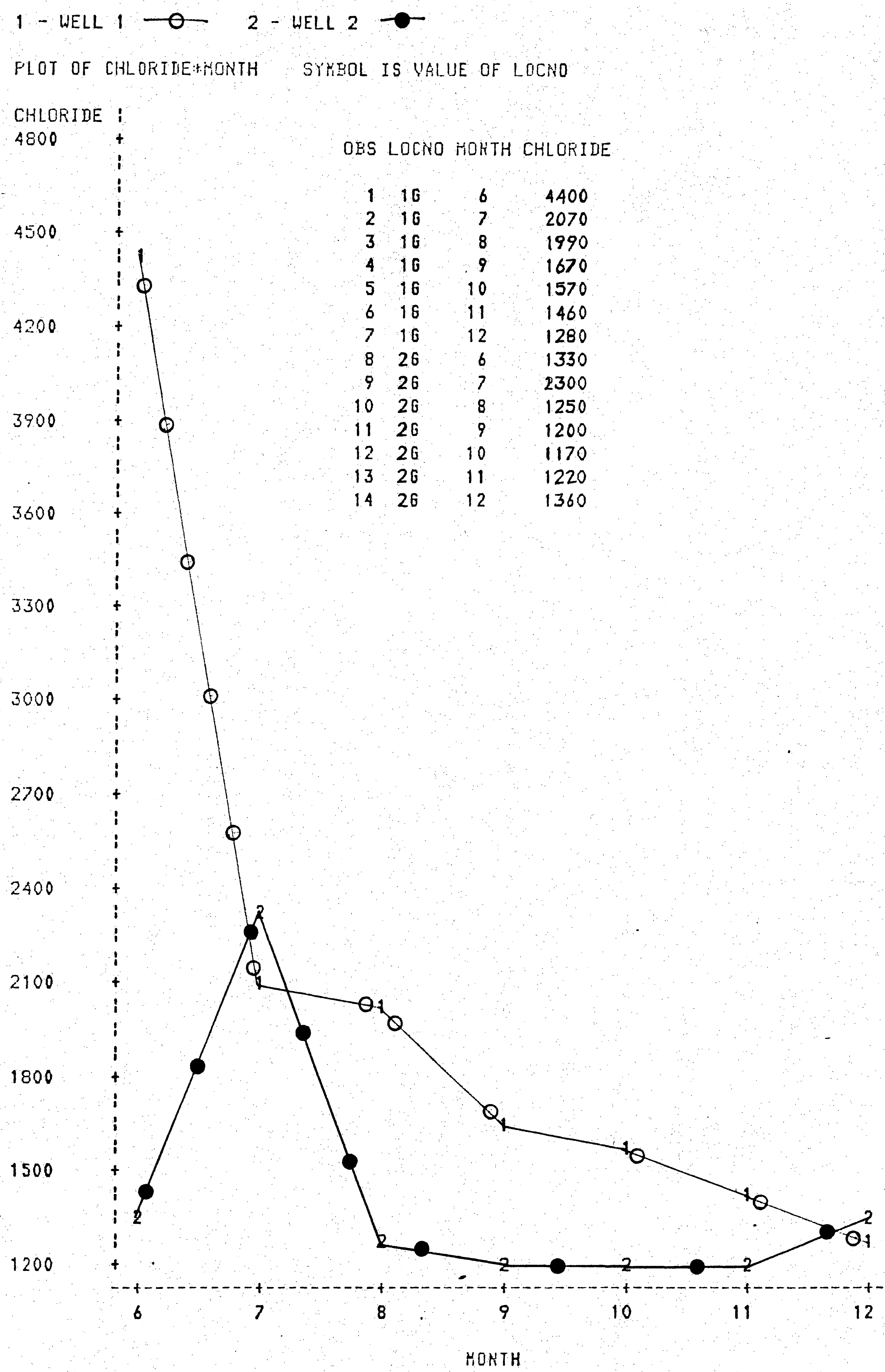
OBS	LOCNO	MONTH	SODIUM
1	1G	6	2520
2	1G	7	1190
3	1G	8	1040
4	1G	9	920
5	1G	10	920
6	1G	11	820
7	1G	12	820
8	2G	6	804
9	2G	7	750
10	2G	8	720
11	2G	9	720
12	2G	10	790
13	2G	11	760
14	2G	12	800

1 - WELL 1 —o—   2 - WELL 2 —●—

PLOT OF MAGNESUM*MONTH   SYMBOL IS VALUE OF LOCNO



OBS	LOCNO	MONTH	MAGNESUM
1	1G	6	216
2	1G	7	81
3	1G	8	73
4	1G	9	92
5	1G	10	54
6	1G	11	62
7	1G	12	28
8	2G	6	40
9	2G	7	29
10	2G	8	29
11	2G	9	40
12	2G	10	26
13	2G	11	31
14	2G	12	56

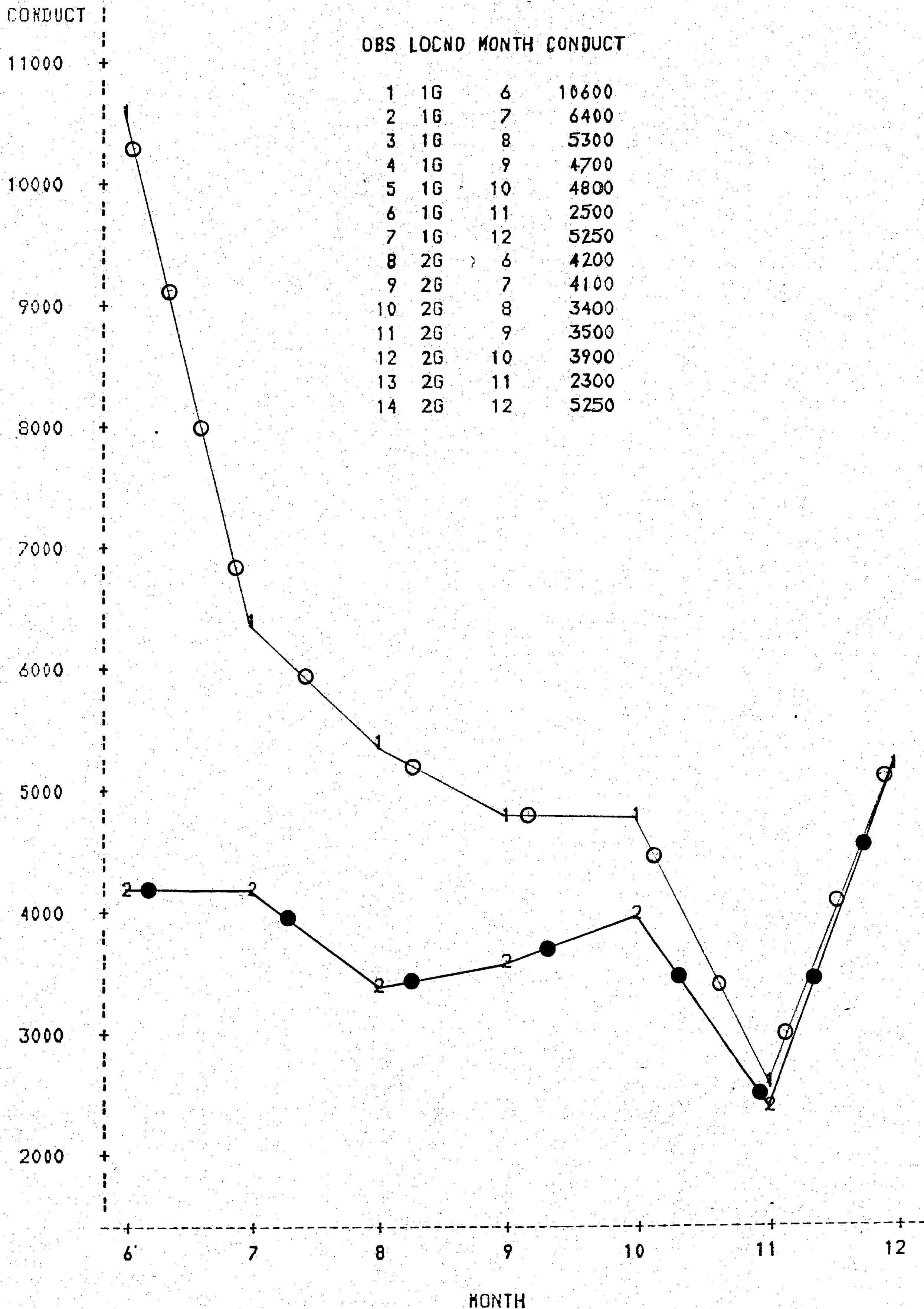


OBS	LOCNO	MONTH	CHLORIDE
1	1G	6	4400
2	1G	7	2070
3	1G	8	1990
4	1G	9	1670
5	1G	10	1570
6	1G	11	1460
7	1G	12	1280
8	2G	6	1330
9	2G	7	2300
10	2G	8	1250
11	2G	9	1200
12	2G	10	1170
13	2G	11	1220
14	2G	12	1360

1 - WELL 1 —O— 2 - WELL 2 —●—

PLOT OF CONDUCT*MONTH SYMBOL IS VALUE OF LOCNO

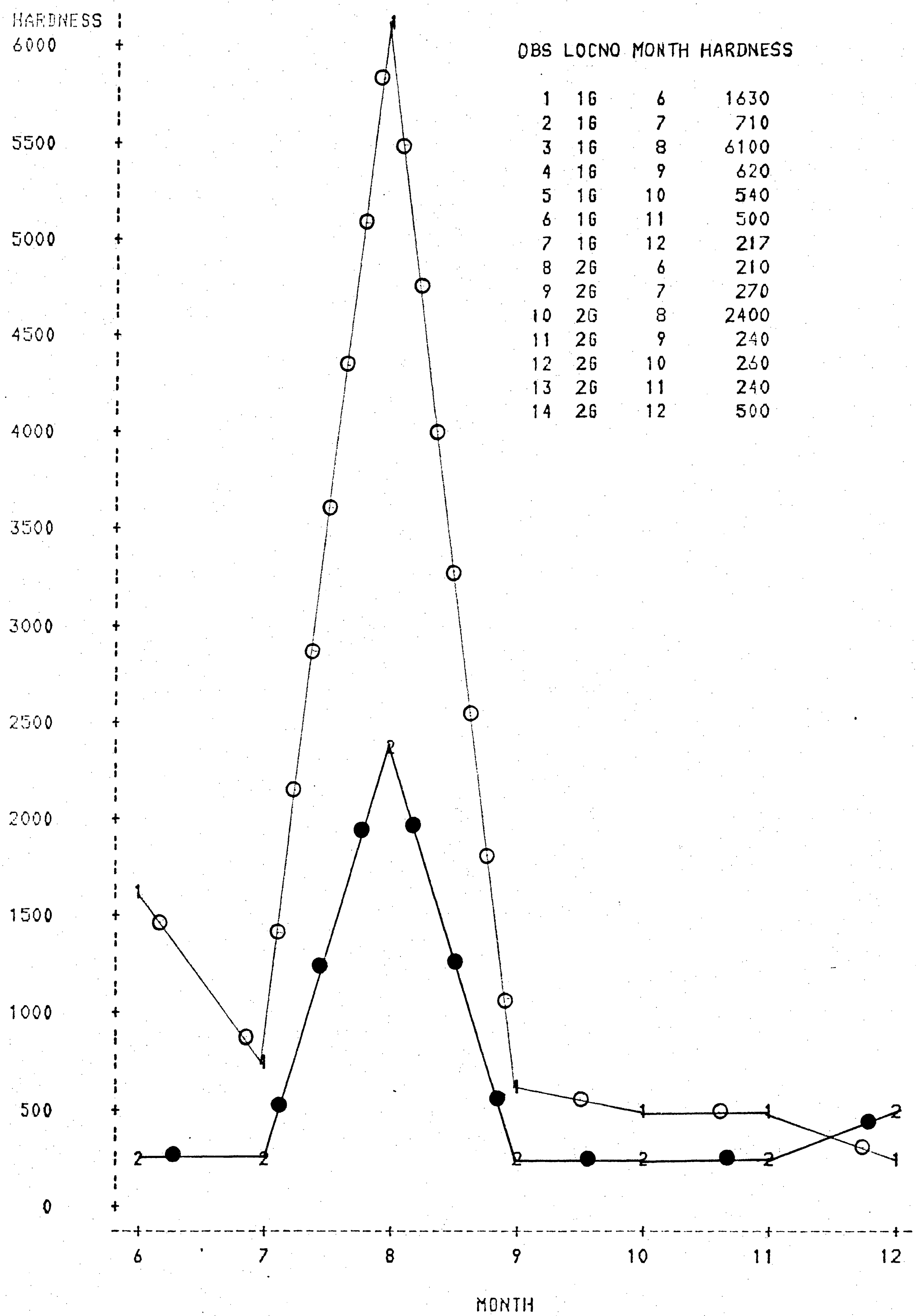
OBS	LOCNO	MONTH	CONDUCT
1	1G	6	10600
2	1G	7	6400
3	1G	8	5300
4	1G	9	4700
5	1G	10	4800
6	1G	11	2500
7	1G	12	5250
8	2G	6	4200
9	2G	7	4100
10	2G	8	3400
11	2G	9	3500
12	2G	10	3900
13	2G	11	2300
14	2G	12	5250



NOTE: 1 OBS HIDDEN

1 - WELL 1 —O—   2 - WELL 2 —●—

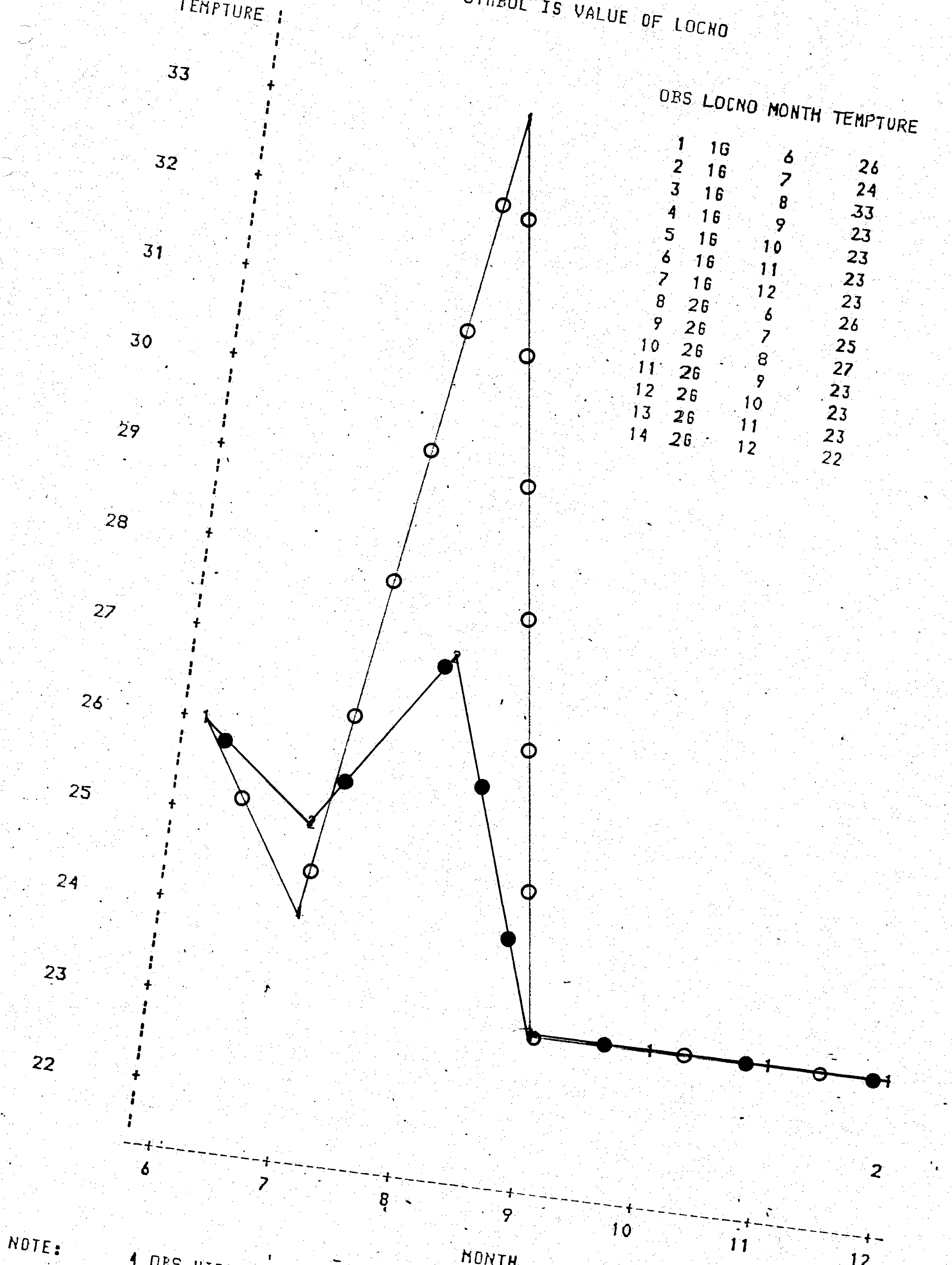
PLOT OF HARDNESS*MONTH   SYMBOL IS VALUE OF LOCNO



OBS	LOCNO	MONTH	HARDNESS
1	1G	6	1630
2	1G	7	710
3	1G	8	6100
4	1G	9	620
5	1G	10	540
6	1G	11	500
7	1G	12	217
8	2G	6	210
9	2G	7	270
10	2G	8	2400
11	2G	9	240
12	2G	10	260
13	2G	11	240
14	2G	12	500

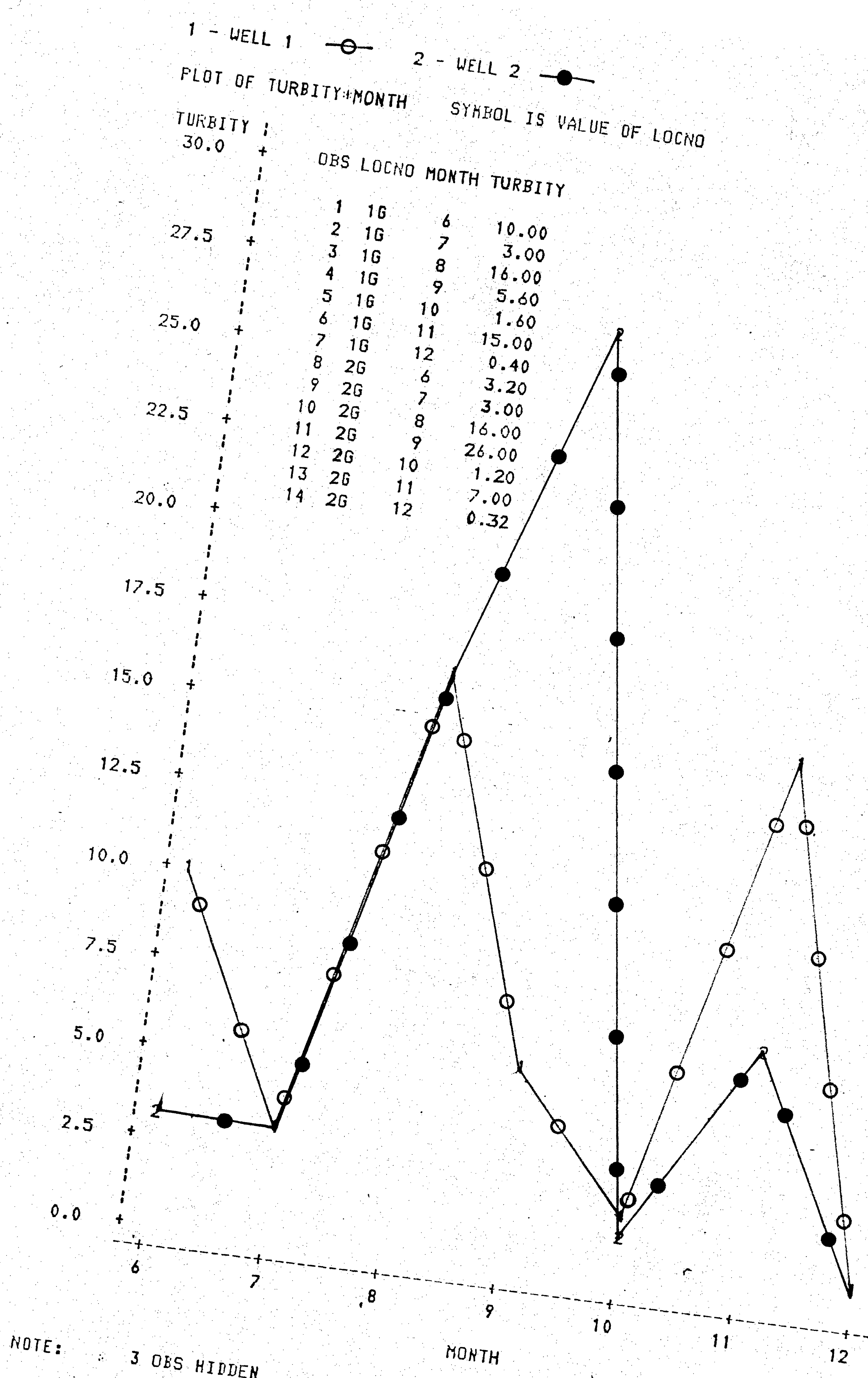
1 - WELL 1 —O— 2 - WELL 2 —●—

PLOT OF TEMPTURE*MONTH SYMBOL IS VALUE OF LOCNO



OBS	LOCNO	MONTH	TEMPTURE
1	16	6	26
2	16	7	24
3	16	8	33
4	16	9	23
5	16	10	23
6	16	11	23
7	16	12	23
8	26	6	26
9	26	7	25
10	26	8	27
11	26	9	23
12	26	10	23
13	26	11	23
14	26	12	22

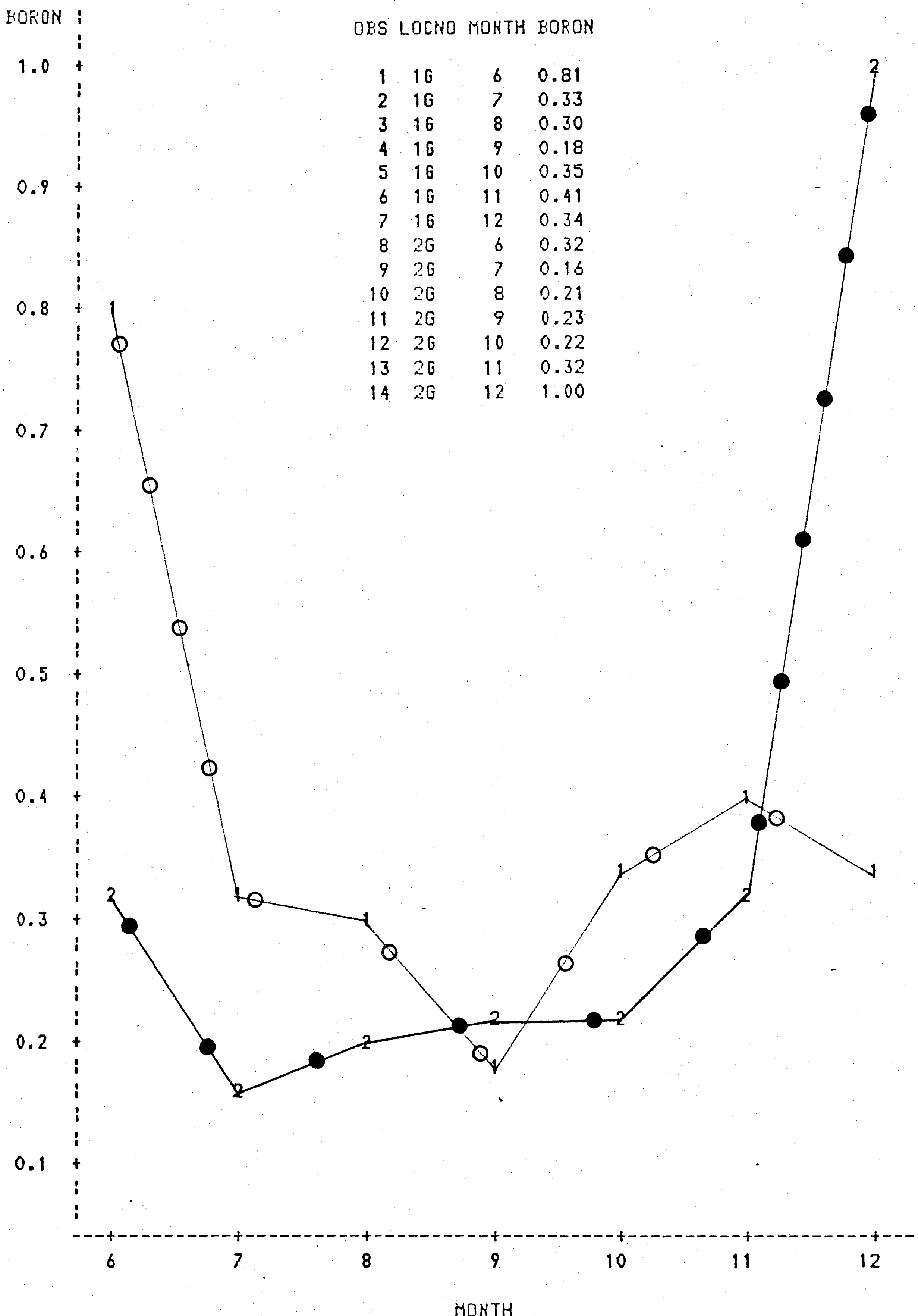
NOTE: 4 OBS HIDDEN



OBS	LOCNO	MONTH	TURBITY
1	1G	6	10.00
2	1G	7	3.00
3	1G	8	16.00
4	1G	9	5.60
5	1G	10	1.60
6	1G	11	15.00
7	1G	12	0.40
8	2G	6	3.20
9	2G	7	3.00
10	2G	8	16.00
11	2G	9	26.00
12	2G	10	1.20
13	2G	11	7.00
14	2G	12	0.32

1 - WELL 1   2 - WELL 2

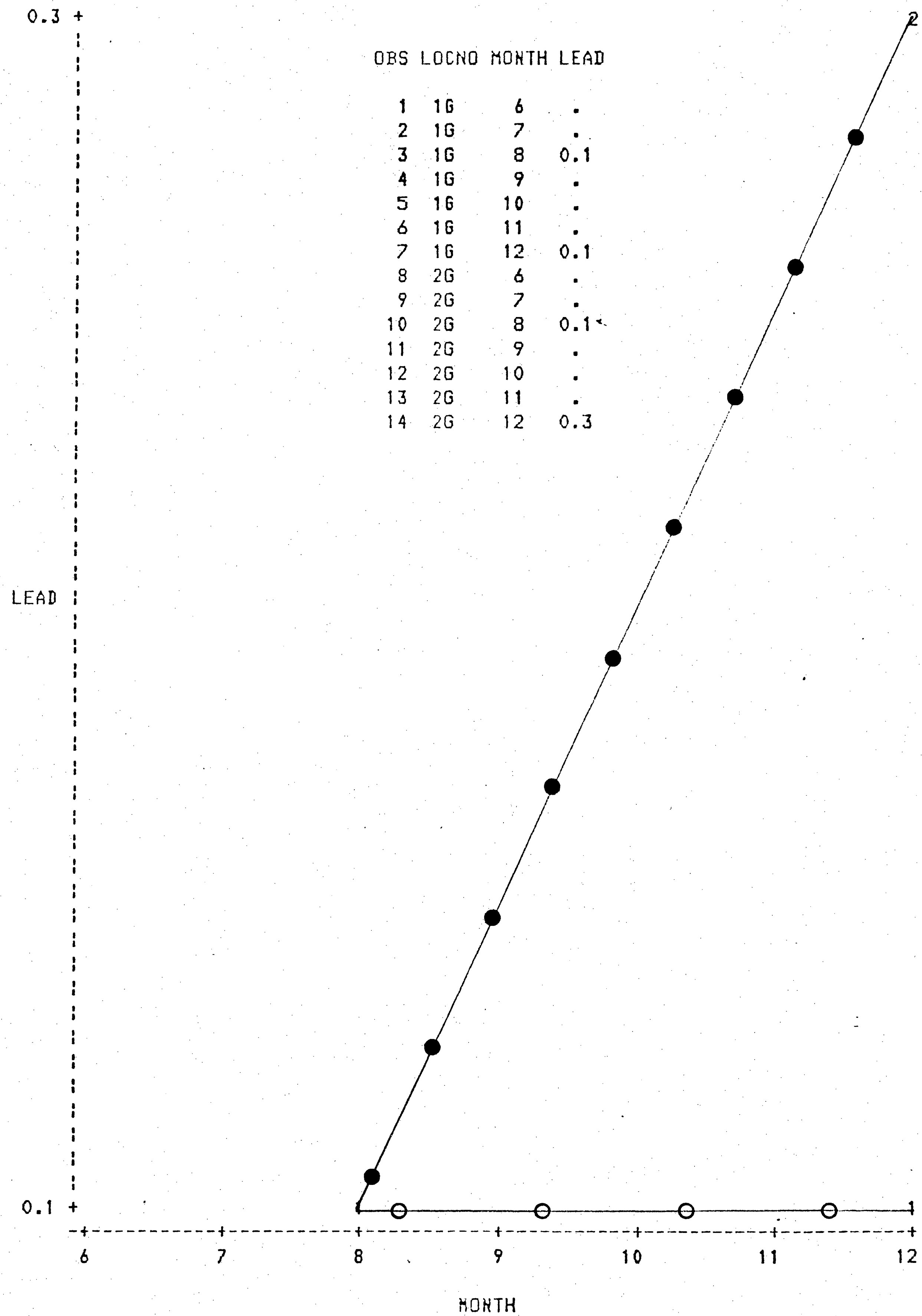
PLOT OF BORON*MONTH   SYMBOL IS VALUE OF LOCNO



OBS	LOCNO	MONTH	BORON
1	1G	6	0.81
2	1G	7	0.33
3	1G	8	0.30
4	1G	9	0.18
5	1G	10	0.35
6	1G	11	0.41
7	1G	12	0.34
8	2G	6	0.32
9	2G	7	0.16
10	2G	8	0.21
11	2G	9	0.23
12	2G	10	0.22
13	2G	11	0.32
14	2G	12	1.00

1 - WELL 1 —O—   2 - WELL 2 —●—

PLOT OF LEAD*MONTH   SYMBOL IS VALUE OF LOCNO

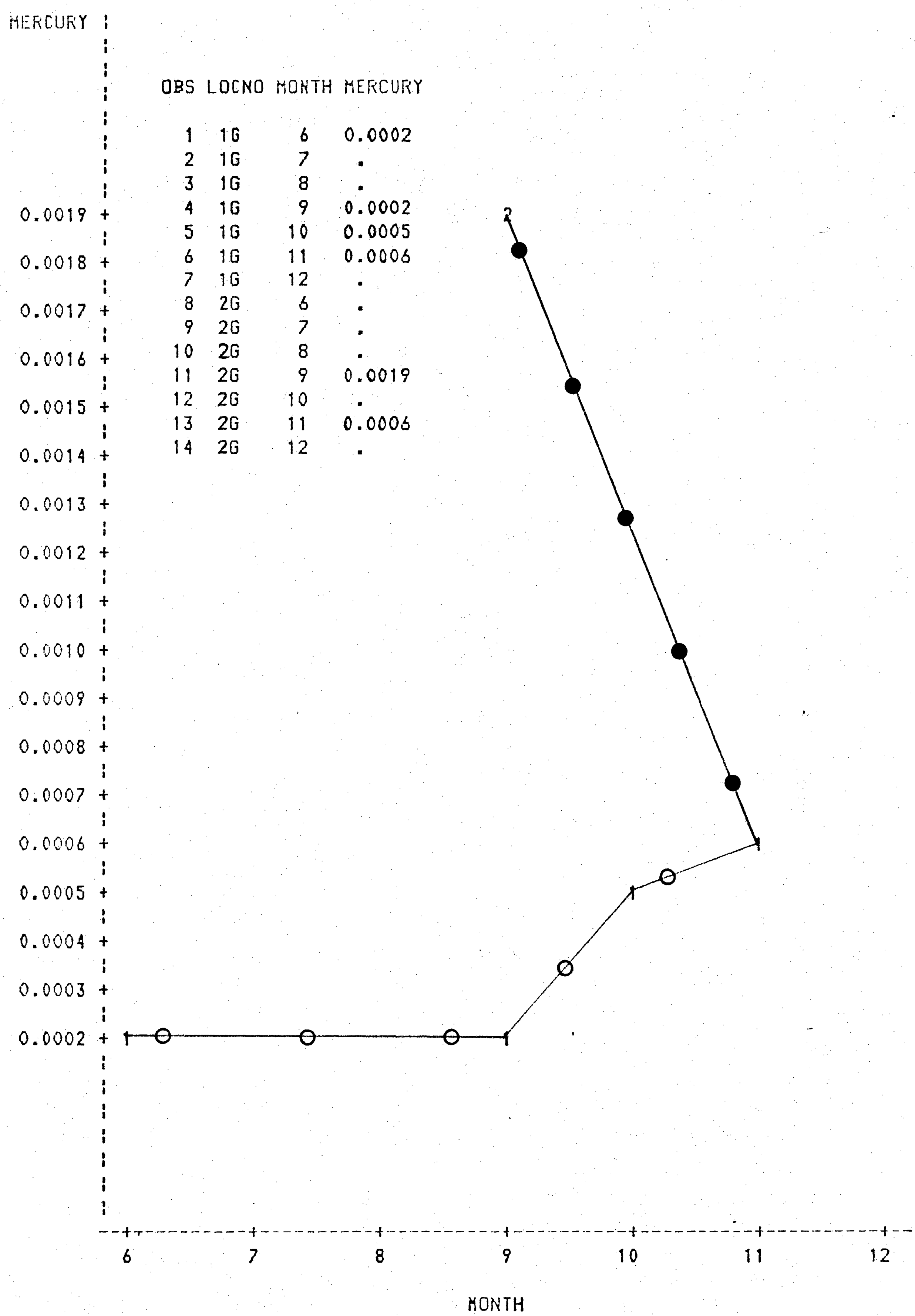


OBS	LOCNO	MONTH	LEAD
1	1G	6	.
2	1G	7	.
3	1G	8	0.1
4	1G	9	.
5	1G	10	.
6	1G	11	.
7	1G	12	0.1
8	2G	6	.
9	2G	7	.
10	2G	8	0.1
11	2G	9	.
12	2G	10	.
13	2G	11	.
14	2G	12	0.3

NOTE: 10 OBS HAD MISSING VALUES   1 OBS HIDDEN

1 - WELL 1 —O— 2 - WELL 2 —●—

PLOT OF MERCURY*MONTH SYMBOL IS VALUE OF LOCNO

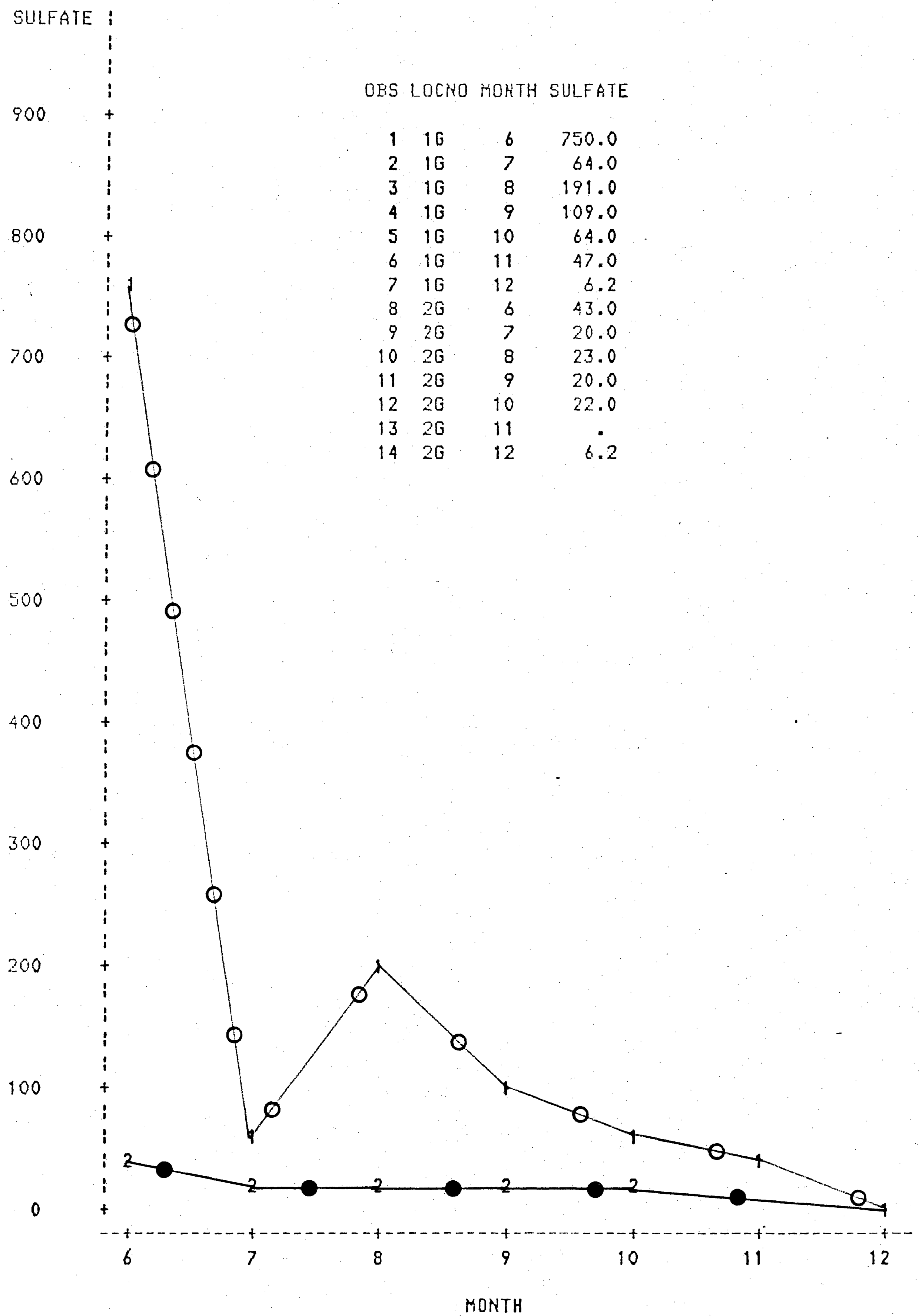


OBS	LOCNO	MONTH	MERCURY
1	1G	6	0.0002
2	1G	7	.
3	1G	8	.
4	1G	9	0.0002
5	1G	10	0.0005
6	1G	11	0.0006
7	1G	12	.
8	2G	6	.
9	2G	7	.
10	2G	8	.
11	2G	9	0.0019
12	2G	10	.
13	2G	11	0.0006
14	2G	12	.

NOTE: 8 OBS HAD MISSING VALUES 1 OBS HIDDEN

1 - WELL 1 —O—   2 - WELL 2 —●—

PLOT OF SULFATE*MONTH   SYMBOL IS VALUE OF LOCNO



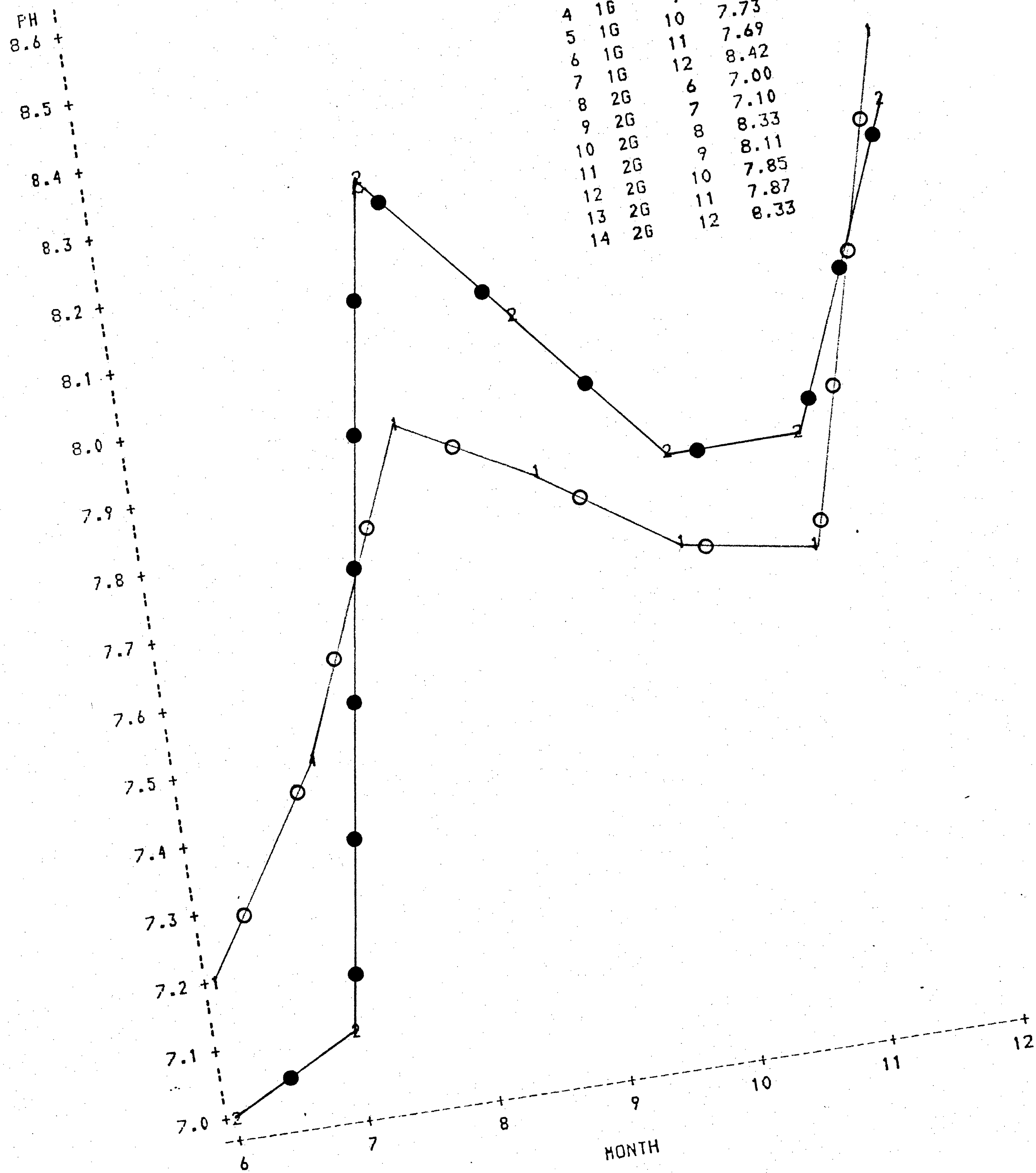
OBS	LOCNO	MONTH	SULFATE
1	1G	6	750.0
2	1G	7	64.0
3	1G	8	191.0
4	1G	9	109.0
5	1G	10	64.0
6	1G	11	47.0
7	1G	12	6.2
8	2G	6	43.0
9	2G	7	20.0
10	2G	8	23.0
11	2G	9	20.0
12	2G	10	22.0
13	2G	11	.
14	2G	12	6.2

NOTE: 1 OBS HAD MISSING VALUES   1 OBS HIDDEN

1 - WELL 1 —O— 2 - WELL 2 —●—

PLOT OF PH*MONTH SYMBOL IS VALUE OF LOCNO

OBS	LOCNO	MONTH	PH
1	1G	6	7.20
2	1G	7	7.50
3	1G	8	7.98
4	1G	9	7.85
5	1G	10	7.73
6	1G	11	7.69
7	1G	12	8.42
8	2G	6	7.00
9	2G	7	7.10
10	2G	8	8.33
11	2G	9	8.11
12	2G	10	7.85
13	2G	11	7.87
14	2G	12	8.33



APPENDIX B

Parcperdue

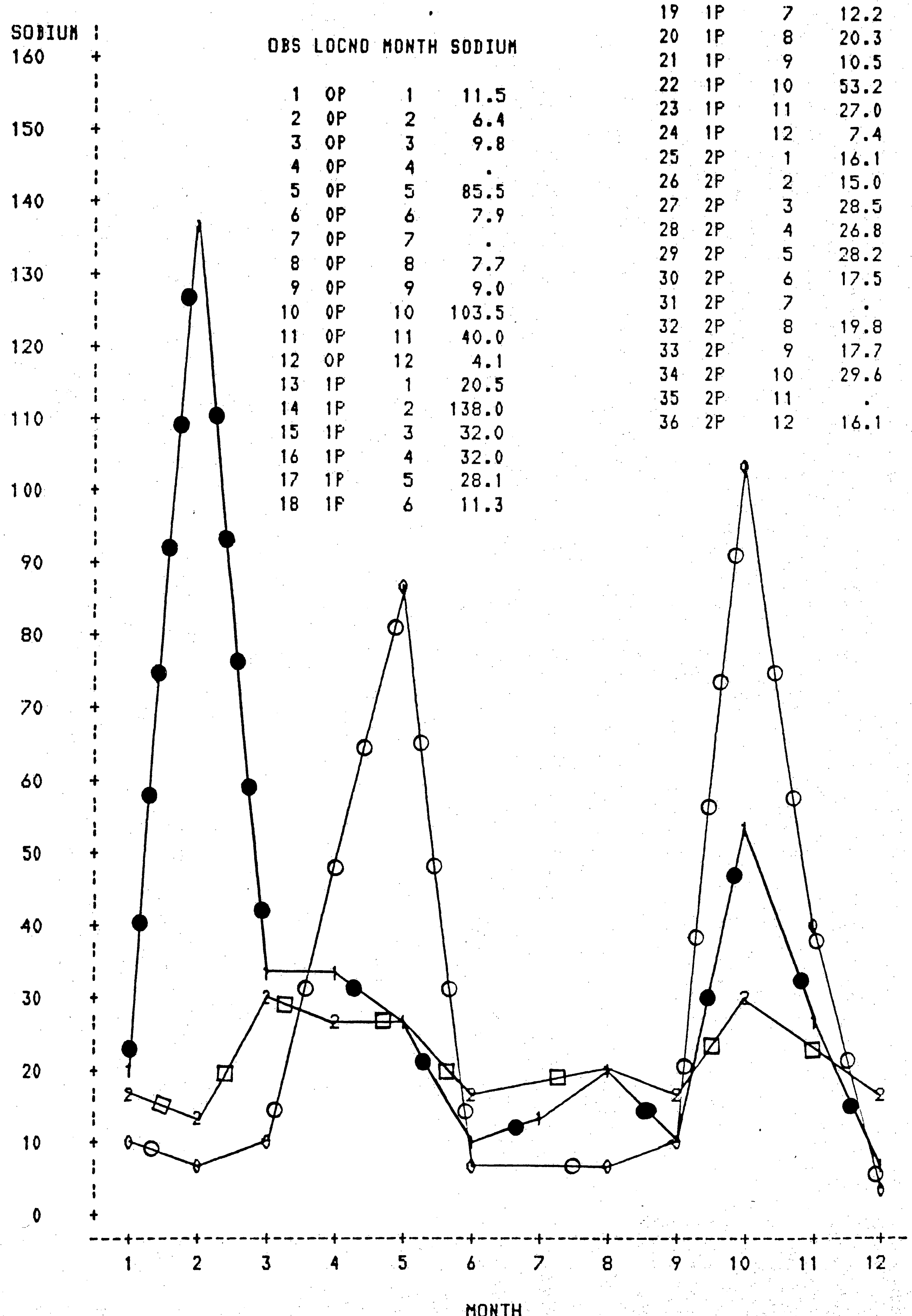
Section 1
Surface Water-Quality

Constituent vs. Time Profiles

Constituent	Concentration Units
Sodium	$\mu g/ml$ Na
Magnesium	$\mu g/ml$ Mg
Chloride	$\mu g/ml$ Cl^-
Conductivity	$\mu mho/cm$
Hardness	$\mu g/ml$ $CaCO_3$
Temperature	°C
Turbidity	turbidity units
Boron	$\mu g/ml$ B
Sulfate	$\mu g/ml$ SO_4
pH	pH units

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF SODIUM*MONTH SYMBOL IS VALUE OF LOCNO

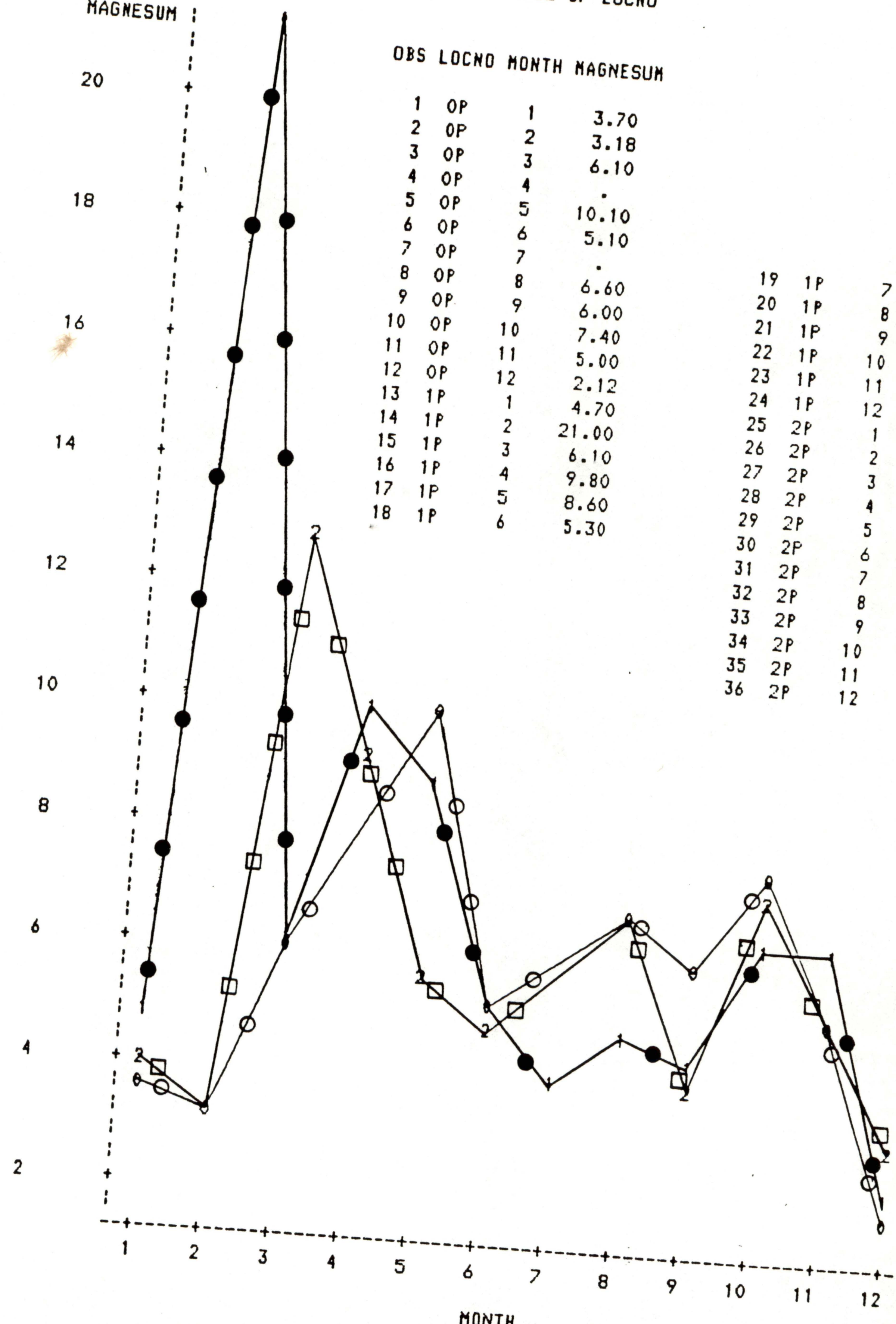


OBS	LOCNO	MONTH	SODIUM
1	0P	1	11.5
2	0P	2	6.4
3	0P	3	9.8
4	0P	4	.
5	0P	5	85.5
6	0P	6	7.9
7	0P	7	.
8	0P	8	7.7
9	0P	9	9.0
10	0P	10	103.5
11	0P	11	40.0
12	0P	12	4.1
13	1P	1	20.5
14	1P	2	138.0
15	1P	3	32.0
16	1P	4	32.0
17	1P	5	28.1
18	1P	6	11.3
19	1P	7	12.2
20	1P	8	20.3
21	1P	9	10.5
22	1P	10	53.2
23	1P	11	27.0
24	1P	12	7.4
25	2P	1	16.1
26	2P	2	15.0
27	2P	3	28.5
28	2P	4	26.8
29	2P	5	28.2
30	2P	6	17.5
31	2P	7	.
32	2P	8	19.8
33	2P	9	17.7
34	2P	10	29.6
35	2P	11	.
36	2P	12	16.1

NOTE: 4 OBS HAD MISSING VALUES 3 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, ○ 1- BAYOU, ● 2- LEBLANCH NEAR RIVER □

PLOT OF MAGNESUM*MONTH SYMBOL IS VALUE OF LOCNO

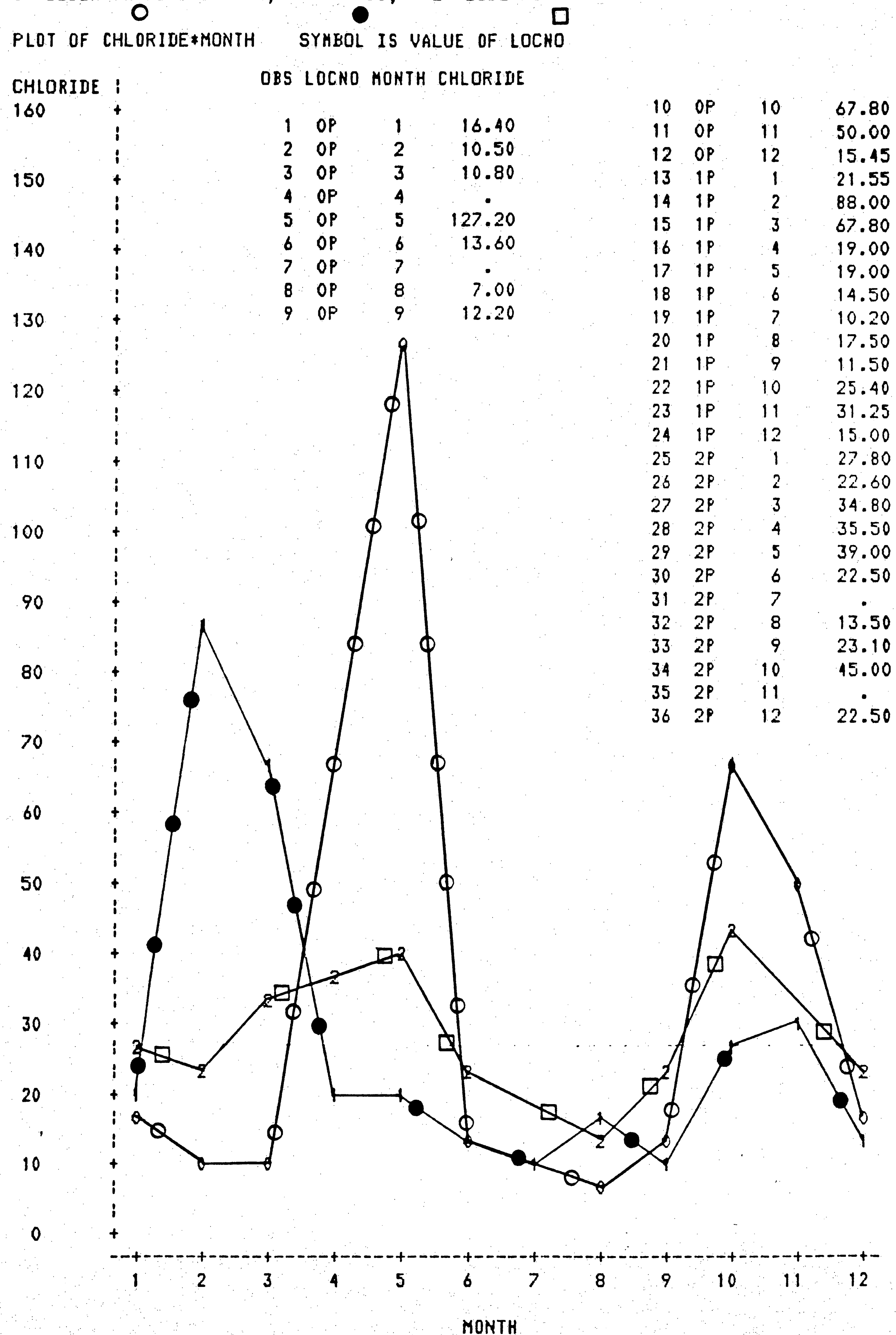


OBS	LOCNO	MONTH	MAGNESUM
1	0P	1	3.70
2	0P	2	3.18
3	0P	3	6.10
4	0P	4	.
5	0P	5	10.10
6	0P	6	5.10
7	0P	7	.
8	0P	8	6.60
9	0P	9	6.00
10	0P	10	7.40
11	0P	11	5.00
12	0P	12	2.12
13	1P	1	4.70
14	1P	2	21.00
15	1P	3	6.10
16	1P	4	9.80
17	1P	5	8.60
18	1P	6	5.30
19	1P	7	3.9
20	1P	8	4.9
21	1P	9	4.2
22	1P	10	6.3
23	1P	11	6.30
24	1P	12	2.58
25	2P	1	4.14
26	2P	2	3.30
27	2P	3	12.60
28	2P	4	9.00
29	2P	5	5.70
30	2P	6	4.60
31	2P	7	.
32	2P	8	6.90
33	2P	9	4.10
34	2P	10	7.10
35	2P	11	.
36	2P	12	3.26

NOTE: 4 OBS HAD MISSING VALUES 4 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF CHLORIDE*MONTH SYMBOL IS VALUE OF LOCNO

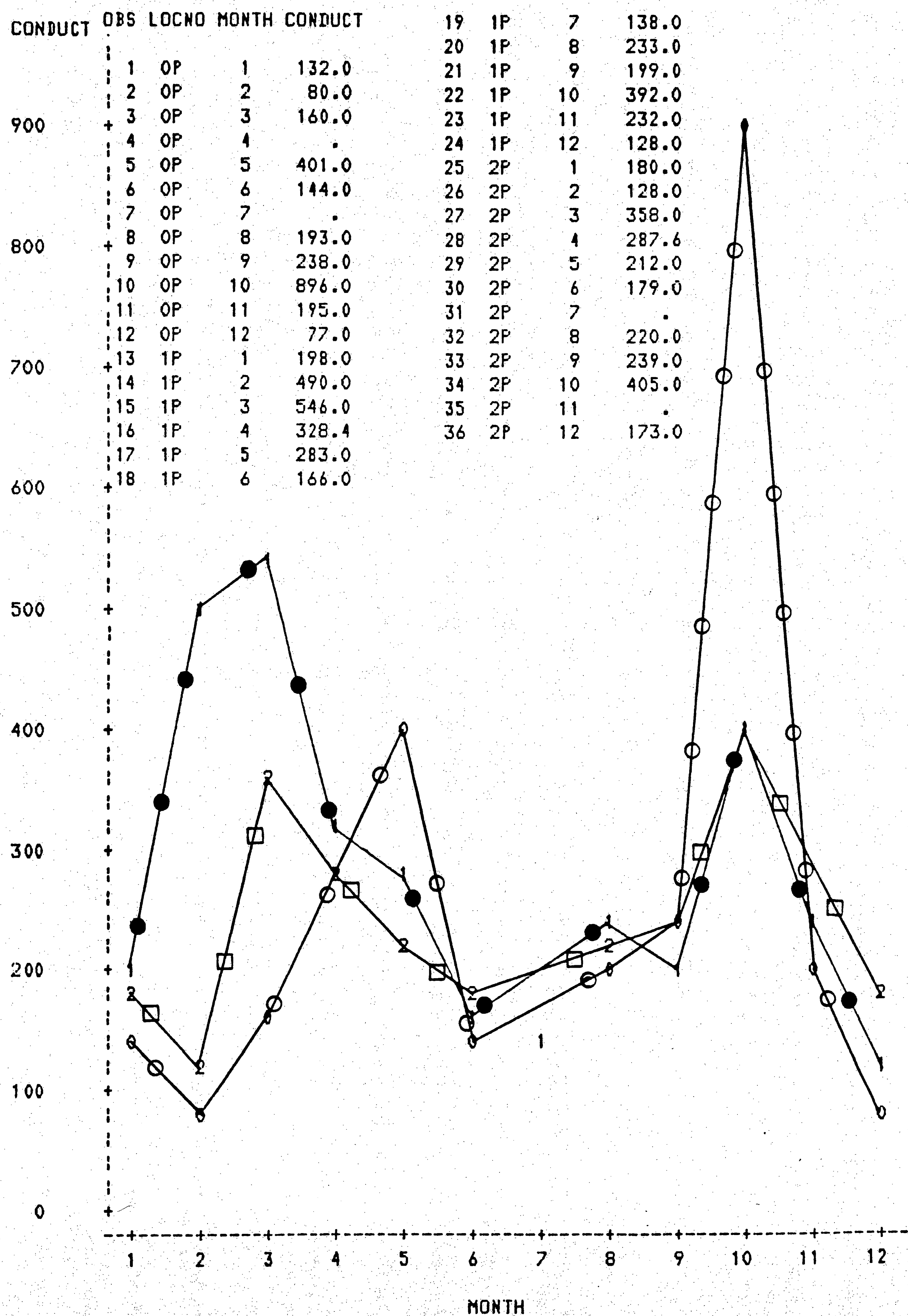


OBS	LOCNO	MONTH	CHLORIDE
1	0P	1	16.40
2	0P	2	10.50
3	0P	3	10.80
4	0P	4	.
5	0P	5	127.20
6	0P	6	13.60
7	0P	7	.
8	0P	8	7.00
9	0P	9	12.20
10	0P	10	67.80
11	0P	11	50.00
12	0P	12	15.45
13	1P	1	21.55
14	1P	2	88.00
15	1P	3	67.80
16	1P	4	19.00
17	1P	5	19.00
18	1P	6	14.50
19	1P	7	10.20
20	1P	8	17.50
21	1P	9	11.50
22	1P	10	25.40
23	1P	11	31.25
24	1P	12	15.00
25	2P	1	27.80
26	2P	2	22.60
27	2P	3	34.80
28	2P	4	35.50
29	2P	5	39.00
30	2P	6	22.50
31	2P	7	.
32	2P	8	13.50
33	2P	9	23.10
34	2P	10	45.00
35	2P	11	.
36	2P	12	22.50

NOTE: 4 OBS HAD MISSING VALUES 1 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF CONDUCT*MONTH SYMBOL IS VALUE OF LOCNO

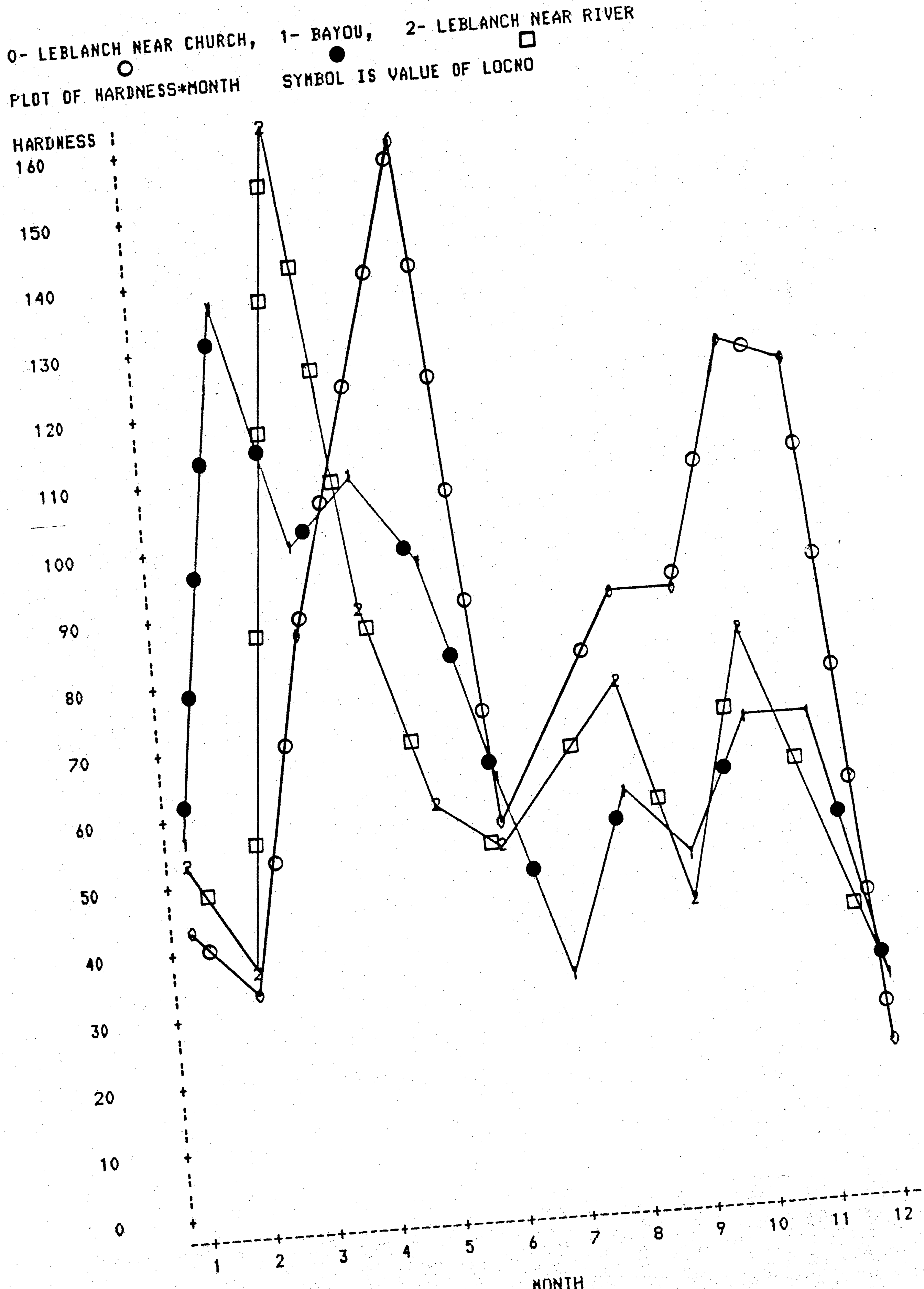


OBS	LOCNO	MONTH	CONDUCT
1	0P	1	132.0
2	0P	2	80.0
3	0P	3	160.0
4	0P	4	.
5	0P	5	401.0
6	0P	6	144.0
7	0P	7	.
8	0P	8	193.0
9	0P	9	238.0
10	0P	10	896.0
11	0P	11	195.0
12	0P	12	77.0
13	1P	1	198.0
14	1P	2	490.0
15	1P	3	546.0
16	1P	4	328.4
17	1P	5	283.0
18	1P	6	166.0
19	1P	7	138.0
20	1P	8	233.0
21	1P	9	199.0
22	1P	10	392.0
23	1P	11	232.0
24	1P	12	128.0
25	2P	1	180.0
26	2P	2	128.0
27	2P	3	358.0
28	2P	4	287.6
29	2P	5	212.0
30	2P	6	179.0
31	2P	7	.
32	2P	8	220.0
33	2P	9	239.0
34	2P	10	405.0
35	2P	11	.
36	2P	12	173.0

NOTE: 4 OBS HAD MISSING VALUES 2 OBS HIDDEN

OBS	LOCNO	MONTH	HARDNESS
1	0P	1	43.0
2	0P	2	34.8
3	0P	3	85.1
4	0P	4	.
5	0P	5	158.4
6	0P	6	56.7
7	0P	7	.
8	0P	8	91.0
9	0P	9	91.6
10	0P	10	127.3
11	0P	11	124.3
12	0P	12	18.9
13	1P	1	55.7
14	1P	2	138.2
15	1P	3	99.9
16	1P	4	108.5
17	1P	5	95.6
18	1P	6	64.0
19	1P	7	32.7
20	1P	8	59.3
21	1P	9	49.7
22	1P	10	69.5
23	1P	11	69.9
24	1P	12	28.9
25	2P	1	53.7
26	2P	2	35.9
27	2P	3	162.4
28	2P	4	90.7
29	2P	5	61.5
30	2P	6	51.7
31	2P	7	.
32	2P	8	77.3
33	2P	9	43.8
34	2P	10	84.2
35	2P	11	.
36	2P	12	30.6

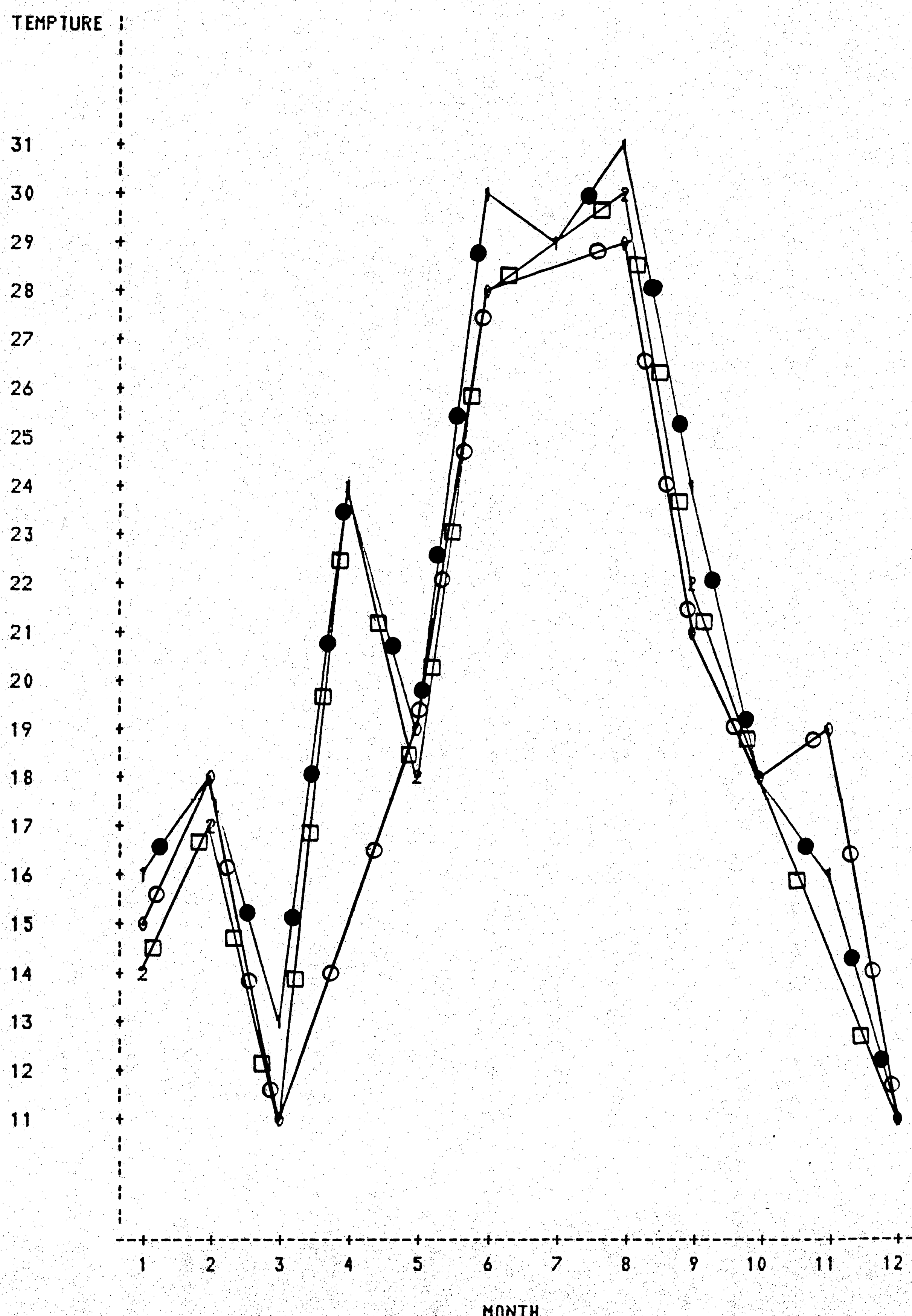
OBS	LOCNO	MONTH	TEMPTURE
1	0P	1	15
2	0P	2	18
3	0P	3	11
4	0P	4	.
5	0P	5	19
6	0P	6	28
7	0P	7	.
8	0P	8	29
9	0P	9	21
10	0P	10	18
11	0P	11	19
12	0P	12	11
13	1P	1	16
14	1P	2	18
15	1P	3	13
16	1P	4	24
17	1P	5	19
18	1P	6	30
19	1P	7	29
20	1P	8	31
21	1P	9	24
22	1P	10	18
23	1P	11	16
24	1P	12	11
25	2P	1	14
26	2P	2	17
27	2P	3	11
28	2P	4	24
29	2P	5	18
30	2P	6	28
31	2P	7	.
32	2P	8	30
33	2P	9	22
34	2P	10	18
35	2P	11	.
36	2P	12	11



NOTE: 4 OBS HAD MISSING VALUES 1 OBS HIDDEN

O- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

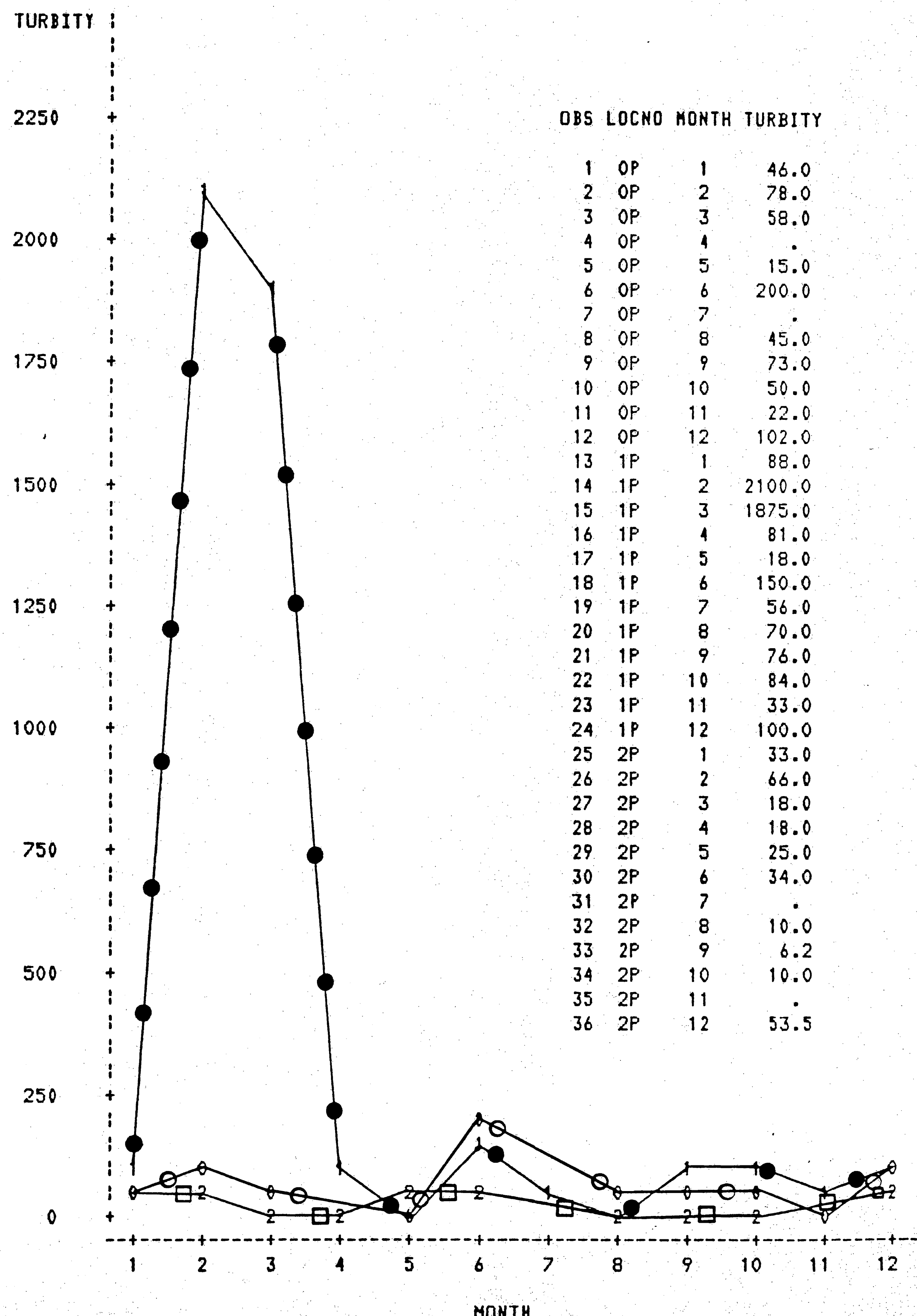
PLOT OF TEMPTURE*MONTH SYMBOL IS VALUE OF LOCNO



NOTE: 4 OBS HAD MISSING VALUES 9 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF TURBITY*MONTH SYMBOL IS VALUE OF LOCNO

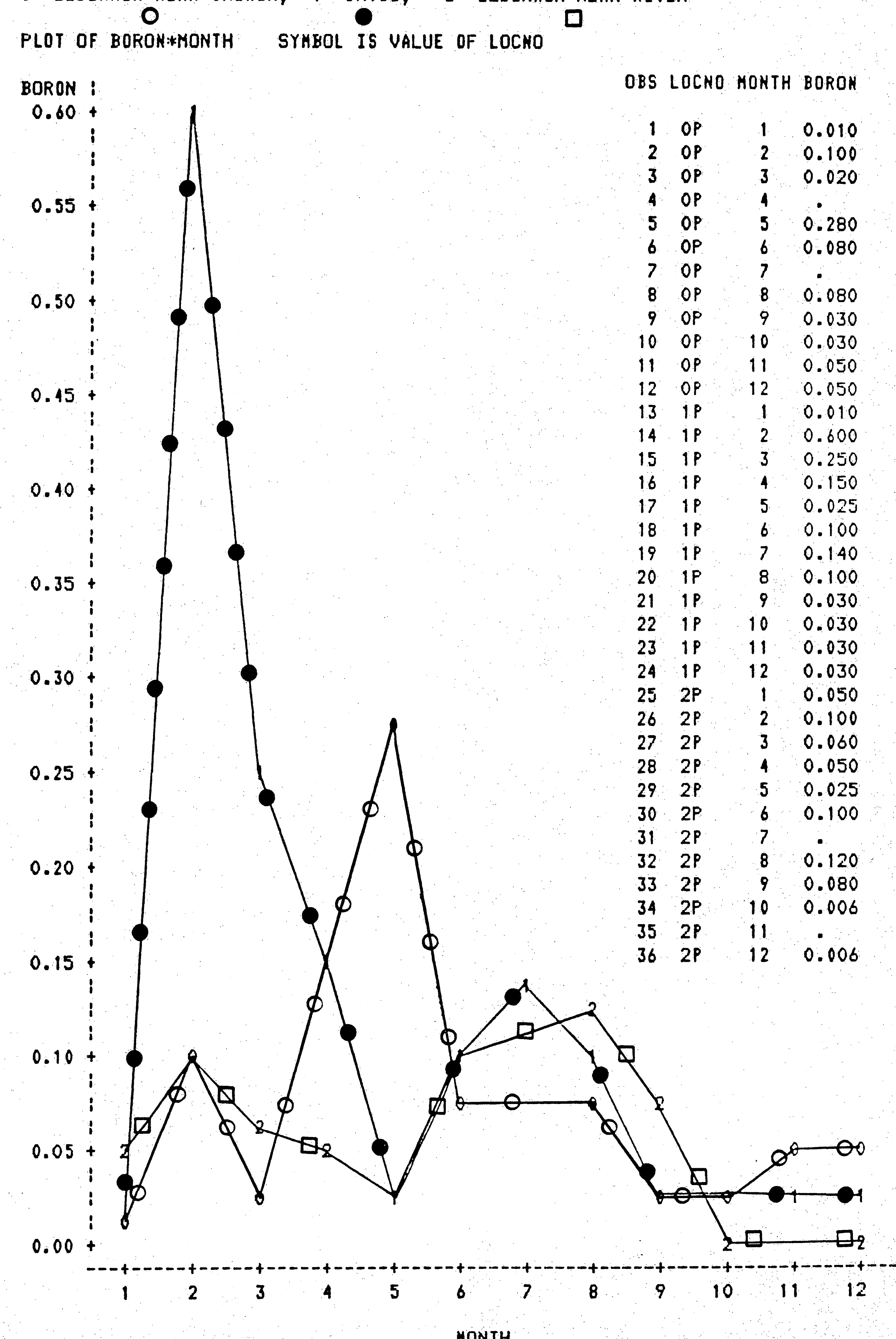


OBS	LOCNO	MONTH	TURBITY
1	0P	1	46.0
2	0P	2	78.0
3	0P	3	58.0
4	0P	4	.
5	0P	5	15.0
6	0P	6	200.0
7	0P	7	.
8	0P	8	45.0
9	0P	9	73.0
10	0P	10	50.0
11	0P	11	22.0
12	0P	12	102.0
13	1P	1	88.0
14	1P	2	2100.0
15	1P	3	1875.0
16	1P	4	81.0
17	1P	5	18.0
18	1P	6	150.0
19	1P	7	56.0
20	1P	8	70.0
21	1P	9	76.0
22	1P	10	84.0
23	1P	11	33.0
24	1P	12	100.0
25	2P	1	33.0
26	2P	2	66.0
27	2P	3	18.0
28	2P	4	18.0
29	2P	5	25.0
30	2P	6	34.0
31	2P	7	.
32	2P	8	10.0
33	2P	9	6.2
34	2P	10	10.0
35	2P	11	.
36	2P	12	53.5

NOTE: 4 OBS HAD MISSING VALUES 4 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF BORON*MONTH SYMBOL IS VALUE OF LOCNO

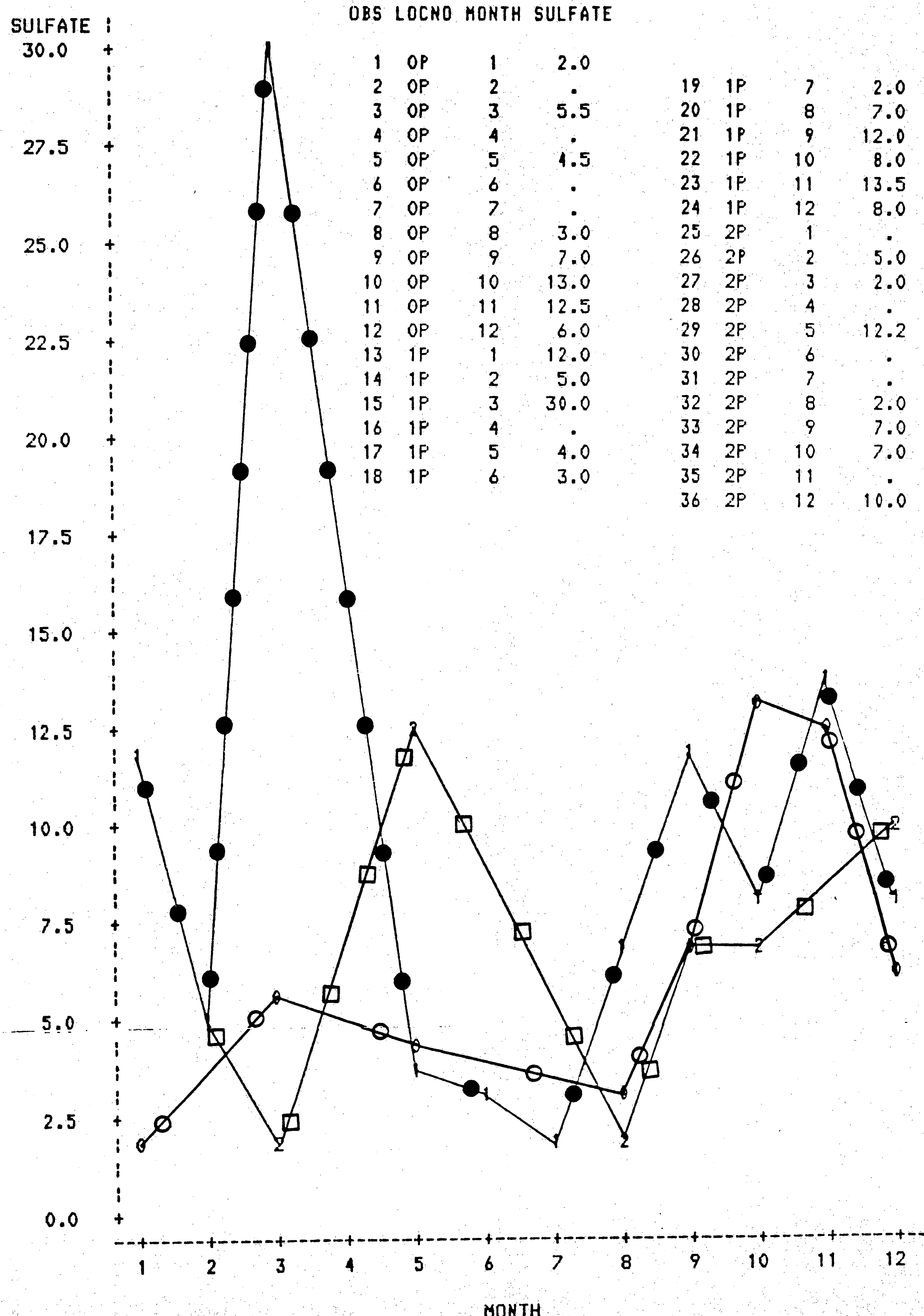


OBS	LOCNO	MONTH	BORON
1	OP	1	0.010
2	OP	2	0.100
3	OP	3	0.020
4	OP	4	.
5	OP	5	0.280
6	OP	6	0.080
7	OP	7	.
8	OP	8	0.080
9	OP	9	0.030
10	OP	10	0.030
11	OP	11	0.050
12	OP	12	0.050
13	1P	1	0.010
14	1P	2	0.600
15	1P	3	0.250
16	1P	4	0.150
17	1P	5	0.025
18	1P	6	0.100
19	1P	7	0.140
20	1P	8	0.100
21	1P	9	0.030
22	1P	10	0.030
23	1P	11	0.030
24	1P	12	0.030
25	2P	1	0.050
26	2P	2	0.100
27	2P	3	0.060
28	2P	4	0.050
29	2P	5	0.025
30	2P	6	0.100
31	2P	7	.
32	2P	8	0.120
33	2P	9	0.080
34	2P	10	0.006
35	2P	11	.
36	2P	12	0.006

NOTE: 4 OBS HAD MISSING VALUES 6 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF SULFATE*MONTH SYMBOL IS VALUE OF LOCNO

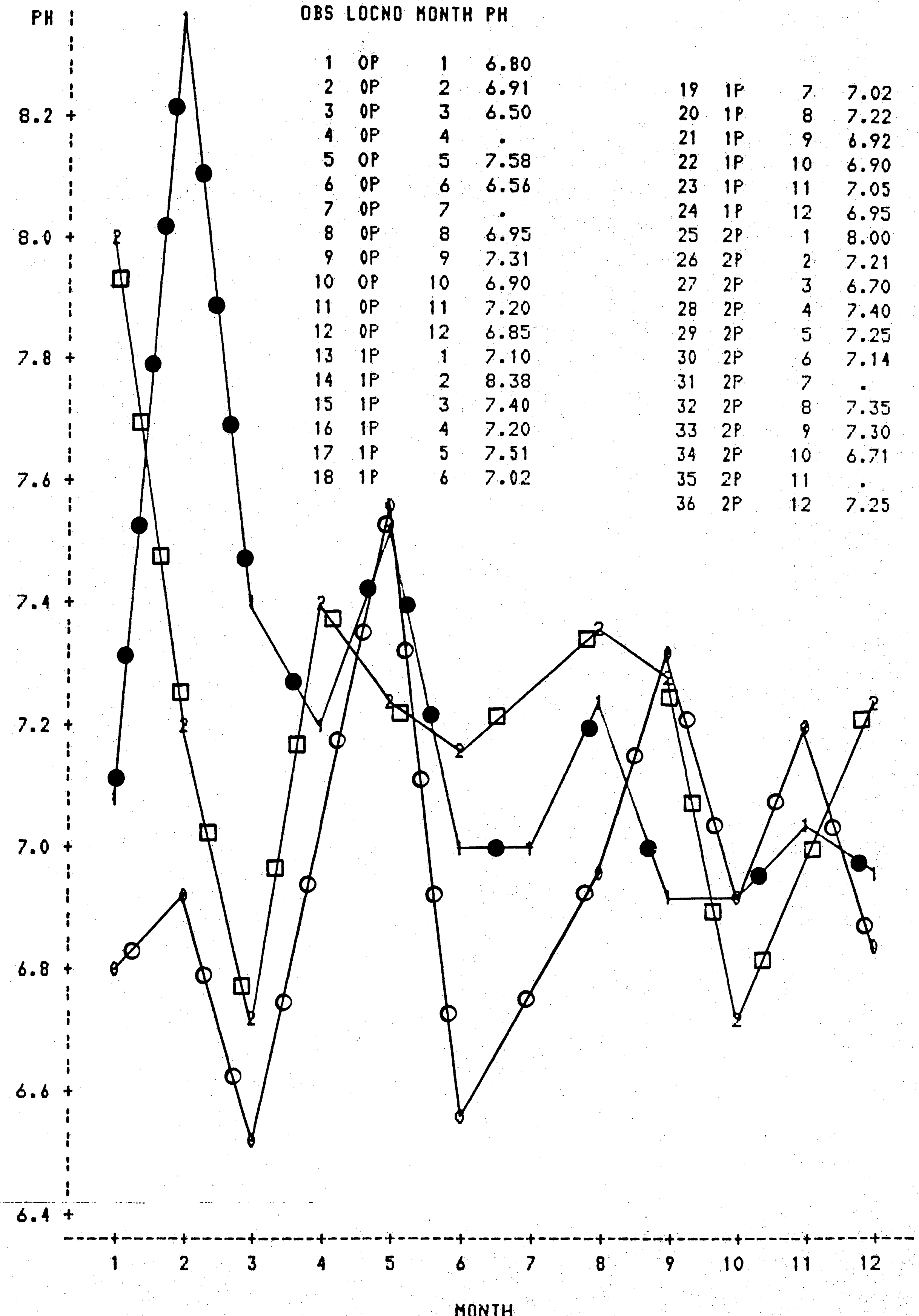


OBS	LOCNO	MONTH	SULFATE
1	0P	1	2.0
2	0P	2	.
3	0P	3	5.5
4	0P	4	.
5	0P	5	4.5
6	0P	6	.
7	0P	7	.
8	0P	8	3.0
9	0P	9	7.0
10	0P	10	13.0
11	0P	11	12.5
12	0P	12	6.0
13	1P	1	12.0
14	1P	2	5.0
15	1P	3	30.0
16	1P	4	.
17	1P	5	4.0
18	1P	6	3.0
19	1P	7	2.0
20	1P	8	7.0
21	1P	9	12.0
22	1P	10	8.0
23	1P	11	13.5
24	1P	12	8.0
25	2P	1	.
26	2P	2	5.0
27	2P	3	2.0
28	2P	4	.
29	2P	5	12.2
30	2P	6	.
31	2P	7	.
32	2P	8	2.0
33	2P	9	7.0
34	2P	10	7.0
35	2P	11	.
36	2P	12	10.0

NOTE: 10 OBS HAD MISSING VALUES 2 OBS HIDDEN

0- LEBLANCH NEAR CHURCH, 1- BAYOU, 2- LEBLANCH NEAR RIVER

PLOT OF PH*MONTH SYMBOL IS VALUE OF LOCNO



OBS	LOCNO	MONTH	PH
1	0P	1	6.80
2	0P	2	6.91
3	0P	3	6.50
4	0P	4	.
5	0P	5	7.58
6	0P	6	6.56
7	0P	7	.
8	0P	8	6.95
9	0P	9	7.31
10	0P	10	6.90
11	0P	11	7.20
12	0P	12	6.85
13	1P	1	7.10
14	1P	2	8.38
15	1P	3	7.40
16	1P	4	7.20
17	1P	5	7.51
18	1P	6	7.02
19	1P	7	7.02
20	1P	8	7.22
21	1P	9	6.92
22	1P	10	6.90
23	1P	11	7.05
24	1P	12	6.95
25	2P	1	8.00
26	2P	2	7.21
27	2P	3	6.70
28	2P	4	7.40
29	2P	5	7.25
30	2P	6	7.14
31	2P	7	.
32	2P	8	7.35
33	2P	9	7.30
34	2P	10	6.71
35	2P	11	.
36	2P	12	7.25

NOTE: 4 OBS HAD MISSING VALUES 1 OBS HIDDEN

APPENDIX B

Parcperdue

Section 2
Ground Water-Quality

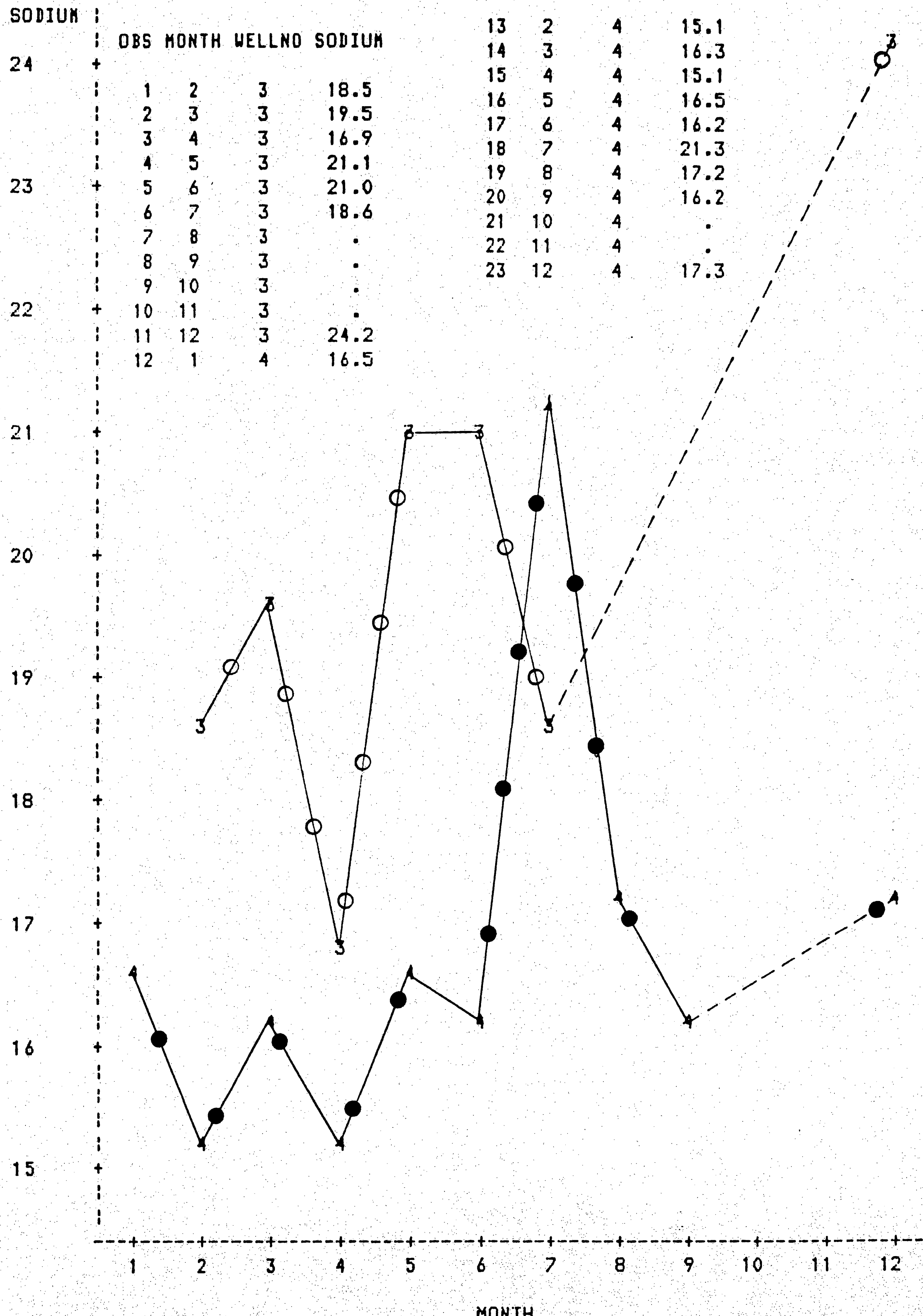
Constituent vs. Time Profiles

Constituent	Concentration Units
Sodium	μg/ml Na
Magnesium	μg/ml Mg
Chloride	μg/ml Cl^-
Conductivity	μmho/cm
Hardness	μg/ml $CaCO_3$
Temperature	°C
Turbidity	turbidity units
Boron	μg/ml B
pH	pH units

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) O , 4- NEW 180 FT WELL ●

PLOT OF SODIUM*MONTH   SYMBOL IS VALUE OF WELLNO

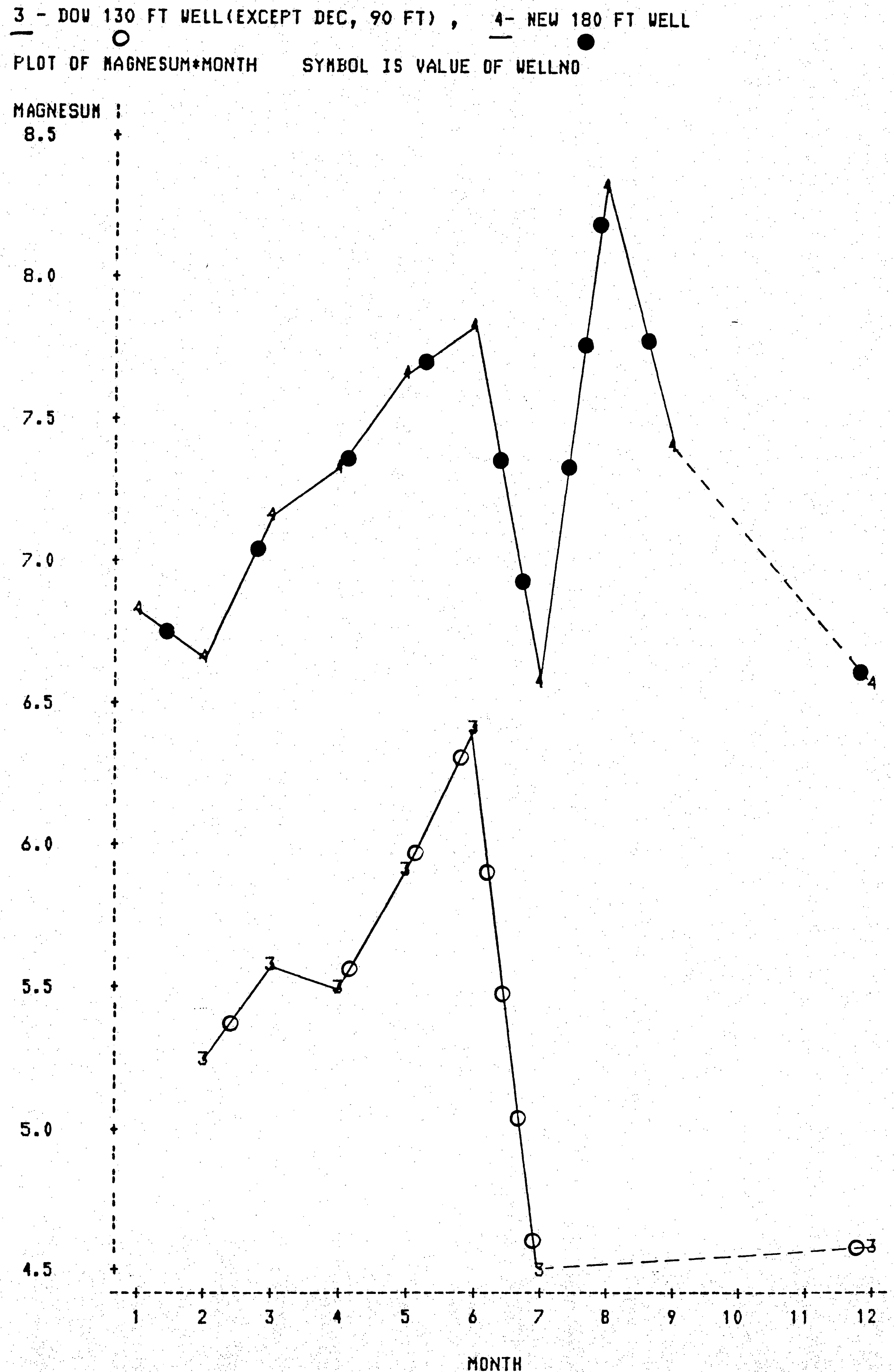
OBS	MONTH	WELLNO	SODIUM
1	2	3	18.5
2	3	3	19.5
3	4	3	16.9
4	5	3	21.1
5	6	3	21.0
6	7	3	18.6
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	24.2
12	1	4	16.5
13	2	4	15.1
14	3	4	16.3
15	4	4	15.1
16	5	4	16.5
17	6	4	16.2
18	7	4	21.3
19	8	4	17.2
20	9	4	16.2
21	10	4	.
22	11	4	.
23	12	4	17.3



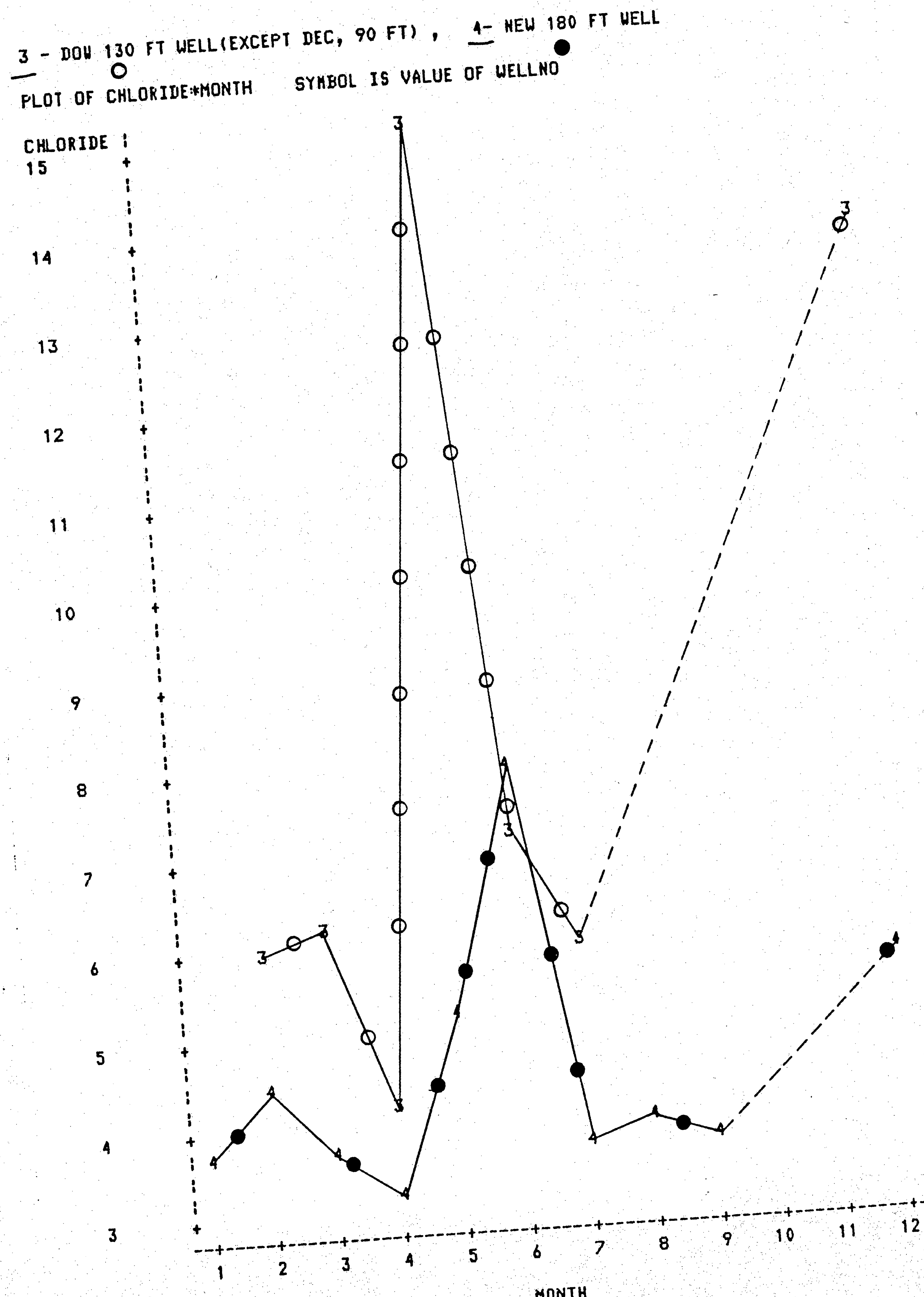
NOTE: 6 OBS HAD MISSING VALUES

OBS	MONTH	WELLNO	MAGNESUM
1	2	3	5.23
2	3	3	5.60
3	4	3	5.50
4	5	3	5.90
5	6	3	6.40
6	7	3	4.50
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	4.61
12	1	4	6.82
13	2	4	6.70
14	3	4	7.20
15	4	4	7.30
16	5	4	7.70
17	6	4	7.80
18	7	4	6.60
19	8	4	8.30
20	9	4	7.40
21	10	4	.
22	11	4	.
23	12	4	6.62

OBS	MONTH	WELLNO	CHLORIDE
1	2	3	6.00
2	3	3	6.20
3	4	3	4.20
4	5	3	15.20
5	6	3	7.30
6	7	3	6.00
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	14.10
12	1	4	3.76
13	2	4	4.50
14	3	4	3.80
15	4	4	3.30
16	5	4	5.20
17	6	4	8.00
18	7	4	3.80
19	8	4	4.00
20	9	4	3.80
21	10	4	.
22	11	4	.
23	12	4	5.75



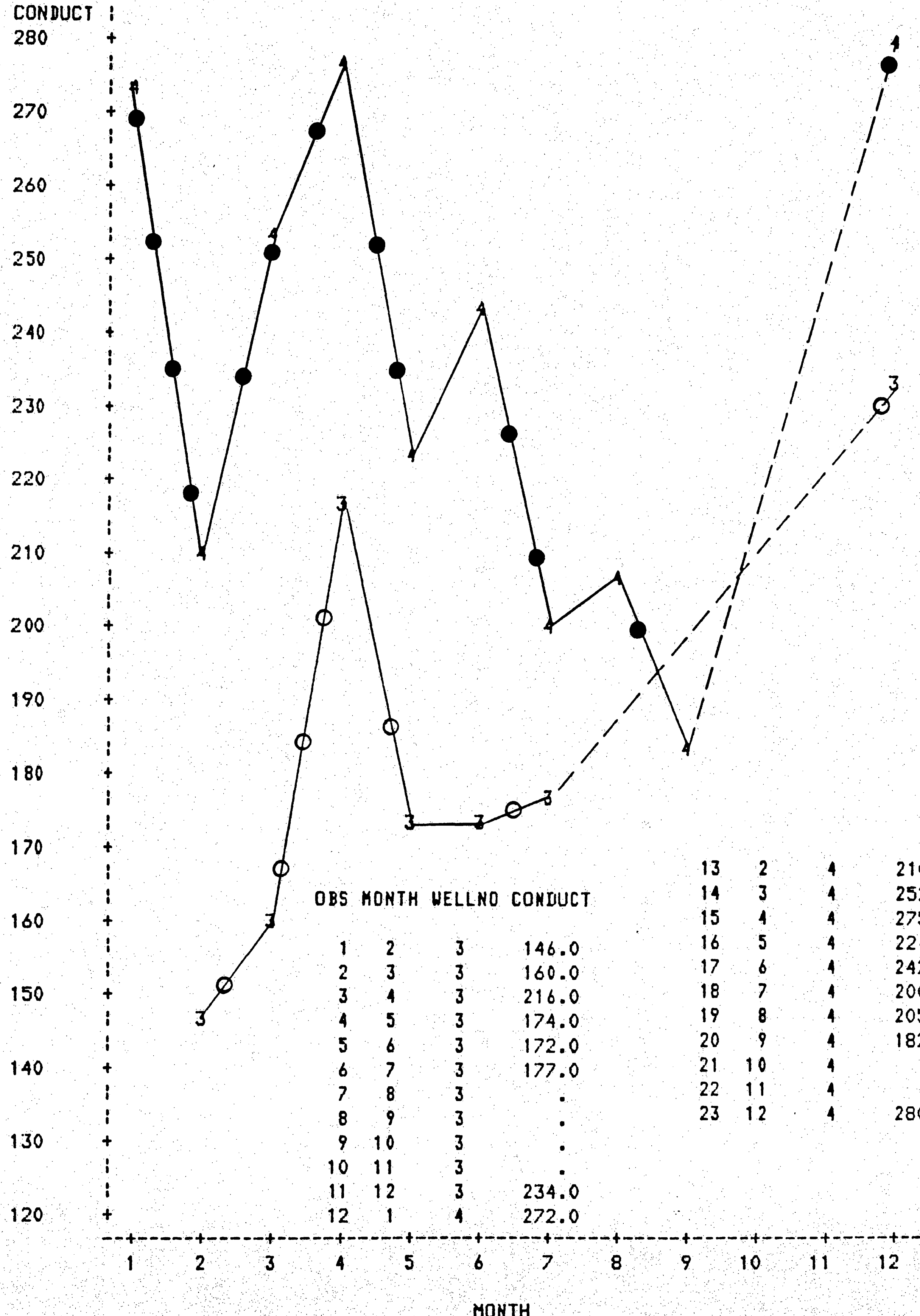
NOTE: 6 OBS HAD MISSING VALUES



NOTE: 6 OBS HAD MISSING VALUES

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) , 4- NEW 180 FT WELL

PLOT OF CONDUCT*MONTH   SYMBOL IS VALUE OF WELLNO



OBS	MONTH	WELLNO	CONDUCT
1	2	3	146.0
2	3	3	160.0
3	4	3	216.0
4	5	3	174.0
5	6	3	172.0
6	7	3	177.0
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	234.0
12	1	4	272.0
13	2	4	210.0
14	3	4	252.0
15	4	4	275.6
16	5	4	224.0
17	6	4	242.0
18	7	4	200.0
19	8	4	205.0
20	9	4	182.0
21	10	4	.
22	11	4	.
23	12	4	280.0

NOTE: 6 OBS HAD MISSING VALUES

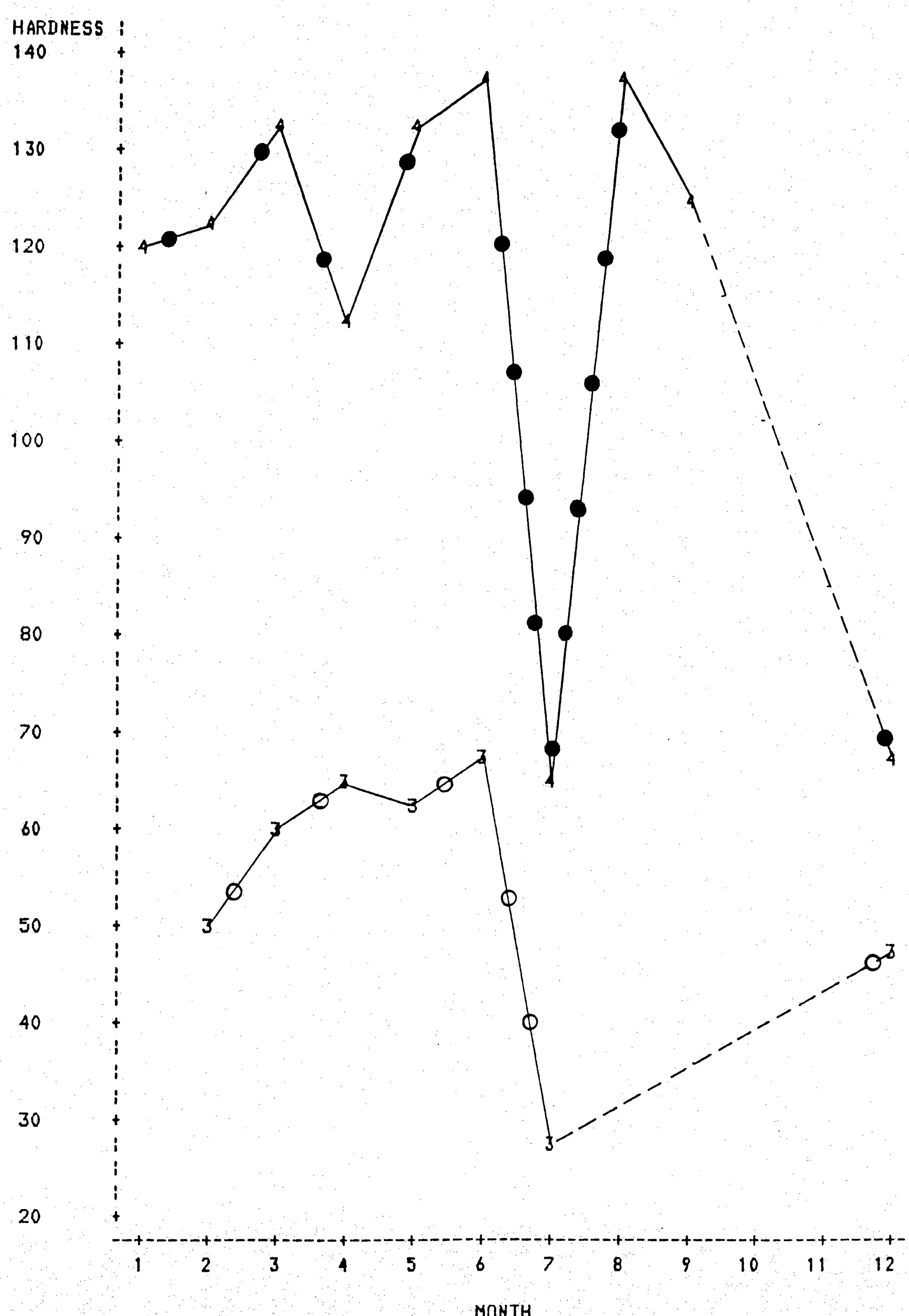
OBS	MONTH	WELLNO	HARDNESS
1	2	3	49.7
2	3	3	59.6
3	4	3	64.6
4	5	3	61.3
5	6	3	66.7
6	7	3	27.8
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	48.2
12	1	4	121.2
13	2	4	121.4
14	3	4	132.7
15	4	4	112.0
16	5	4	132.1
17	6	4	137.7
18	7	4	65.1
19	8	4	136.9
20	9	4	125.4
21	10	4	.
22	11	4	.
23	12	4	66.3

OBS	MONTH	WELLNO	TEMPTURE
1	2	3	32
2	3	3	18
3	4	3	21
4	5	3	18
5	6	3	23
6	7	3	23
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	10
12	1	4	18
13	2	4	22
14	3	4	19
15	4	4	22
16	5	4	16
17	6	4	20
18	7	4	21
19	8	4	21
20	9	4	20
21	10	4	.
22	11	4	.
23	12	4	19

OBS	MONTH	WELLNO	TURBITY
1	2	3	32.0
2	3	3	8.0
3	4	3	7.8
4	5	3	6.2
5	6	3	0.8
6	7	3	8.2
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	3.2
12	1	4	3.4
13	2	4	11.0
14	3	4	6.0
15	4	4	6.8
16	5	4	5.9
17	6	4	0.9
18	7	4	3.8
19	8	4	4.0
20	9	4	4.1
21	10	4	.
22	11	4	.
23	12	4	6.6

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) , 4- NEW 180 FT WELL

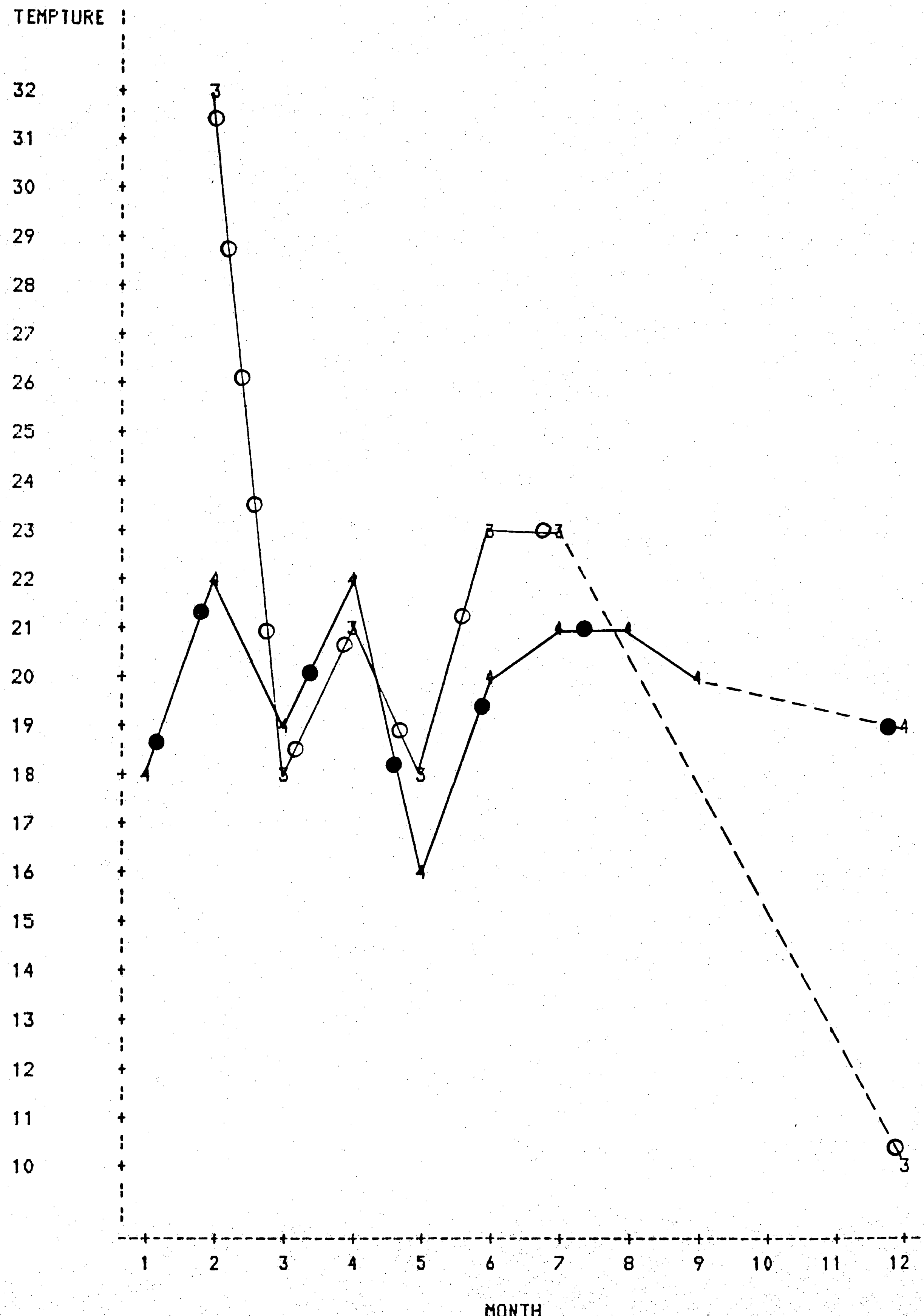
PLOT OF HARDNESS*MONTH   SYMBOL IS VALUE OF WELLNO



NOTE: 6 OBS HAD MISSING VALUES

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) , 4- NEW 180 FT WELL

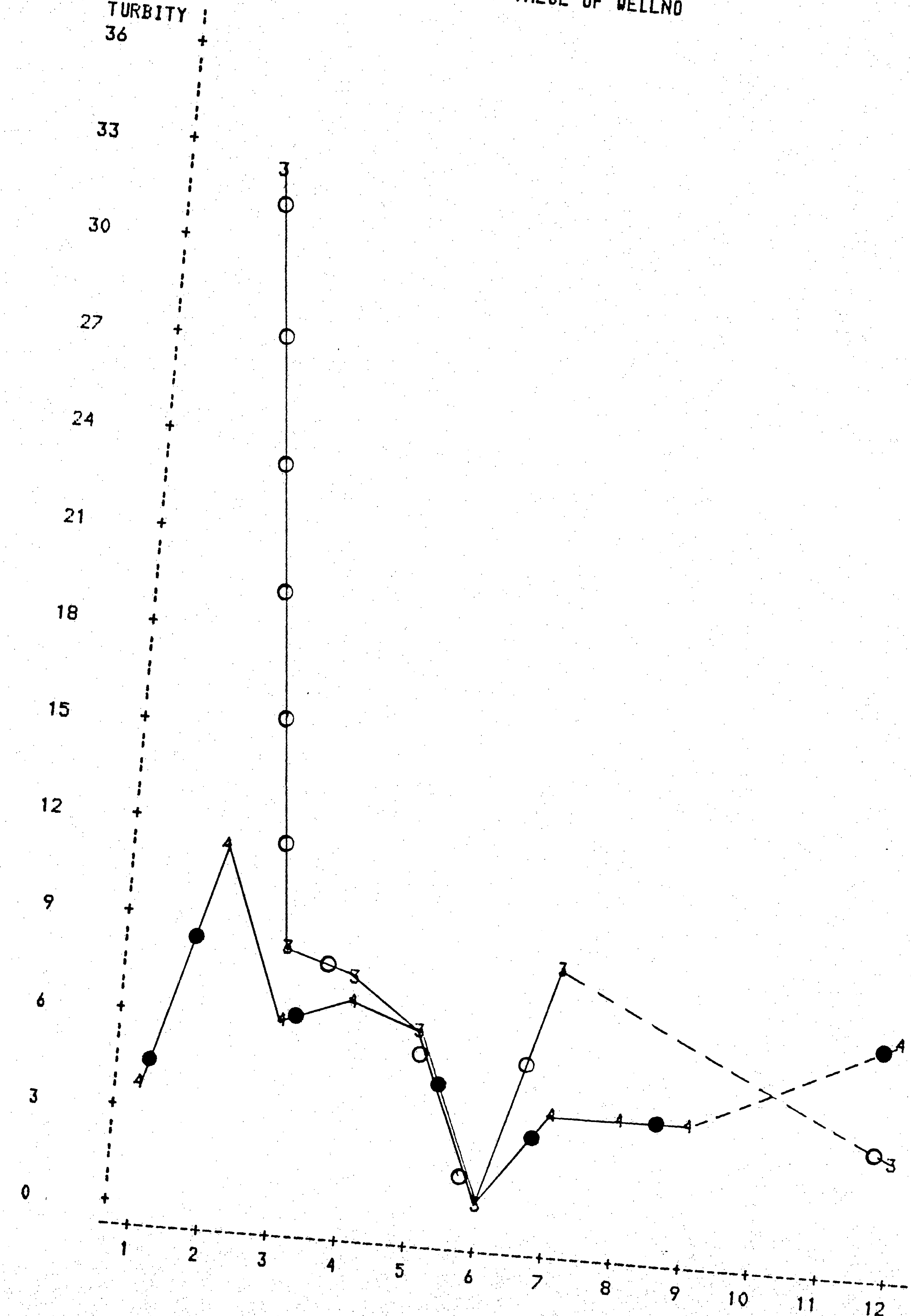
PLOT OF TEMPTURE*MONTH   SYMBOL IS VALUE OF WELLNO



NOTE: 6 OBS HAD MISSING VALUES

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) , 4- NEW 180 FT WELL

PLOT OF TURBITY*MONTH   SYMBOL IS VALUE OF WELLNO

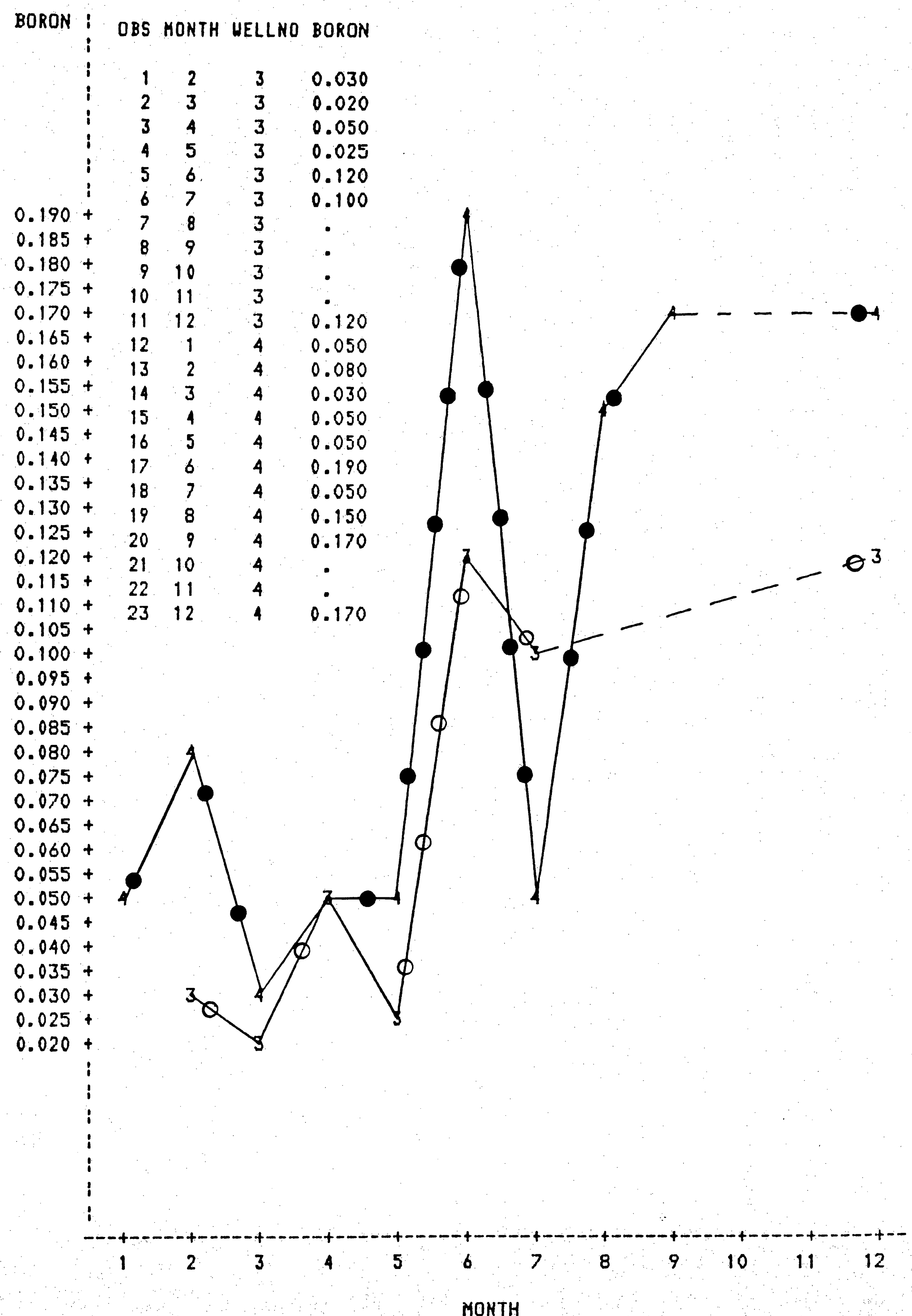


NOTE: 6 OBS HAD MISSING VALUES   2 OBS HIDDEN

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) ○ , 4- NEW 180 FT WELL ●

PLOT OF BORON*MONTH   SYMBOL IS VALUE OF WELLNO

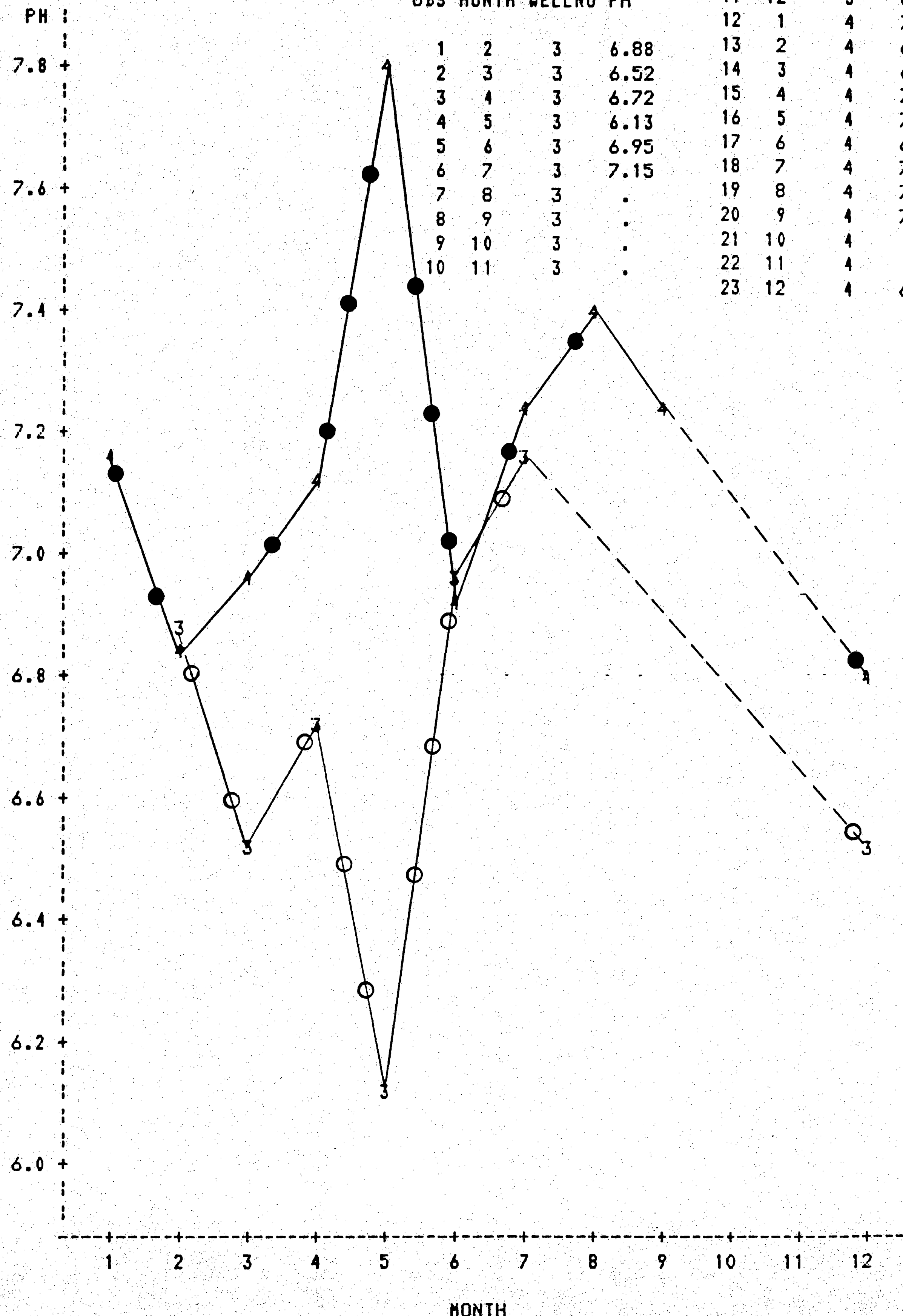
OBS	MONTH	WELLNO	BORON
1	2	3	0.030
2	3	3	0.020
3	4	3	0.050
4	5	3	0.025
5	6	3	0.120
6	7	3	0.100
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	0.120
12	1	4	0.050
13	2	4	0.080
14	3	4	0.030
15	4	4	0.050
16	5	4	0.050
17	6	4	0.190
18	7	4	0.050
19	8	4	0.150
20	9	4	0.170
21	10	4	.
22	11	4	.
23	12	4	0.170



NOTE: 6 OBS HAD MISSING VALUES   1 OBS HIDDEN

3 - DOW 130 FT WELL(EXCEPT DEC, 90 FT) ○ , 4- NEW 180 FT WELL ●

PLOT OF PH*MONTH   SYMBOL IS VALUE OF WELLNO



OBS	MONTH	WELLNO	PH
1	2	3	6.88
2	3	3	6.52
3	4	3	6.72
4	5	3	6.13
5	6	3	6.95
6	7	3	7.15
7	8	3	.
8	9	3	.
9	10	3	.
10	11	3	.
11	12	3	6.52
12	1	4	7.15
13	2	4	6.84
14	3	4	6.95
15	4	4	7.10
16	5	4	7.79
17	6	4	6.93
18	7	4	7.24
19	8	4	7.41
20	9	4	7.23
21	10	4	.
22	11	4	.
23	12	4	6.80

NOTE: 6 OBS HAD MISSING VALUES

APPENDIX C

Sweet Lake

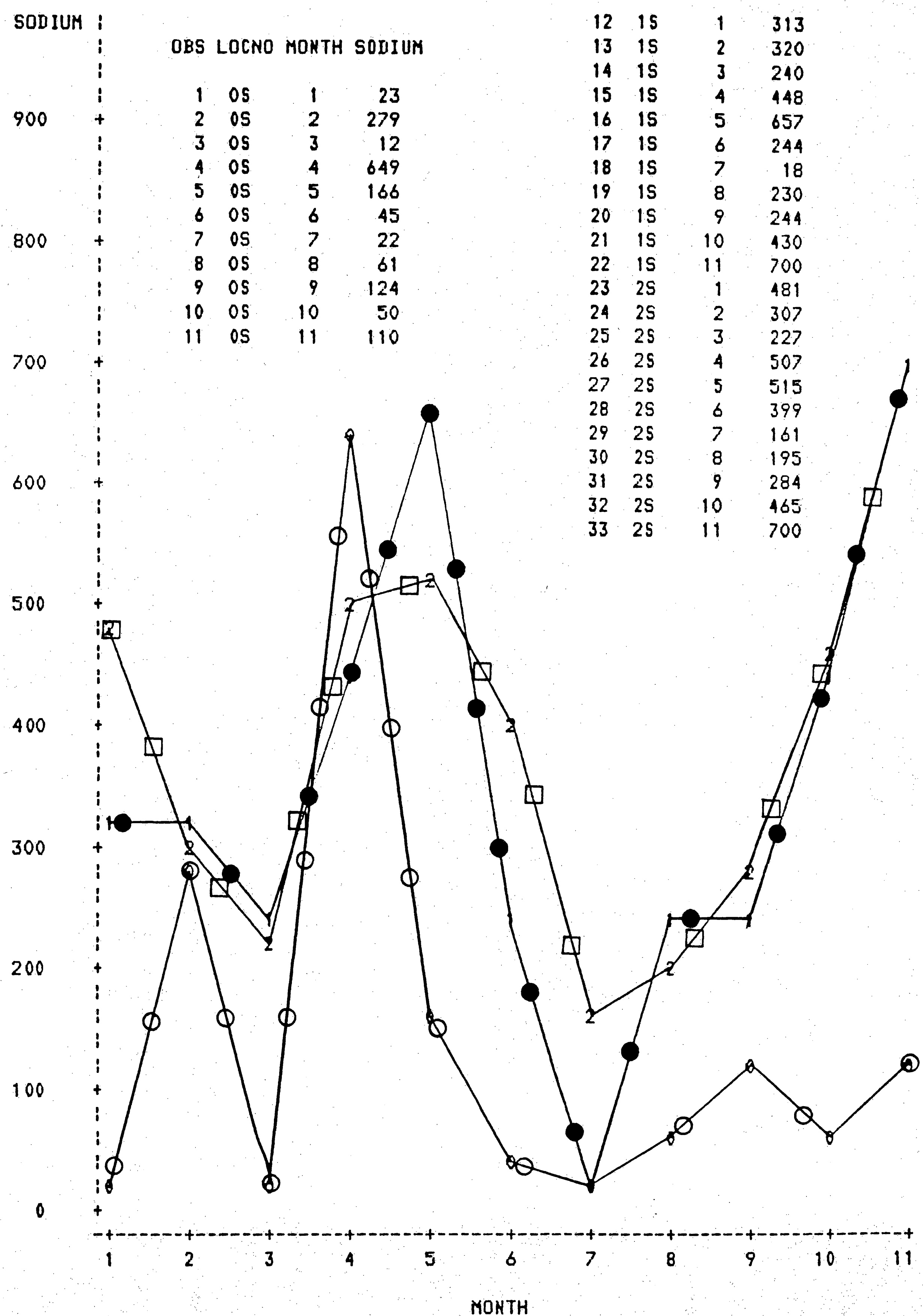
Section 1
Surface-Water Quality

Constituent vs. Time Profiles

Constituent	Concentration Units
Sodium	µg/ml Na
Magnesium	µg/ml Mg
Chloride	µg/ml Cl^-
Conductivity	µmho/cm
Hardness	µg/ml $CaCO_3$
Temperature	°C
Turbidity	turbidity units
Boron	µg/ml B
Lead	µg/ml Pb
Mercury	µg/ml Hg
Sulfate	µg/ml SO_4
pH	pH units

0- BRIDGE, 1- SQUARE LAKE, 2- SWEET LAKE

PLOT OF SODIUM*MONTH SYMBOL IS VALUE OF LOCNO

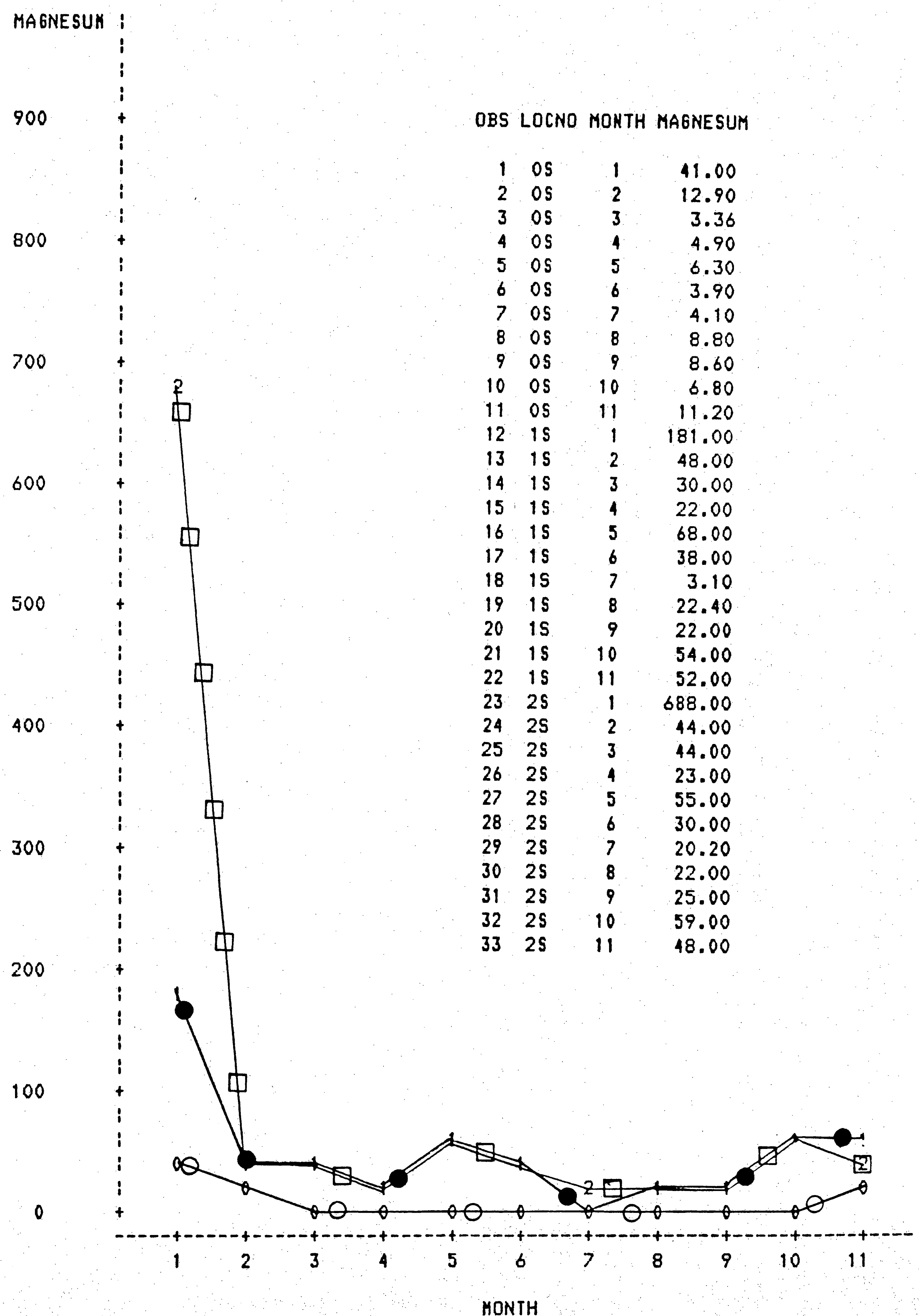


OBS	LOCNO	MONTH	SODIUM
1	0S	1	23
2	0S	2	279
3	0S	3	12
4	0S	4	649
5	0S	5	166
6	0S	6	45
7	0S	7	22
8	0S	8	61
9	0S	9	124
10	0S	10	50
11	0S	11	110
12	1S	1	313
13	1S	2	320
14	1S	3	240
15	1S	4	448
16	1S	5	657
17	1S	6	244
18	1S	7	18
19	1S	8	230
20	1S	9	244
21	1S	10	430
22	1S	11	700
23	2S	1	481
24	2S	2	307
25	2S	3	227
26	2S	4	507
27	2S	5	515
28	2S	6	399
29	2S	7	161
30	2S	8	195
31	2S	9	284
32	2S	10	465
33	2S	11	700

NOTE: 2 OBS HIDDEN

0- BRIDGE, 1- SQUARE LAKE, 2- SWEET LAKE

PLOT OF MAGNESUM*MONTH SYMBOL IS VALUE OF LOCNO

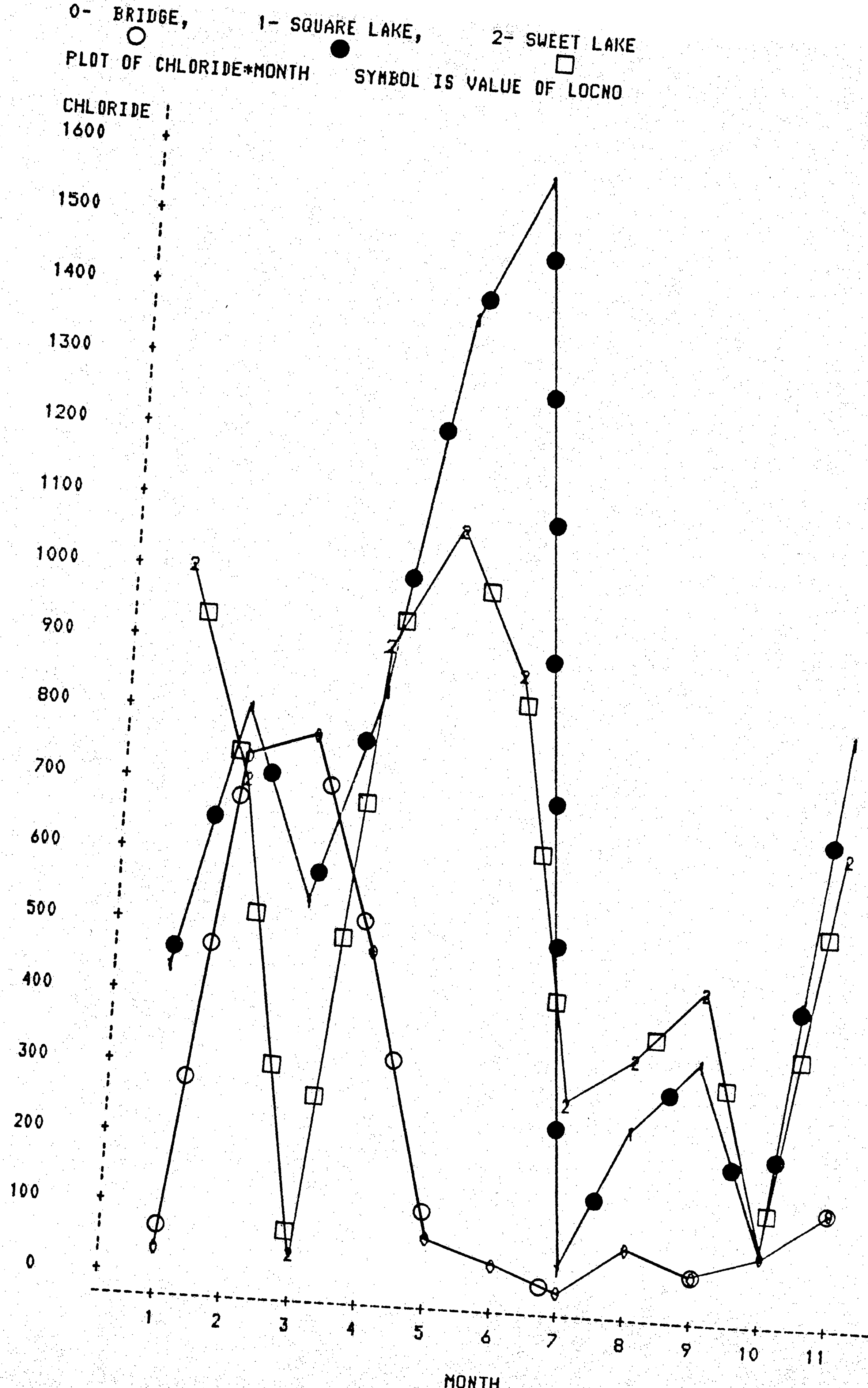


OBS	LOCNO	MONTH	MAGNESUM
1	0S	1	41.00
2	0S	2	12.90
3	0S	3	3.36
4	0S	4	4.90
5	0S	5	6.30
6	0S	6	3.90
7	0S	7	4.10
8	0S	8	8.80
9	0S	9	8.60
10	0S	10	6.80
11	0S	11	11.20
12	1S	1	181.00
13	1S	2	48.00
14	1S	3	30.00
15	1S	4	22.00
16	1S	5	68.00
17	1S	6	38.00
18	1S	7	3.10
19	1S	8	22.40
20	1S	9	22.00
21	1S	10	54.00
22	1S	11	52.00
23	2S	1	688.00
24	2S	2	44.00
25	2S	3	44.00
26	2S	4	23.00
27	2S	5	55.00
28	2S	6	30.00
29	2S	7	20.20
30	2S	8	22.00
31	2S	9	25.00
32	2S	10	59.00
33	2S	11	48.00

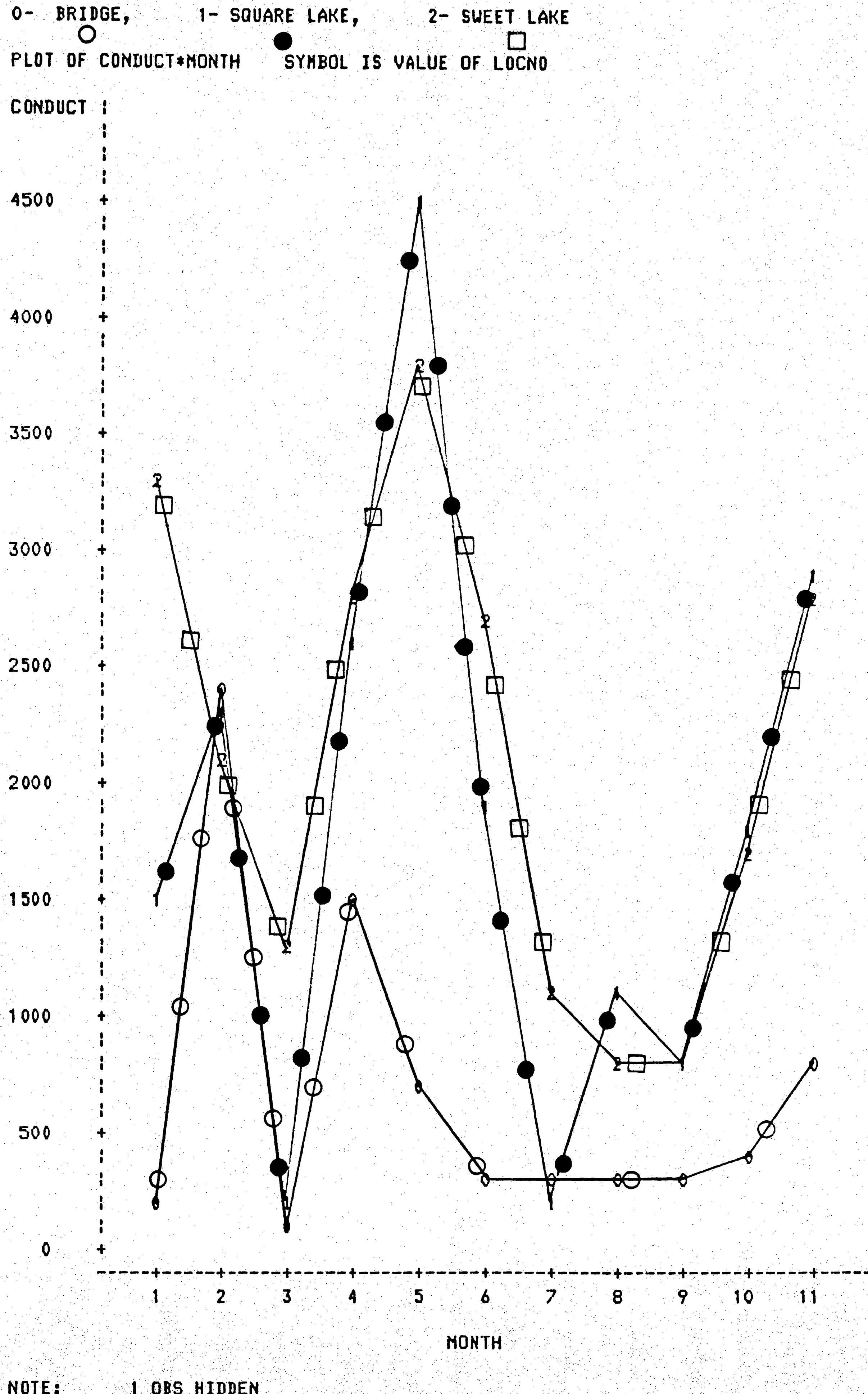
NOTE: 9 OBS HIDDEN

OBS	LOCNO	MONTH	CHLORIDE
1	0S	1	36
2	0S	2	750
3	0S	3	780
4	0S	4	475
5	0S	5	68
6	0S	6	28
7	0S	7	14
8	0S	8	57
9	0S	9	46
10	0S	10	51
11	0S	11	131
12	1S	1	445
13	1S	2	800
14	1S	3	530
15	1S	4	825
16	1S	5	1365
17	1S	6	1570
18	1S	7	31
19	1S	8	228
20	1S	9	350
21	1S	10	69
22	1S	11	799
23	2S	1	1015
24	2S	2	700
25	2S	3	19
26	2S	4	895
27	2S	5	1070
28	2S	6	860
29	2S	7	275
30	2S	8	350
31	2S	9	445
32	2S	10	71
33	2S	11	650

OBS	LOCNO	MONTH	CONDUCT
1	0S	1	238
2	0S	2	2404
3	0S	3	98
4	0S	4	1535
5	0S	5	665
6	0S	6	301
7	0S	7	264
8	0S	8	327
9	0S	9	306
10	0S	10	400
11	0S	11	775
12	1S	1	1490
13	1S	2	2326
14	1S	3	184
15	1S	4	2559
16	1S	5	4488
17	1S	6	1932
18	1S	7	161
19	1S	8	1058
20	1S	9	834
21	1S	10	1840
22	1S	11	2850
23	2S	1	3267
24	2S	2	2065
25	2S	3	1333
26	2S	4	2789
27	2S	5	3796
28	2S	6	2710
29	2S	7	1107
30	2S	8	846
31	2S	9	827
32	2S	10	1720
33	2S	11	2750

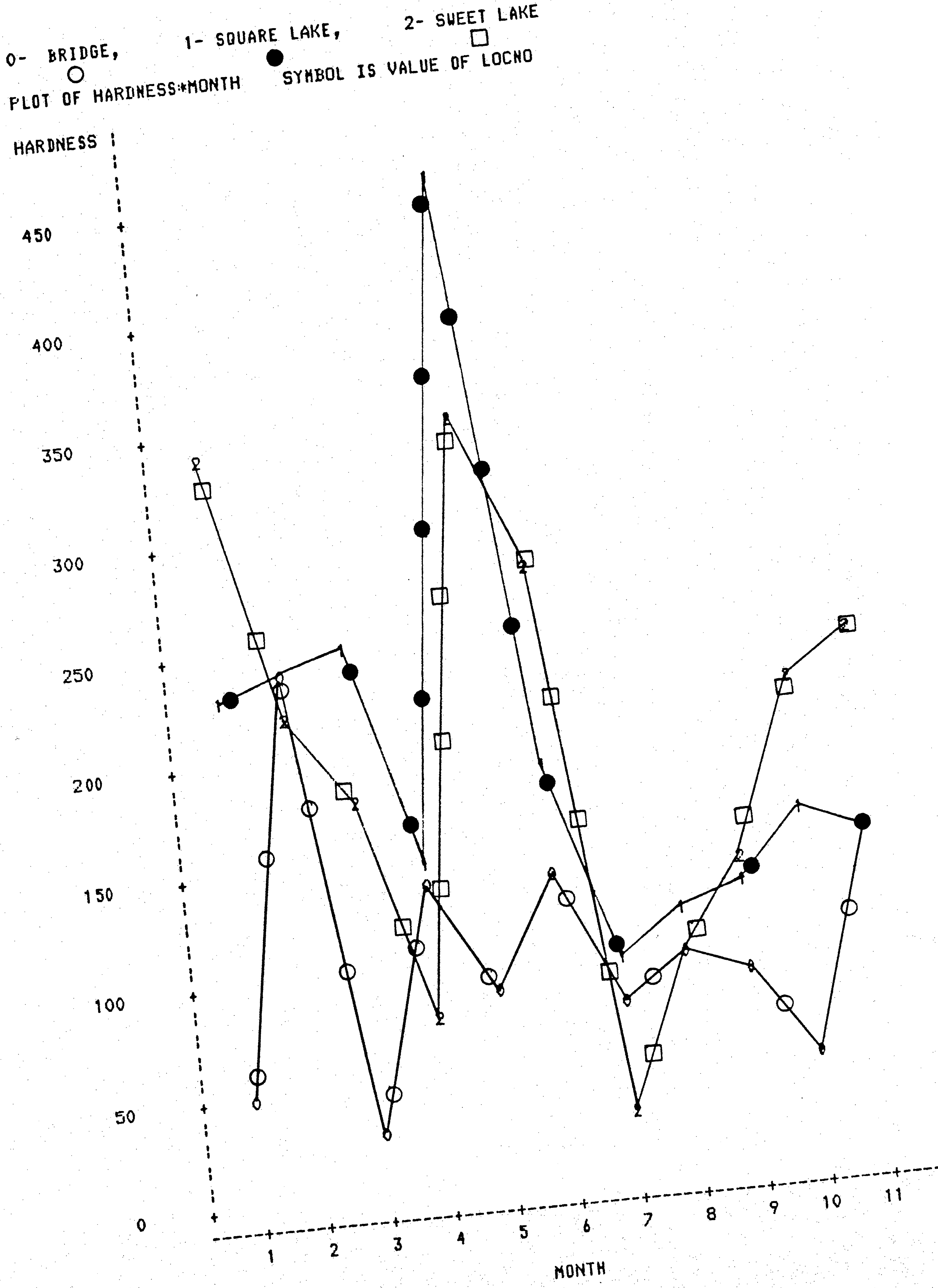


NOTE: 2 OBS HIDDEN


0- BRIDGE, 1- SQUARE LAKE, 2- SWEET LAKE
PLOT OF CONDUCT*MONTH SYMBOL IS VALUE OF LOCNO
CONDUCT
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11
MONTH
NOTE: 1 OBS HIDDEN

OBS	LOCNO	MONTH	HARDNESS
1	0S	1	48
2	0S	2	240
3	0S	3	32
4	0S	4	141
5	0S	5	90
6	0S	6	135
7	0S	7	79
8	0S	8	102
9	0S	9	91
10	0S	10	52
11	0S	11	145
12	1S	1	230
13	1S	2	239
14	1S	3	254
15	1S	4	153
16	1S	5	463
17	1S	6	193
18	1S	7	97
19	1S	8	123
20	1S	9	128
21	1S	10	159
22	1S	11	146
23	2S	1	340
24	2S	2	215
25	2S	3	184
26	2S	4	81
27	2S	5	352
28	2S	6	279
29	2S	7	25
30	2S	8	97
31	2S	9	138
32	2S	10	215
33	2S	11	244

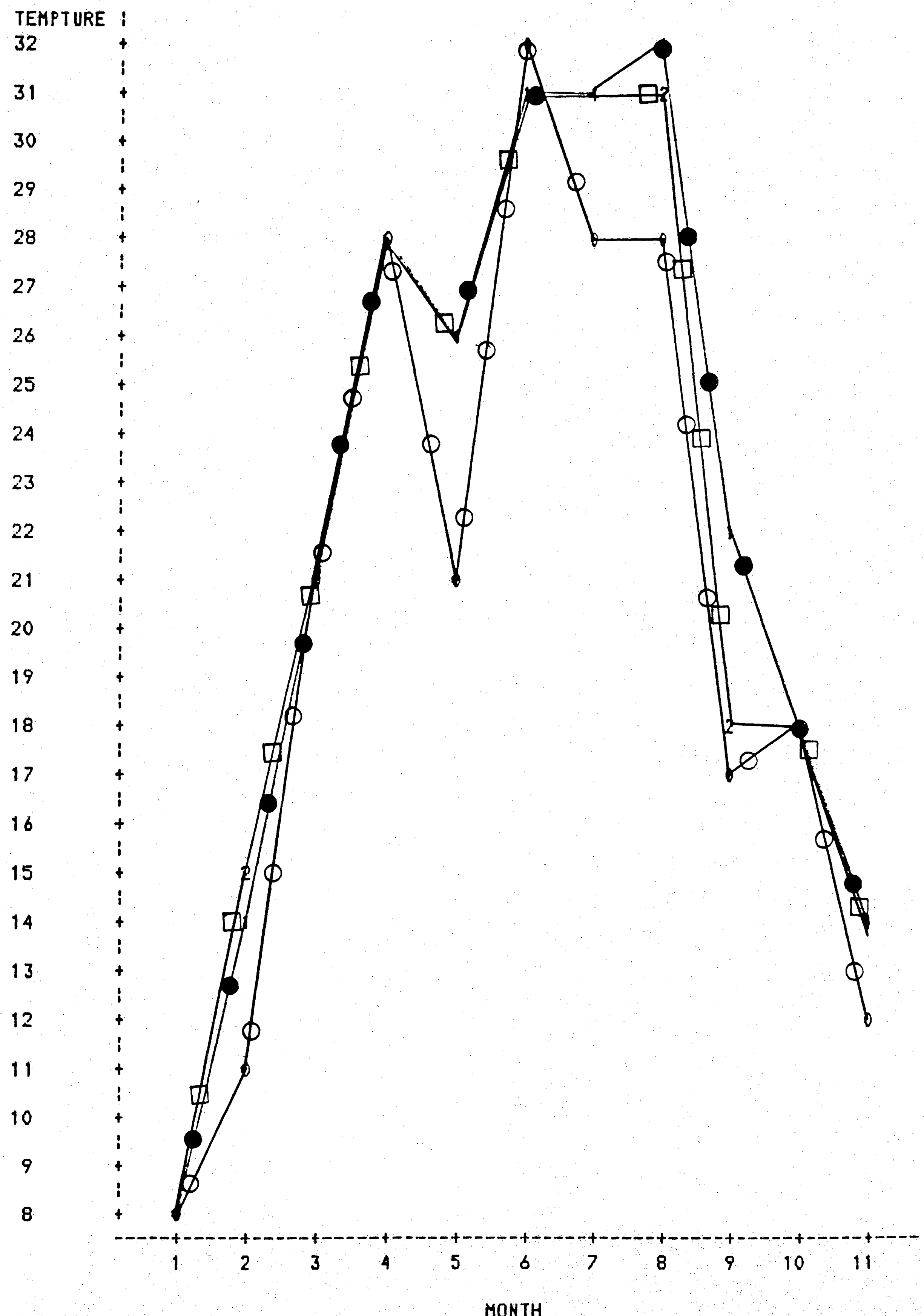
OBS	LOCNO	MONTH	TEMPTURE
1	0S	1	8
2	0S	2	11
3	0S	3	21
4	0S	4	28
5	0S	5	21
6	0S	6	32
7	0S	7	28
8	0S	8	28
9	0S	9	17
10	0S	10	18
11	0S	11	12
12	1S	1	8
13	1S	2	14
14	1S	3	21
15	1S	4	28
16	1S	5	26
17	1S	6	31
18	1S	7	31
19	1S	8	32
20	1S	9	22
21	1S	10	18
22	1S	11	14
23	2S	1	8
24	2S	2	15
25	2S	3	21
26	2S	4	28
27	2S	5	26
28	2S	6	31
29	2S	7	31
30	2S	8	31
31	2S	9	18
32	2S	10	18
33	2S	11	14



NOTE: 3 OBS HIDDEN

0- BRIDGE, 1- SQUARE LAKE, 2- SWEET LAKE

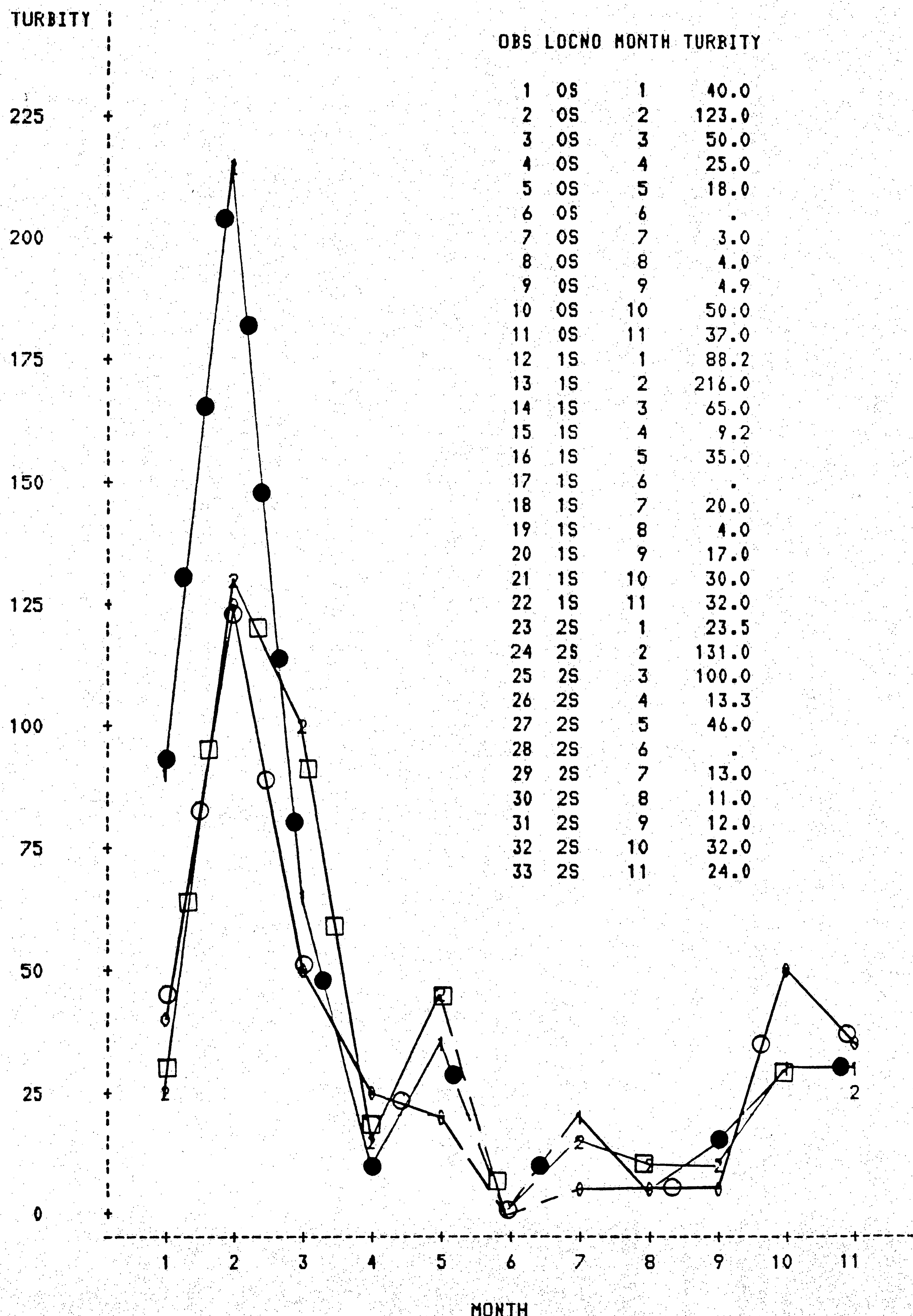
PLOT OF TEMPTURE*MONTH SYMBOL IS VALUE OF LOCNO



NOTE: 12 OBS HIDDEN

0- BRIDGE, ○ 1- SQUARE LAKE, ● 2- SWEET LAKE □

PLOT OF TURBITY*MONTH SYMBOL IS VALUE OF LOCNO

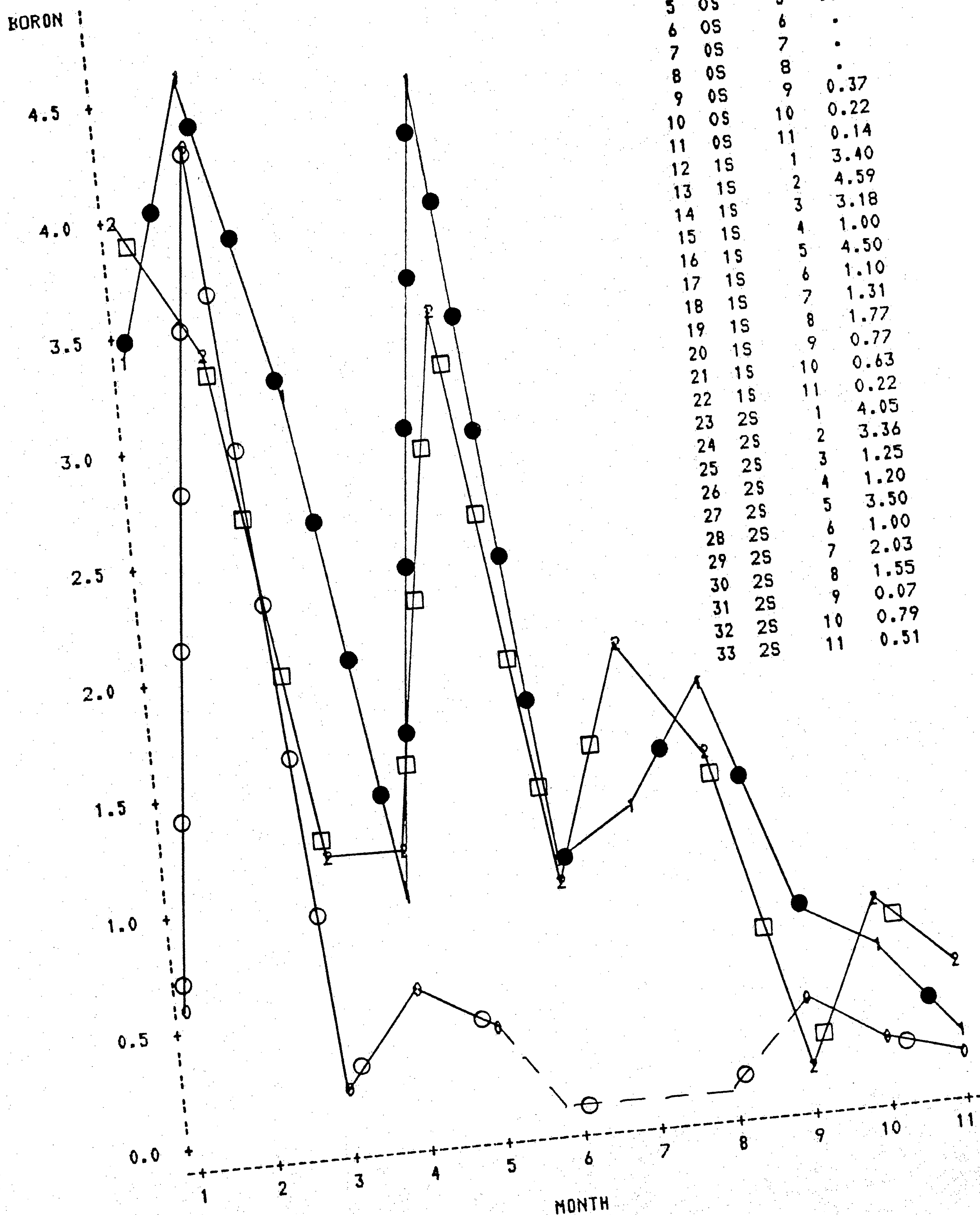


OBS	LOCNO	MONTH	TURRITY
1	0S	1	40.0
2	0S	2	123.0
3	0S	3	50.0
4	0S	4	25.0
5	0S	5	18.0
6	0S	6	.
7	0S	7	3.0
8	0S	8	4.0
9	0S	9	4.9
10	0S	10	50.0
11	0S	11	37.0
12	1S	1	88.2
13	1S	2	216.0
14	1S	3	65.0
15	1S	4	9.2
16	1S	5	35.0
17	1S	6	.
18	1S	7	20.0
19	1S	8	4.0
20	1S	9	17.0
21	1S	10	30.0
22	1S	11	32.0
23	2S	1	23.5
24	2S	2	131.0
25	2S	3	100.0
26	2S	4	13.3
27	2S	5	46.0
28	2S	6	.
29	2S	7	13.0
30	2S	8	11.0
31	2S	9	12.0
32	2S	10	32.0
33	2S	11	24.0

NOTE: 3 OBS HAD MISSING VALUES 2 OBS HIDDEN

0- BRIDGE, ○ 1- SQUARE LAKE, ● 2- SWEET LAKE □

PLOT OF BORON*MONTH SYMBOL IS VALUE OF LOCNO

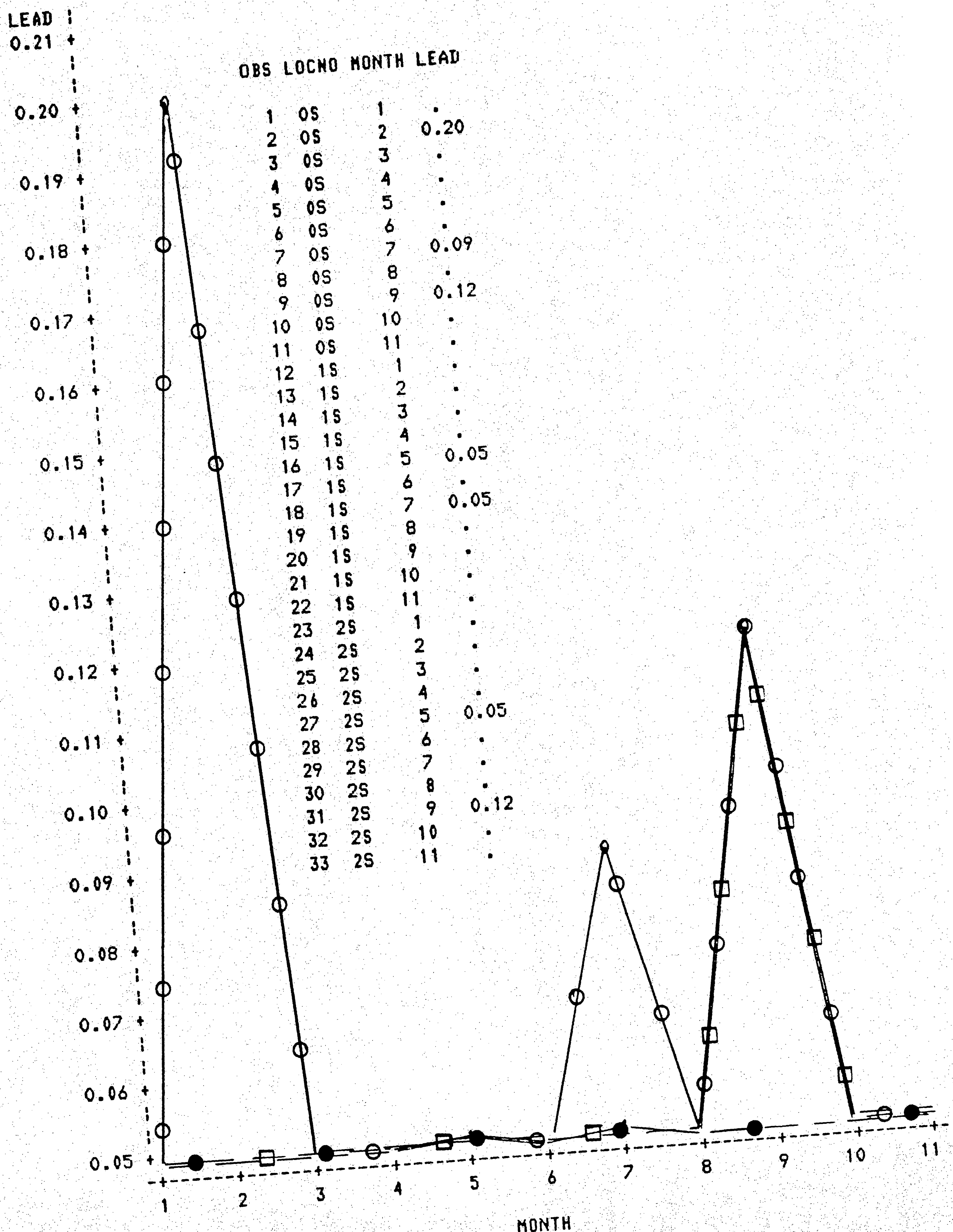


OBS	LOCNO	MONTH	BORON
1	0S	1	0.64
2	0S	2	4.34
3	0S	3	0.23
4	0S	4	0.60
5	0S	5	0.43
6	0S	6	.
7	0S	7	.
8	0S	8	.
9	0S	9	0.37
10	0S	10	0.22
11	0S	11	0.14
12	1S	1	3.40
13	1S	2	4.59
14	1S	3	3.18
15	1S	4	1.00
16	1S	5	4.50
17	1S	6	1.10
18	1S	7	1.31
19	1S	8	1.77
20	1S	9	0.77
21	1S	10	0.63
22	1S	11	0.22
23	2S	1	4.05
24	2S	2	3.36
25	2S	3	1.25
26	2S	4	1.20
27	2S	5	3.50
28	2S	6	1.00
29	2S	7	2.03
30	2S	8	1.55
31	2S	9	0.07
32	2S	10	0.79
33	2S	11	0.51

NOTE: 3 OBS HAD MISSING VALUES

0- BRIDGE, ○ 1- SQUARE LAKE, ● 2- SWEET LAKE □

PLOT OF LEAD*MONTH SYMBOL IS VALUE OF LOCNO

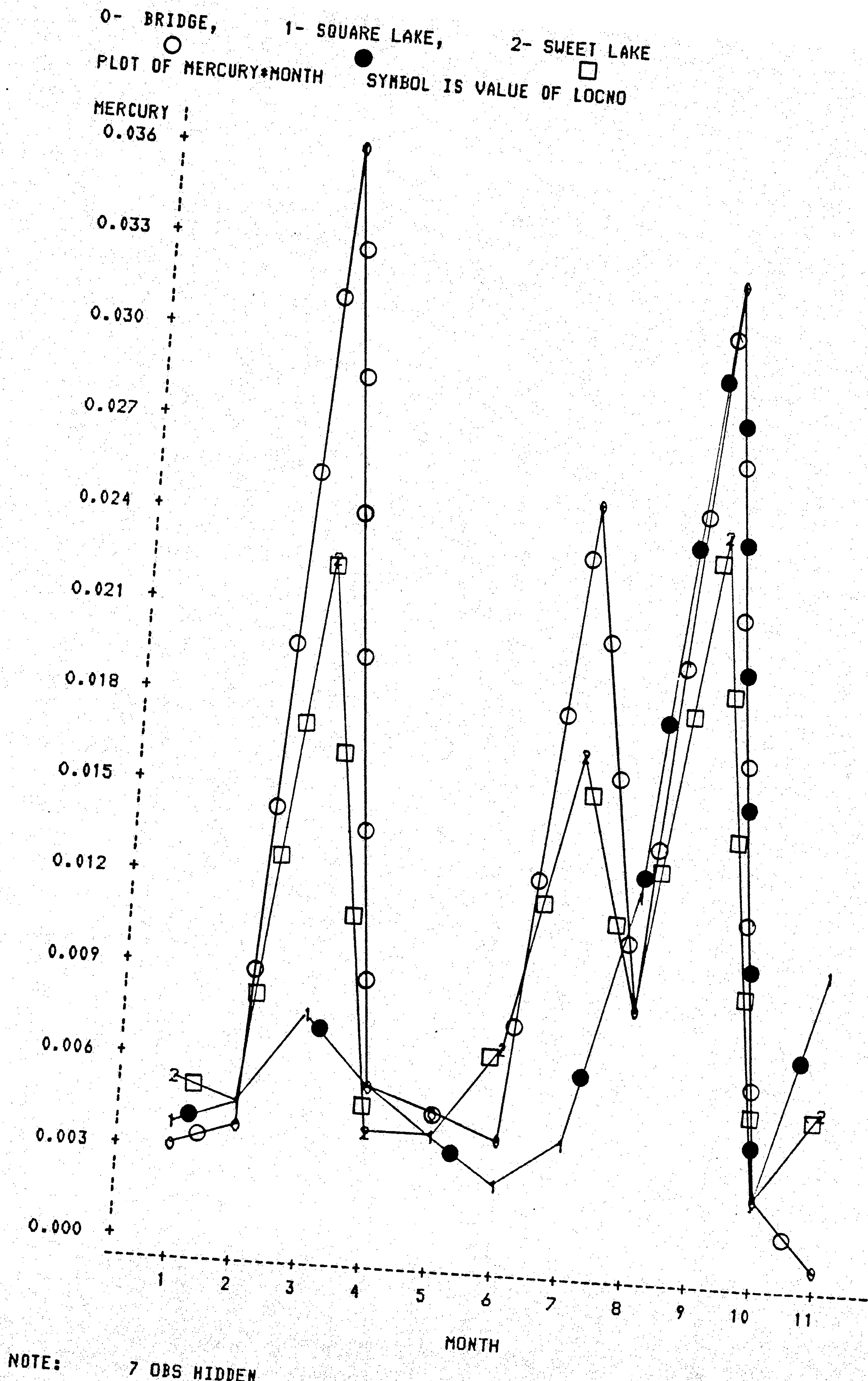


OBS	LOCNO	MONTH	LEAD
1	0S	1	.
2	0S	2	0.20
3	0S	3	.
4	0S	4	.
5	0S	5	.
6	0S	6	.
7	0S	7	0.09
8	0S	8	.
9	0S	9	0.12
10	0S	10	.
11	0S	11	.
12	1S	1	.
13	1S	2	.
14	1S	3	.
15	1S	4	.
16	1S	5	0.05
17	1S	6	.
18	1S	7	0.05
19	1S	8	.
20	1S	9	.
21	1S	10	.
22	1S	11	.
23	2S	1	.
24	2S	2	.
25	2S	3	.
26	2S	4	.
27	2S	5	0.05
28	2S	6	.
29	2S	7	.
30	2S	8	.
31	2S	9	0.12
32	2S	10	.
33	2S	11	.

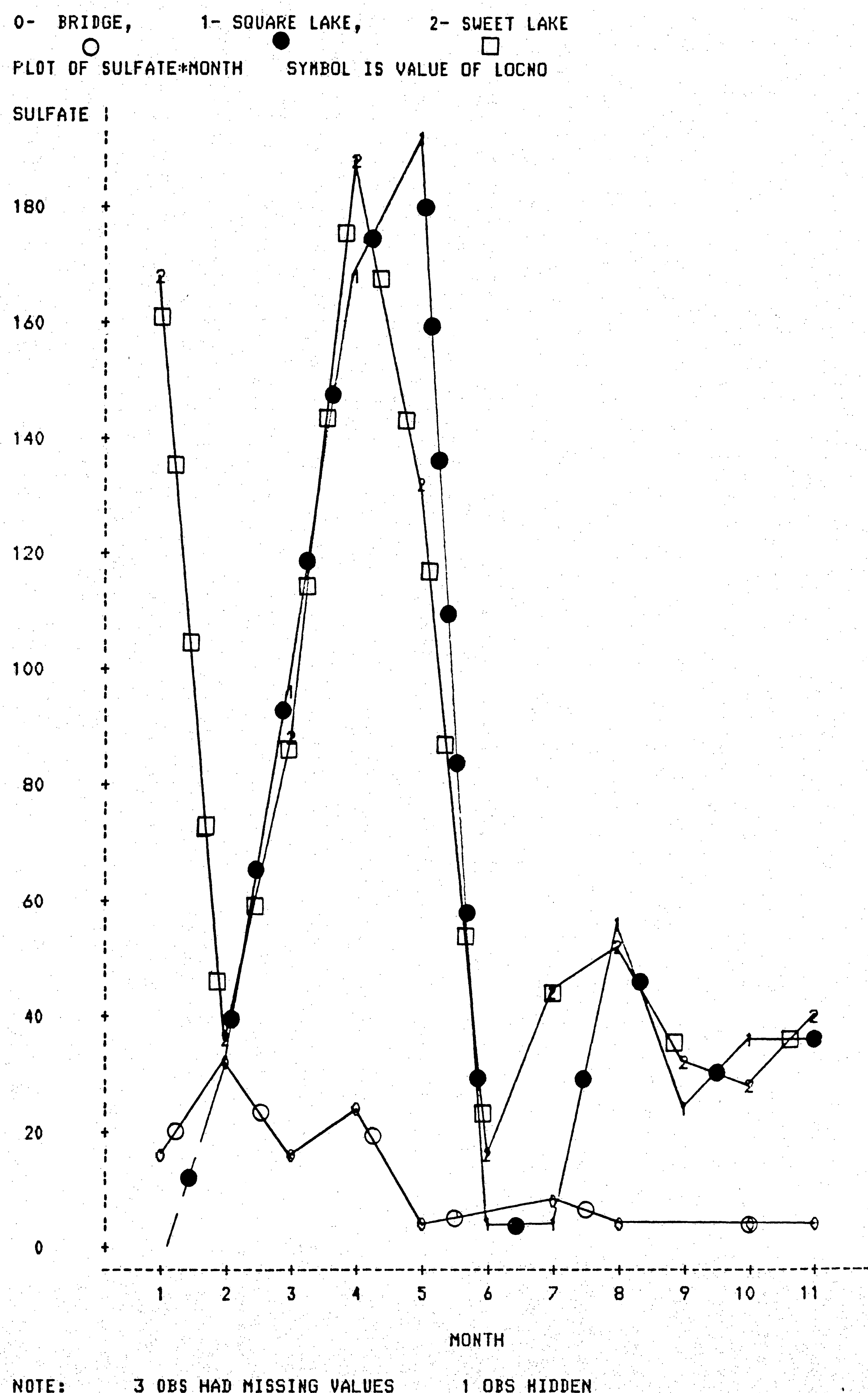
NOTE: 26 OBS HAD MISSING VALUES 2 OBS HIDDEN

OBS	LOCNO	MONTH	MERCURY
1	0S	1	0.0033
2	0S	2	0.0038
3	0S	3	0.0362
4	0S	4	0.0054
5	0S	5	0.0046
6	0S	6	0.0035
7	0S	7	0.0248
8	0S	8	0.0080
9	0S	9	0.0320
10	0S	10	0.0023
11	0S	11	0.0003
12	1S	1	0.0034
13	1S	2	0.0045
14	1S	3	0.0078
15	1S	4	0.0049
16	1S	5	0.0034
17	1S	6	0.0024
18	1S	7	0.0035
19	1S	8	0.0117
20	1S	9	0.0320
21	1S	10	0.0024
22	1S	11	0.0095
23	2S	1	0.0051
24	2S	2	0.0041
25	2S	3	0.0227
26	2S	4	0.0039
27	2S	5	0.0035
28	2S	6	0.0066
29	2S	7	0.0166
30	2S	8	0.0084
31	2S	9	0.0240
32	2S	10	0.0022
33	2S	11	0.0051

OBS	LOCNO	MONTH	SULFATE
1	0S	1	15.0
2	0S	2	31.0
3	0S	3	16.0
4	0S	4	24.0
5	0S	5	4.2
6	0S	6	.
7	0S	7	6.4
8	0S	8	2.5
9	0S	9	.
10	0S	10	5.5
11	0S	11	5.3
12	1S	1	.
13	1S	2	32.0
14	1S	3	95.0
15	1S	4	168.0
16	1S	5	190.0
17	1S	6	3.0
18	1S	7	3.9
19	1S	8	55.1
20	1S	9	25.0
21	1S	10	35.0
22	1S	11	35.0
23	2S	1	168.6
24	2S	2	34.0
25	2S	3	88.0
26	2S	4	186.0
27	2S	5	133.0
28	2S	6	16.6
29	2S	7	45.6
30	2S	8	53.2
31	2S	9	30.0
32	2S	10	29.0
33	2S	11	39.0



0- BRIDGE,
1- SQUARE LAKE,
2- SWEET LAKE
PLOT OF MERCURY*MONTH
SYMBOL IS VALUE OF LOCNO
MERCURY
0.036
0.033
0.030
0.027
0.024
0.021
0.018
0.015
0.012
0.009
0.006
0.003
0.000
1
2
3
4
5
6
7
8
9
10
11
MONTH
NOTE: 7 OBS HIDDEN

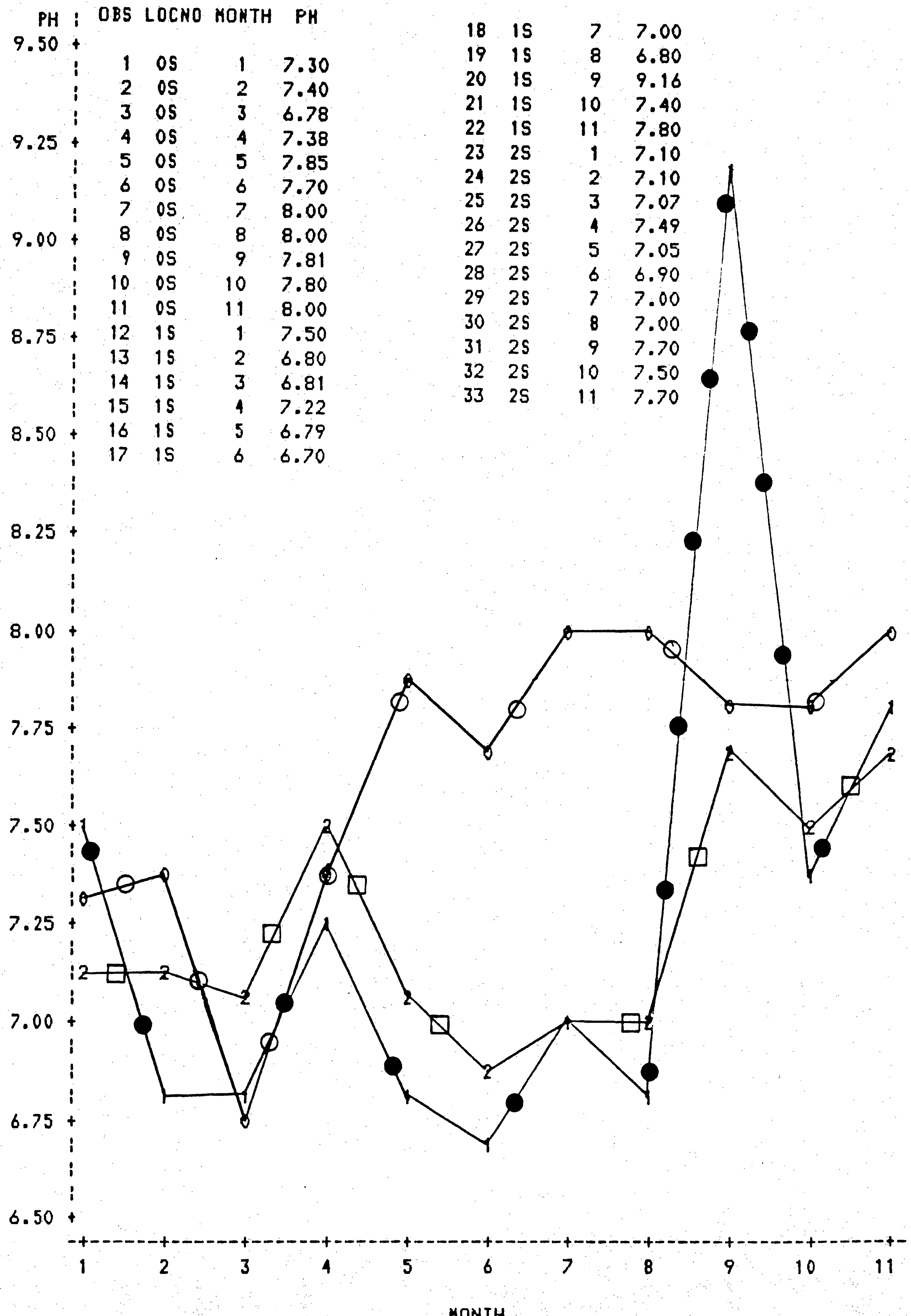


0- BRIDGE, 1- SQUARE LAKE, 2- SWEET LAKE
PLOT OF SULFATE*MONTH SYMBOL IS VALUE OF LOCNO
SULFATE
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
MONTH
NOTE: 3 OBS HAD MISSING VALUES 1 OBS HIDDEN

0- BRIDGE, ○　　1- SQUARE LAKE, ●　　2- SWEET LAKE □

PLOT OF PH*MONTH　　SYMBOL IS VALUE OF LOCNO

OBS	LOCNO	MONTH	PH
1	0S	1	7.30
2	0S	2	7.40
3	0S	3	6.78
4	0S	4	7.38
5	0S	5	7.85
6	0S	6	7.70
7	0S	7	8.00
8	0S	8	8.00
9	0S	9	7.81
10	0S	10	7.80
11	0S	11	8.00
12	1S	1	7.50
13	1S	2	6.80
14	1S	3	6.81
15	1S	4	7.22
16	1S	5	6.79
17	1S	6	6.70
18	1S	7	7.00
19	1S	8	6.80
20	1S	9	9.16
21	1S	10	7.40
22	1S	11	7.80
23	2S	1	7.10
24	2S	2	7.10
25	2S	3	7.07
26	2S	4	7.49
27	2S	5	7.05
28	2S	6	6.90
29	2S	7	7.00
30	2S	8	7.00
31	2S	9	7.70
32	2S	10	7.50
33	2S	11	7.70



NOTE: 1 OBS HIDDEN

APPENDIX C

Sweet Lake

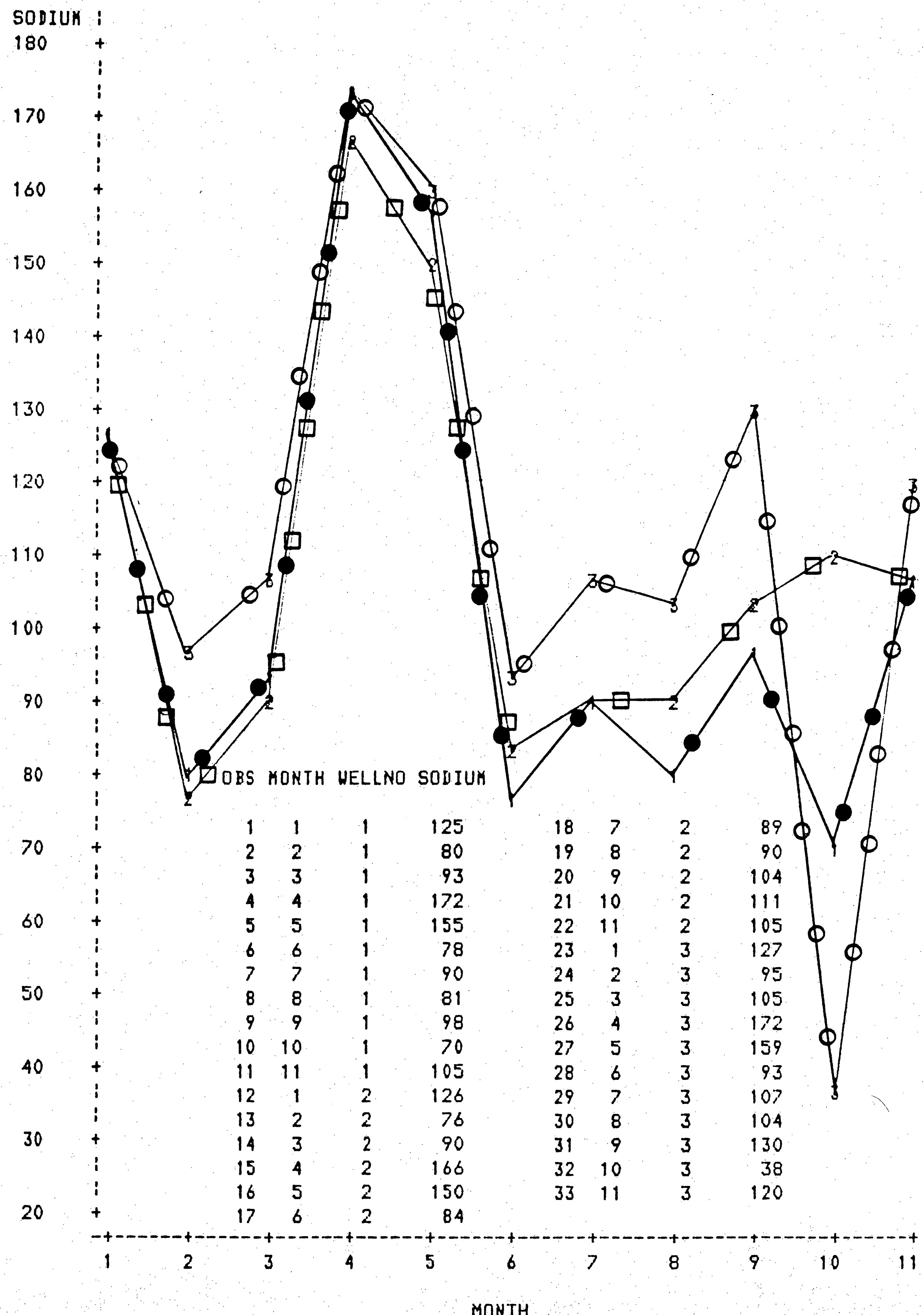
Section 2
Ground-Water Quality

Constituent vs. Time Profiles

Constituent	Concentration Units
Sodium	μg/ml Na
Magnesium	μg/ml Mg
Chloride	μg/ml Cl^-
Conductivity	μmho/cm
Hardness	μg/ml $CaCO_3$
Temperature	°C
Turbidity	turbidity units
Boron	μg/ml B
Lead	μg/ml Pb
Mercury	μg/ml Hg
Sulfate	μg/ml SO_4
pH	pH units

1- WELL#1, 2- WELL#2, 3- WELL#3

PLOT OF SODIUM*MONTH SYMBOL IS VALUE OF WELLNO

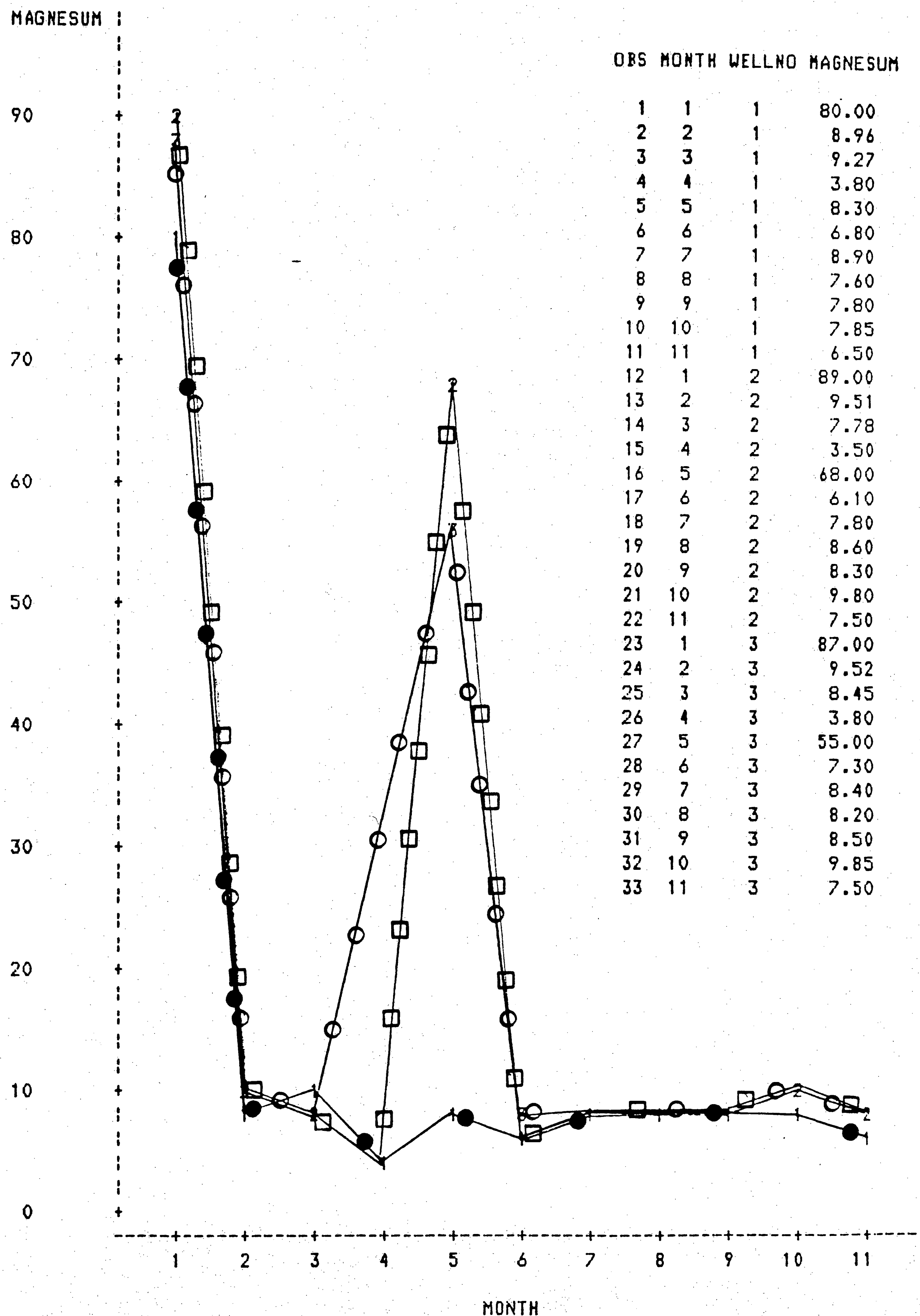


OBS	MONTH	WELLNO	SODIUM
1	1	1	125
2	2	1	80
3	3	1	93
4	4	1	172
5	5	1	155
6	6	1	78
7	7	1	90
8	8	1	81
9	9	1	98
10	10	1	70
11	11	1	105
12	1	2	126
13	2	2	76
14	3	2	90
15	4	2	166
16	5	2	150
17	6	2	84
18	7	2	89
19	8	2	90
20	9	2	104
21	10	2	111
22	11	2	105
23	1	3	127
24	2	3	95
25	3	3	105
26	4	3	172
27	5	3	159
28	6	3	93
29	7	3	107
30	8	3	104
31	9	3	130
32	10	3	38
33	11	3	120

NOTE: 5 OBS HIDDEN

1- WELL#1, 2- WELL#2, 3- WELL#3

PLOT OF MAGNESUM*MONTH SYMBOL IS VALUE OF WELLNO

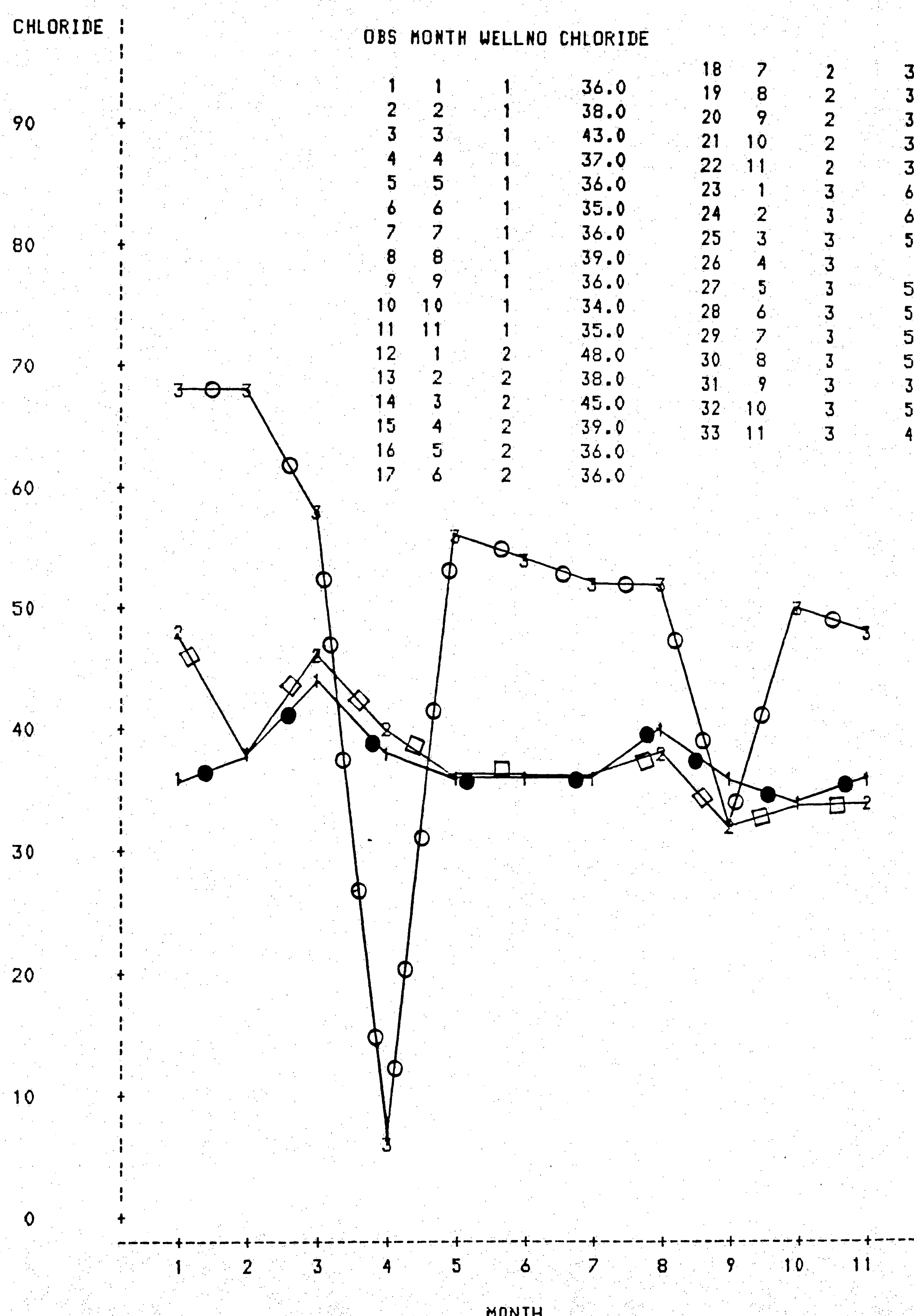


OBS	MONTH	WELLNO	MAGNESUM
1	1	1	80.00
2	2	1	8.96
3	3	1	9.27
4	4	1	3.80
5	5	1	8.30
6	6	1	6.80
7	7	1	8.90
8	8	1	7.60
9	9	1	7.80
10	10	1	7.85
11	11	1	6.50
12	1	2	89.00
13	2	2	9.51
14	3	2	7.78
15	4	2	3.50
16	5	2	68.00
17	6	2	6.10
18	7	2	7.80
19	8	2	8.60
20	9	2	8.30
21	10	2	9.80
22	11	2	7.50
23	1	3	87.00
24	2	3	9.52
25	3	3	8.45
26	4	3	3.80
27	5	3	55.00
28	6	3	7.30
29	7	3	8.40
30	8	3	8.20
31	9	3	8.50
32	10	3	9.85
33	11	3	7.50

NOTE: 13 OBS HIDDEN

1- WELL#1, 2- WELL#2, 3- WELL#3

PLOT OF CHLORIDE*MONTH SYMBOL IS VALUE OF WELLNO

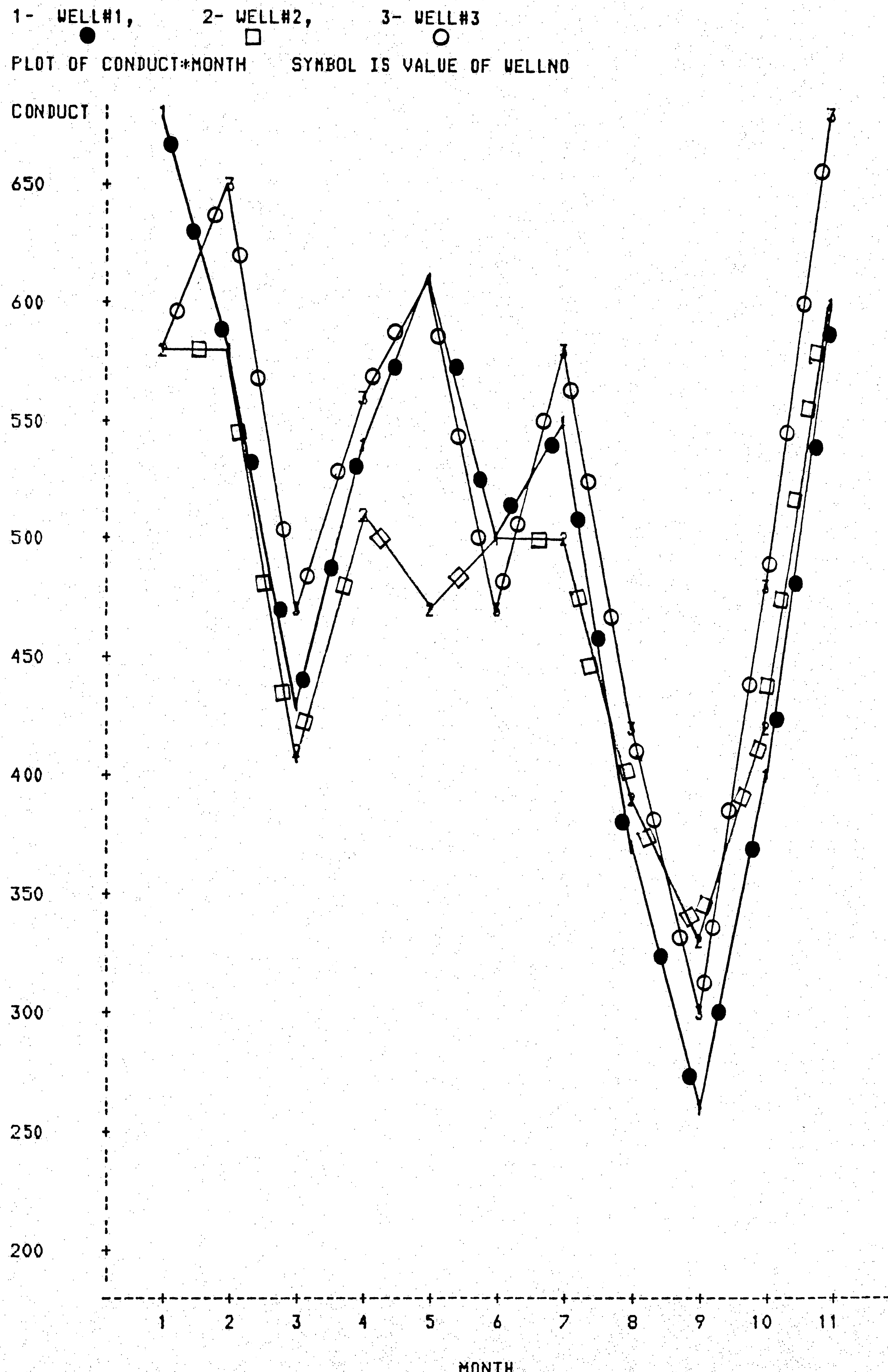


OBS	MONTH	WELLNO	CHLORIDE
1	1	1	36.0
2	2	1	38.0
3	3	1	43.0
4	4	1	37.0
5	5	1	36.0
6	6	1	35.0
7	7	1	36.0
8	8	1	39.0
9	9	1	36.0
10	10	1	34.0
11	11	1	35.0
12	1	2	48.0
13	2	2	38.0
14	3	2	45.0
15	4	2	39.0
16	5	2	36.0
17	6	2	36.0
18	7	2	35.0
19	8	2	37.0
20	9	2	31.0
21	10	2	34.0
22	11	2	33.0
23	1	3	68.0
24	2	3	67.0
25	3	3	57.0
26	4	3	5.3
27	5	3	55.0
28	6	3	53.0
29	7	3	51.0
30	8	3	51.0
31	9	3	32.0
32	10	3	50.0
33	11	3	47.0

NOTE: 6 OBS HIDDEN

OBS	MONTH	WELLNO	CONDUCT
1	1	1	680
2	2	1	575
3	3	1	431
4	4	1	537
5	5	1	610
6	6	1	502
7	7	1	553
8	8	1	365
9	9	1	259
10	10	1	400
11	11	1	600
12	1	2	575
13	2	2	575
14	3	2	411
15	4	2	512
16	5	2	471
17	6	2	502
18	7	2	501
19	8	2	385
20	9	2	333
21	10	2	420
22	11	2	600
23	1	3	575
24	2	3	653
25	3	3	470
26	4	3	563
27	5	3	610
28	6	3	470
29	7	3	580
30	8	3	423
31	9	3	299
32	10	3	480
33	11	3	675

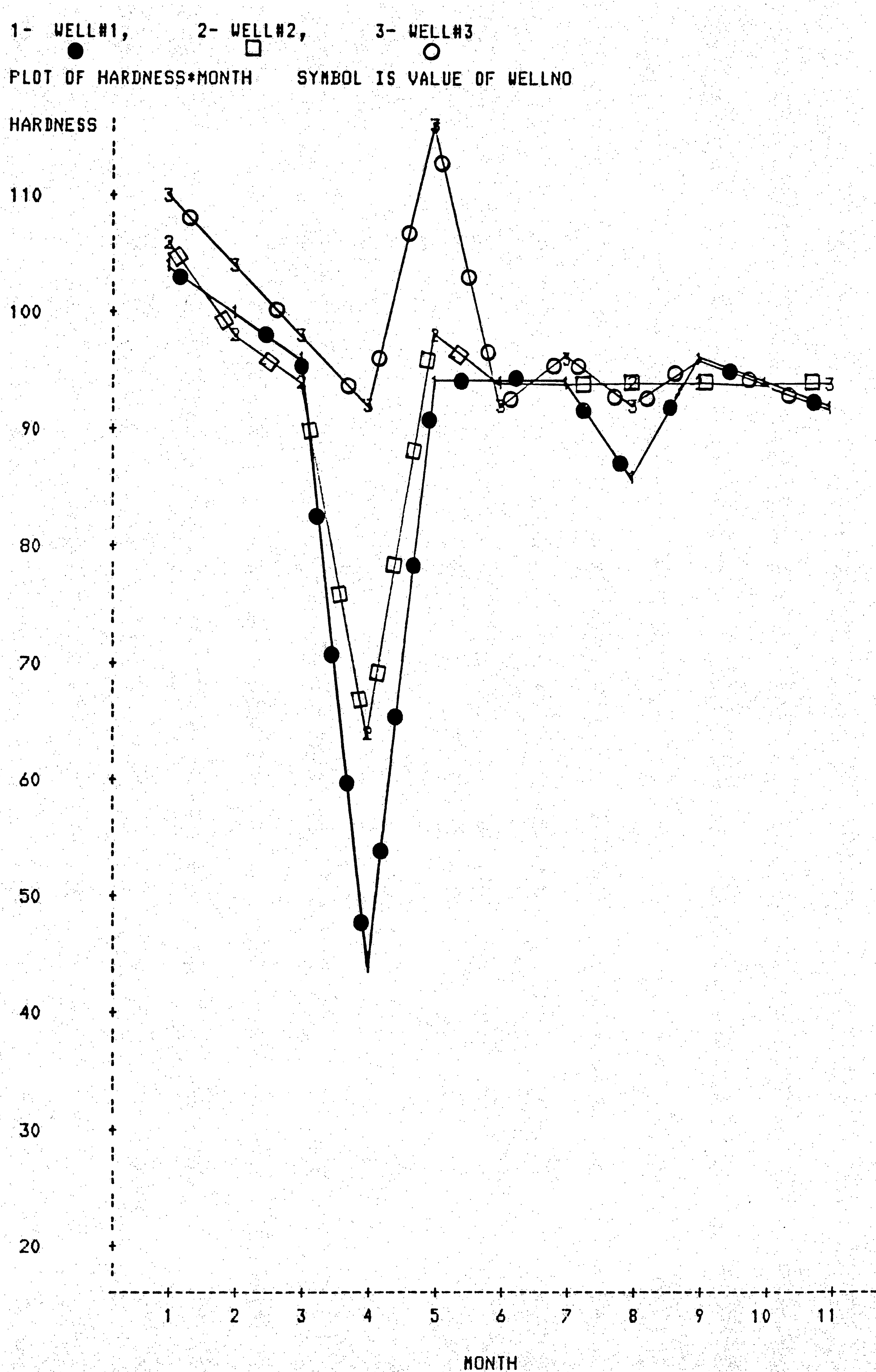
OBS	MONTH	WELLNO	HARDNESS
1	1	1	103
2	2	1	100
3	3	1	95
4	4	1	44
5	5	1	94
6	6	1	94
7	7	1	94
8	8	1	85
9	9	1	95
10	10	1	93
11	11	1	91
12	1	2	106
13	2	2	98
14	3	2	94
15	4	2	63
16	5	2	97
17	6	2	94
18	7	2	94
19	8	2	93
20	9	2	94
21	10	2	93
22	11	2	92
23	1	3	110
24	2	3	104
25	3	3	97
26	4	3	91
27	5	3	116
28	6	3	91
29	7	3	95
30	8	3	92
31	9	3	96
32	10	3	94
33	11	3	94



NOTE: 5 OBS HIDDEN

1- WELL#1, 2- WELL#2, 3- WELL#3

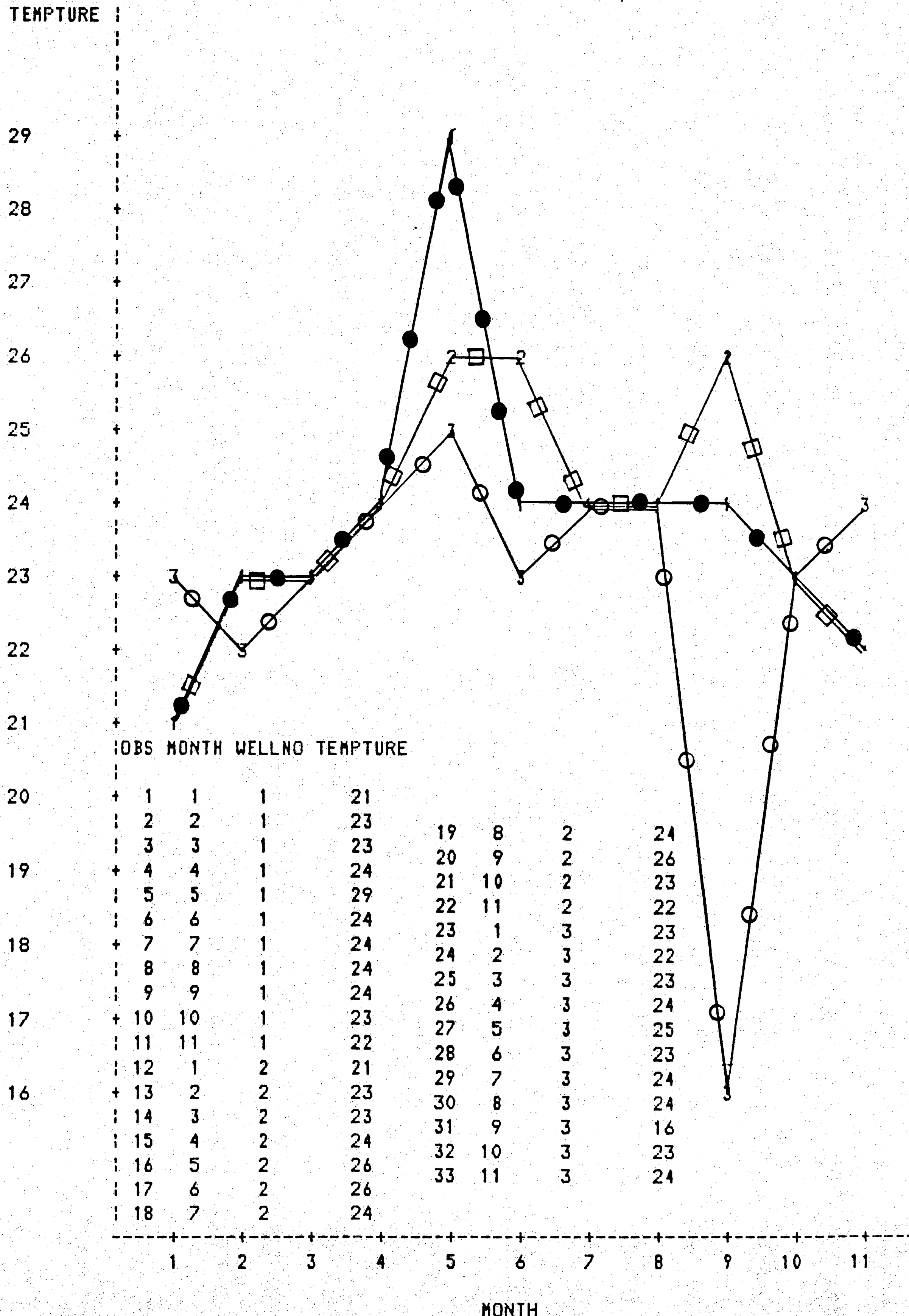
PLOT OF HARDNESS*MONTH SYMBOL IS VALUE OF WELLNO



NOTE: 6 OBS HIDDEN

1- WELL#1, ● 2- WELL#2, □ 3- WELL#3 ○

PLOT OF TEMPTURE*MONTH SYMBOL IS VALUE OF WELLNO

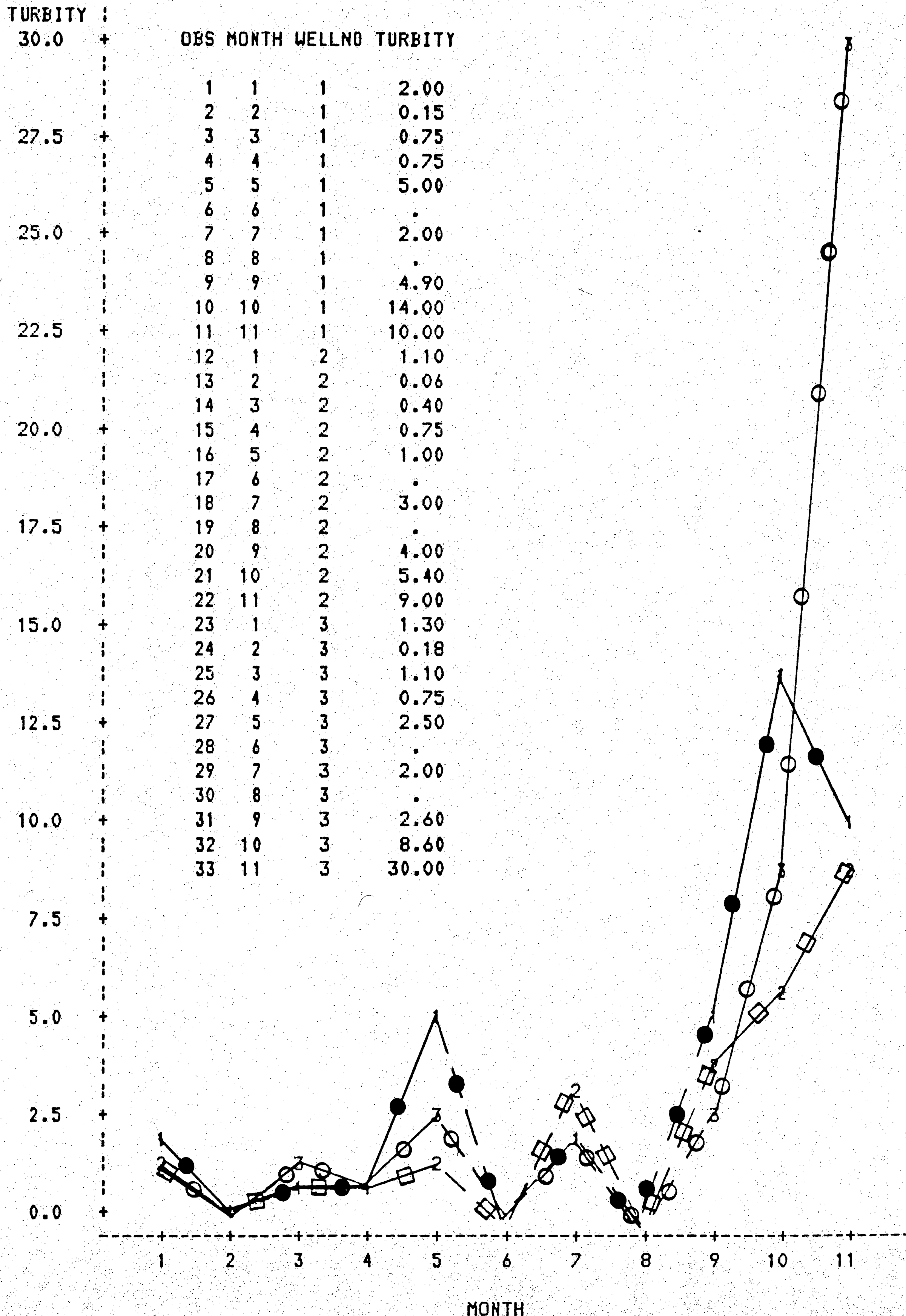


OBS	MONTH	WELLNO	TEMPTURE
1	1	1	21
2	2	1	23
3	3	1	23
4	4	1	24
5	5	1	29
6	6	1	24
7	7	1	24
8	8	1	24
9	9	1	24
10	10	1	23
11	11	1	22
12	1	2	21
13	2	2	23
14	3	2	23
15	4	2	24
16	5	2	26
17	6	2	26
18	7	2	24
19	8	2	24
20	9	2	26
21	10	2	23
22	11	2	22
23	1	3	23
24	2	3	22
25	3	3	23
26	4	3	24
27	5	3	25
28	6	3	23
29	7	3	24
30	8	3	24
31	9	3	16
32	10	3	23
33	11	3	24

NOTE: 13 OBS HIDDEN

1- WELL#1, 2- WELL#2, 3- WELL#3

PLOT OF TURBITY*MONTH SYMBOL IS VALUE OF WELLNO

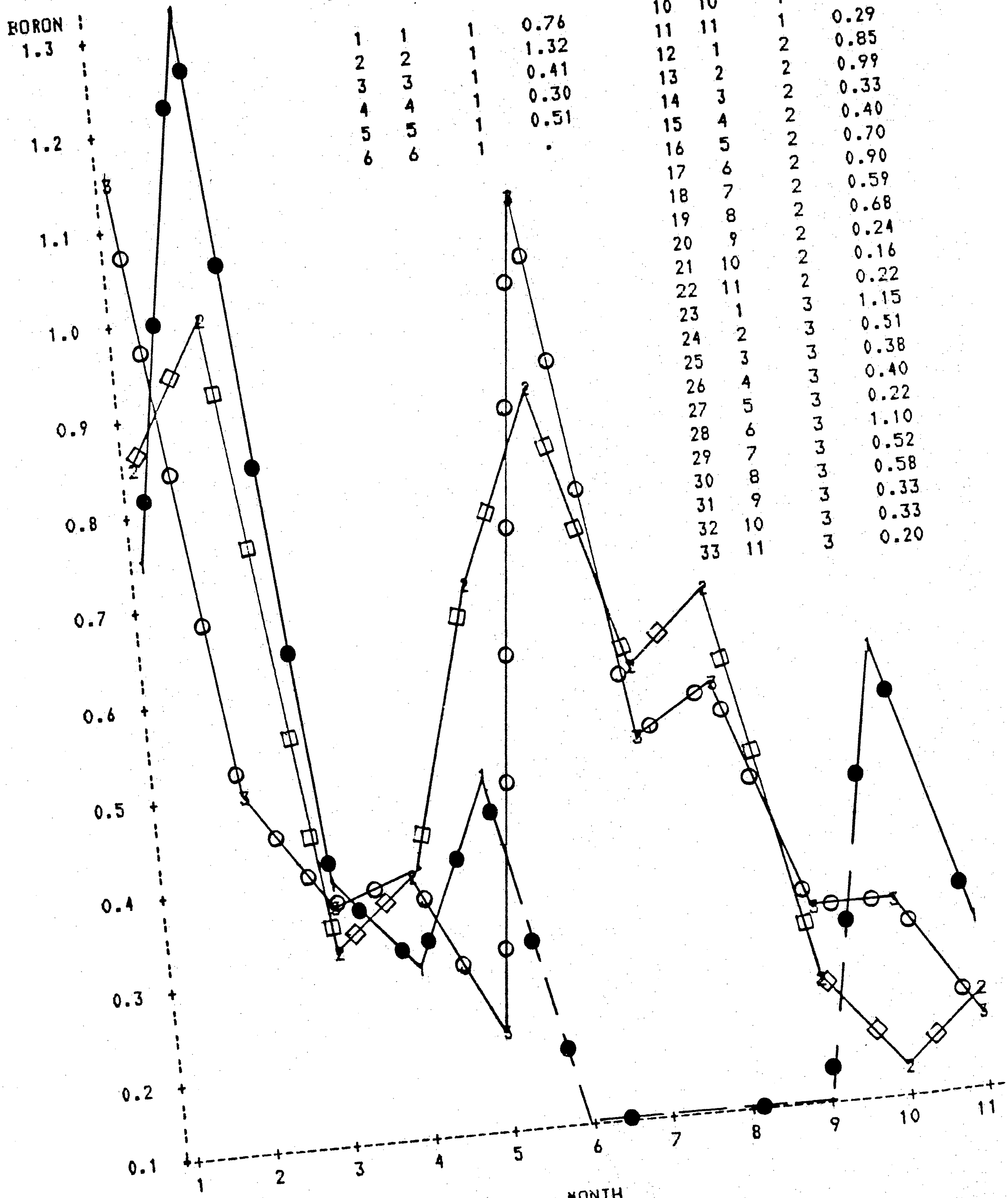


OBS	MONTH	WELLNO	TURBITY
1	1	1	2.00
2	2	1	0.15
3	3	1	0.75
4	4	1	0.75
5	5	1	5.00
6	6	1	.
7	7	1	2.00
8	8	1	.
9	9	1	4.90
10	10	1	14.00
11	11	1	10.00
12	1	2	1.10
13	2	2	0.06
14	3	2	0.40
15	4	2	0.75
16	5	2	1.00
17	6	2	.
18	7	2	3.00
19	8	2	.
20	9	2	4.00
21	10	2	5.40
22	11	2	9.00
23	1	3	1.30
24	2	3	0.18
25	3	3	1.10
26	4	3	0.75
27	5	3	2.50
28	6	3	.
29	7	3	2.00
30	8	3	.
31	9	3	2.60
32	10	3	8.60
33	11	3	30.00

NOTE: 6 OBS HAD MISSING VALUES 7 OBS HIDDEN

1- WELL#1, ● 2- WELL#2, □ 3- WELL#3 ○

PLOT OF BORON*MONTH SYMBOL IS VALUE OF WELLNO

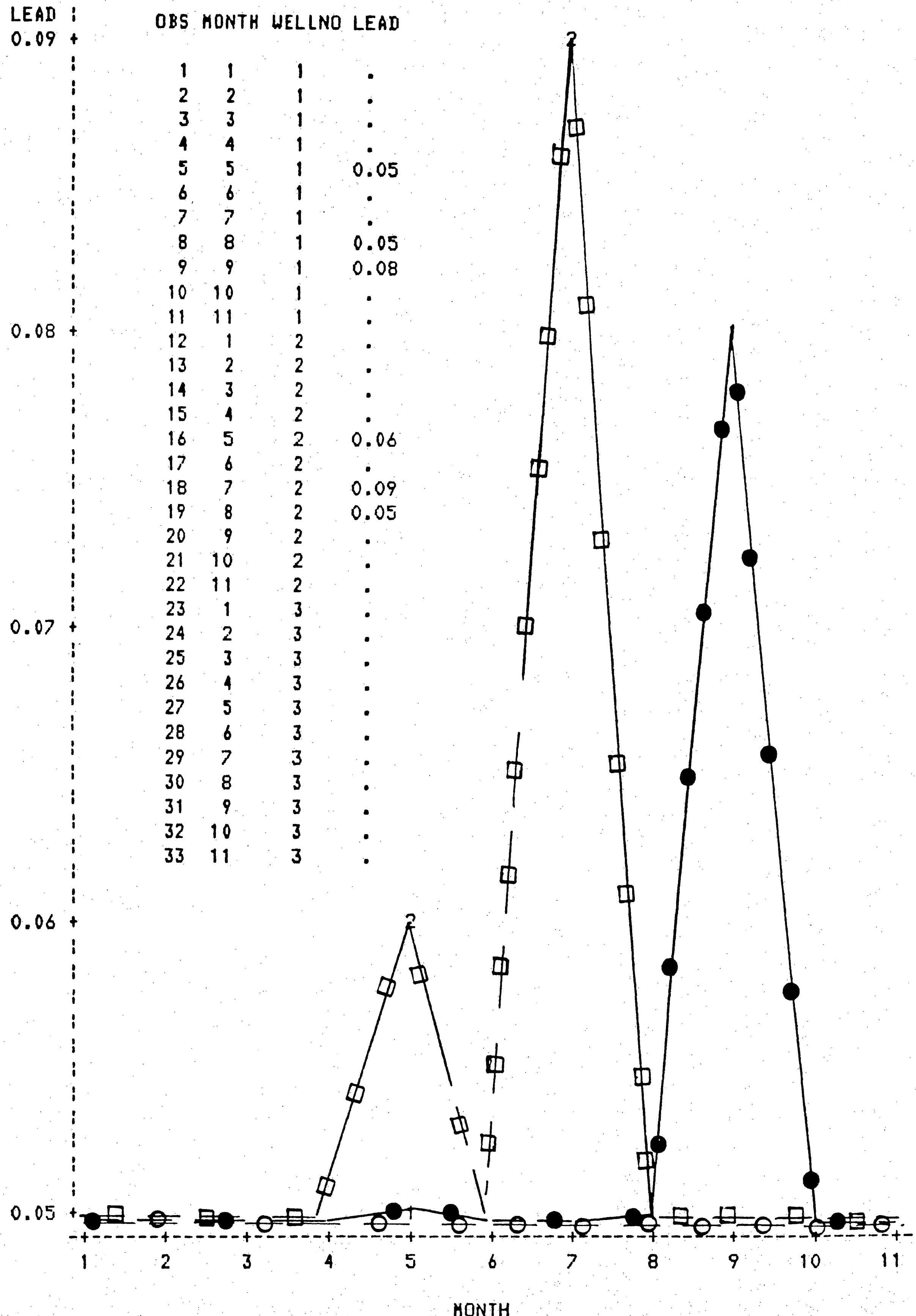


OBS	MONTH	WELLNO	BORON
1	1	1	0.76
2	2	1	1.32
3	3	1	0.41
4	4	1	0.30
5	5	1	0.51
6	6	1	.
7	7	1	.
8	8	1	.
9	9	1	.
10	10	1	0.60
11	11	1	0.29
12	1	2	0.85
13	2	2	0.99
14	3	2	0.33
15	4	2	0.40
16	5	2	0.70
17	6	2	0.90
18	7	2	0.59
19	8	2	0.68
20	9	2	0.24
21	10	2	0.16
22	11	2	0.22
23	1	3	1.15
24	2	3	0.51
25	3	3	0.38
26	4	3	0.40
27	5	3	0.22
28	6	3	1.10
29	7	3	0.52
30	8	3	0.58
31	9	3	0.33
32	10	3	0.33
33	11	3	0.20

NOTE: 4 OBS HAD MISSING VALUES 1 OBS HIDDEN

1- WELL#1, ● 2- WELL#2, □ 3- WELL#3 ○

PLOT OF LEAD*MONTH SYMBOL IS VALUE OF WELLNO

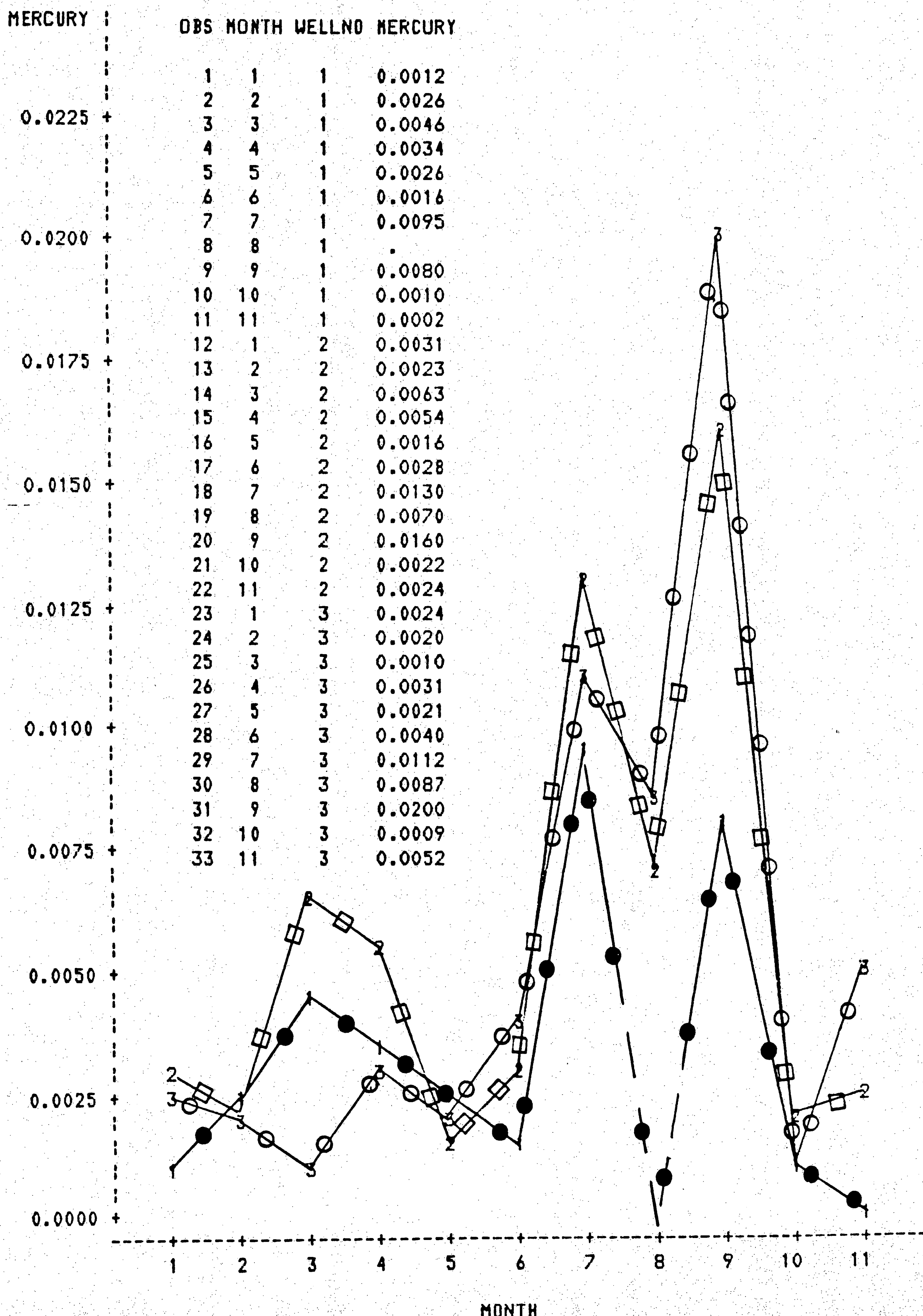


OBS	MONTH	WELLNO	LEAD
1	1	1	.
2	2	1	.
3	3	1	.
4	4	1	.
5	5	1	0.05
6	6	1	.
7	7	1	.
8	8	1	0.05
9	9	1	0.08
10	10	1	.
11	11	1	.
12	1	2	.
13	2	2	.
14	3	2	.
15	4	2	.
16	5	2	0.06
17	6	2	.
18	7	2	0.09
19	8	2	0.05
20	9	2	.
21	10	2	.
22	11	2	.
23	1	3	.
24	2	3	.
25	3	3	.
26	4	3	.
27	5	3	.
28	6	3	.
29	7	3	.
30	8	3	.
31	9	3	.
32	10	3	.
33	11	3	.

NOTE: 27 OBS HAD MISSING VALUES 1 OBS HIDDEN

1- WELL#1, ● 2- WELL#2, □ 3- WELL#3 ○

PLOT OF MERCURY*MONTH   SYMBOL IS VALUE OF WELLNO



OBS	MONTH	WELLNO	MERCURY
1	1	1	0.0012
2	2	1	0.0026
3	3	1	0.0046
4	4	1	0.0034
5	5	1	0.0026
6	6	1	0.0016
7	7	1	0.0095
8	8	1	.
9	9	1	0.0080
10	10	1	0.0010
11	11	1	0.0002
12	1	2	0.0031
13	2	2	0.0023
14	3	2	0.0063
15	4	2	0.0054
16	5	2	0.0016
17	6	2	0.0028
18	7	2	0.0130
19	8	2	0.0070
20	9	2	0.0160
21	10	2	0.0022
22	11	2	0.0024
23	1	3	0.0024
24	2	3	0.0020
25	3	3	0.0010
26	4	3	0.0031
27	5	3	0.0021
28	6	3	0.0040
29	7	3	0.0112
30	8	3	0.0087
31	9	3	0.0200
32	10	3	0.0009
33	11	3	0.0052

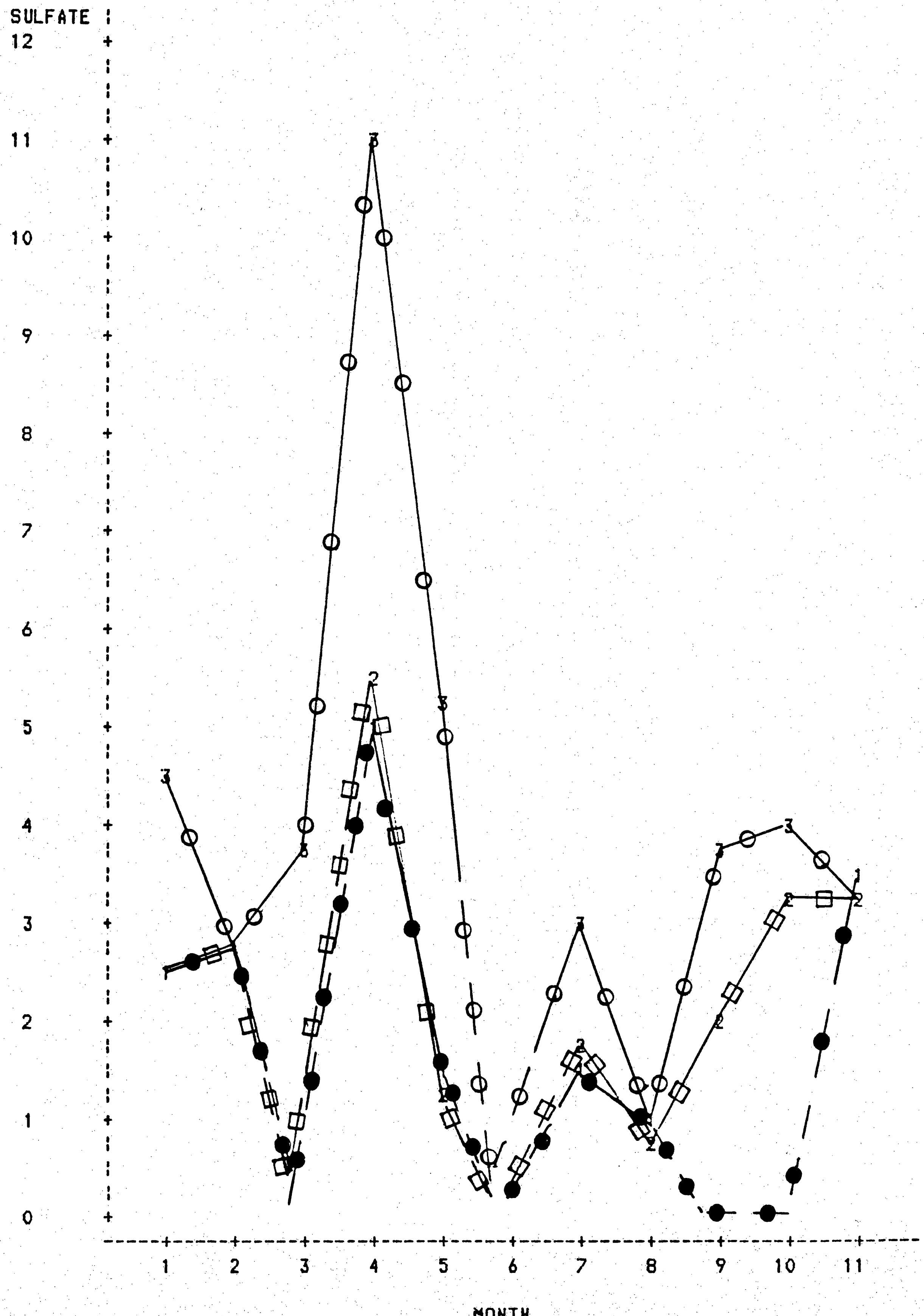
NOTE: 1 OBS HAD MISSING VALUES   2 OBS HIDDEN

OBS	MONTH	WELLNO	SULFATE
1	1	1	2.5
2	2	1	2.7
3	3	1	.
4	4	1	4.9
5	5	1	1.6
6	6	1	.
7	7	1	1.5
8	8	1	1.0
9	9	1	.
10	10	1	.
11	11	1	3.6
12	1	2	2.6
13	2	2	2.7
14	3	2	.
15	4	2	5.4
16	5	2	1.2
17	6	2	.
18	7	2	1.7
19	8	2	0.7
20	9	2	2.0
21	10	2	3.2
22	11	2	3.3
23	1	3	4.5
24	2	3	2.7
25	3	3	3.7
26	4	3	11.1
27	5	3	5.2
28	6	3	.
29	7	3	3.1
30	8	3	1.0
31	9	3	3.8
32	10	3	3.9
33	11	3	3.3

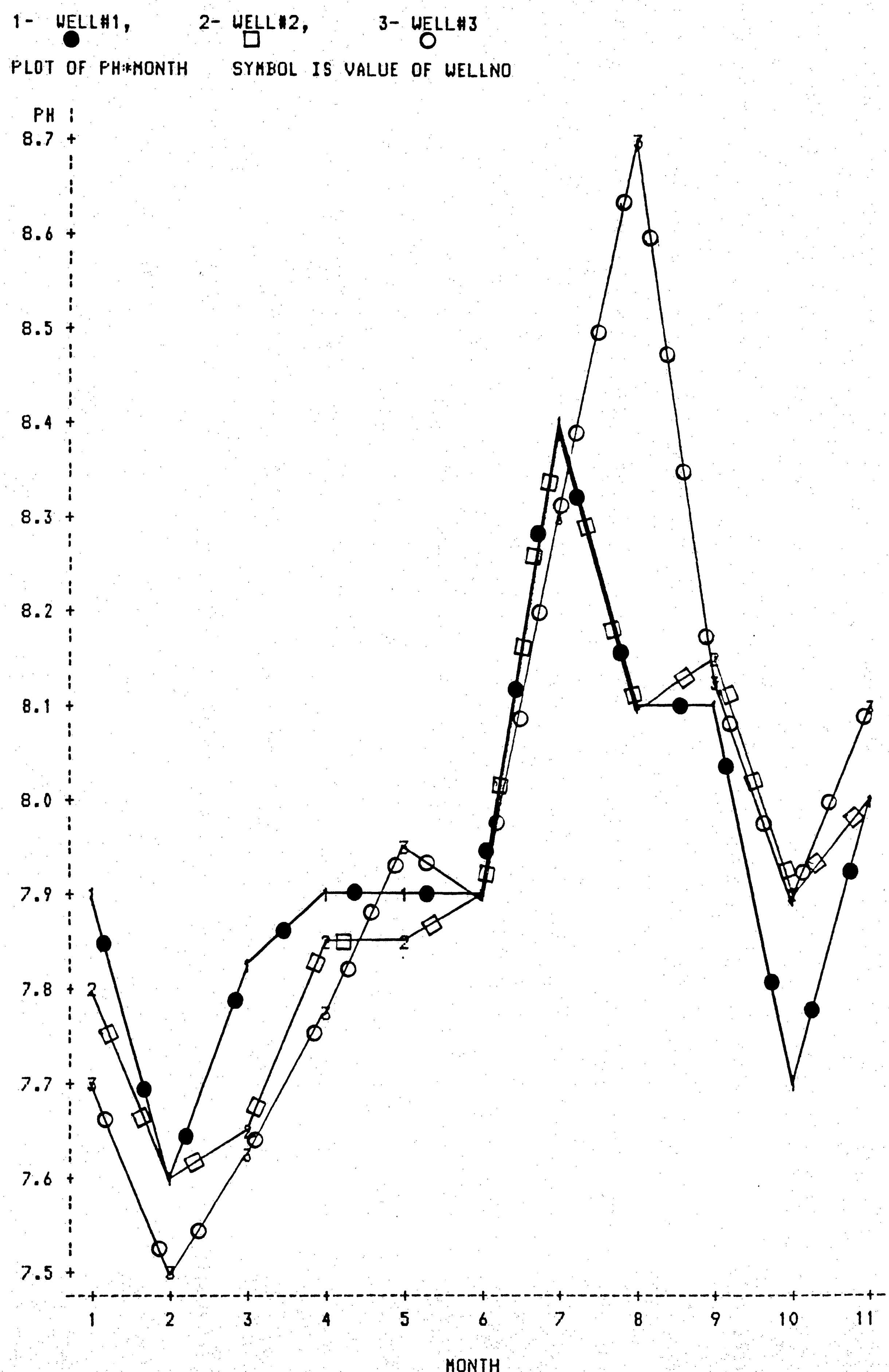
OBS	MONTH	WELLNO	PH
1	1	1	7.90
2	2	1	7.60
3	3	1	7.83
4	4	1	7.90
5	5	1	7.91
6	6	1	7.90
7	7	1	8.40
8	8	1	8.10
9	9	1	8.11
10	10	1	7.70
11	11	1	8.00
12	1	2	7.80
13	2	2	7.60
14	3	2	7.64
15	4	2	7.84
16	5	2	7.86
17	6	2	7.90
18	7	2	8.40
19	8	2	8.10
20	9	2	8.15
21	10	2	7.90
22	11	2	8.00
23	1	3	7.70
24	2	3	7.50
25	3	3	7.62
26	4	3	7.77
27	5	3	7.94
28	6	3	7.90
29	7	3	8.30
30	8	3	8.70
31	9	3	8.12
32	10	3	7.90
33	11	3	8.10

1- WELL#1, ● 2- WELL#2, □ 3- WELL#3 ○

PLOT OF SULFATE*MONTH   SYMBOL IS VALUE OF WELLNO



NOTE: 7 OBS HAD MISSING VALUES   5 OBS HIDDEN



NOTE: 7 OBS HIDDEN