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DOE/NV/10174-2
(DE84007669)

Energy

GEOTHERMAL

TECHNICAL SUPPORT FOR GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

Annual Report for the Period November 1, 1981—October 31, 1982

By
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Work Performed Under Contract No. AC08-81NV10174

Louisiana State University
Baton Rouge, Louisiana

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DOE/NV/10174-2
(DE84007669)

Distribution Category UC-66a

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FOR
GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES
IN LOUISIANA**

**ANNUAL REPORT
for the period
1 NOVEMBER 1981 to 31 OCTOBER 1982**

**D. G. Bebout, Z. Bassiouni, D. R. Carver,
C. G. Groat, A. E. Johnson, Jr., and F. M. Wrighton**

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**Prepared for the
U.S. Department of Energy
Division of Geothermal Energy
Under Contract DE-AC08-81NV10174**

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PREFACE

This annual report of technical support and research covers work done by Louisiana State University during the period 1 November 1981 to 31 October 1982 under Department of Energy (DOE) Contract DE-AC08-81NV10174. The overall purpose of this contract is to provide additional technical support for the DOE program to develop the geopressured-geothermal resource. Specifically, the objectives of the contract are 1) to coordinate ongoing and new projects funded by the geopressured-geothermal program, 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, and 4) to manage and supervise a comprehensive environmental monitoring program for each designed test well in Louisiana. Program management of all research conducted at the university was coordinated by the Louisiana Geological Survey, Don G. Bebout, Principal Investigator.

The components of this annual report and their respective principal investigators are as follows:

<u>COMPONENT</u>	<u>PRINCIPAL INVESTIGATOR (DEPARTMENT)</u>
Resource Assessment	Don G. Bebout (Louisiana Geological Survey)
Rock Mechanics and Subsidence Modeling	Dale R. Carver (Department of Civil Engineering)
Reservoir Analysis and Simulation	Zaki Bassiouni (Department of Petroleum Engineering)
Systems Analysis and Scientific Support	Adrain E. Johnson, Jr. (Department of Chemical Engineering)
Information System	Fred M. Wrighton (Energy Programs Office)
Environmental Monitoring	C. G. Groat (Louisiana Geological Survey)

One component, Site-Specific Studies--Geophysics, Diagenesis, Geochemistry (principal investigator: Rex H. Pilger, Department of Geology), could not be included in this report and will be issued later in a separate volume. All of the components listed above, with the exception of Environmental Monitoring, present work that has been completed and thus are final. Work for the Environmental Monitoring component continues, and results will be presented in subsequent reports.

ACKNOWLEDGMENTS

The Louisiana Geological Survey wishes to thank Geomap Company of Houston, Texas, for granting the Survey permission to use structural information derived from Geomap's structure map service of southwest Louisiana. This information was incorporated in the Resource Assessment component of this report.

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RESOURCE ASSESSMENT

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

INTRODUCTION

Exploration for geopressured-geothermal reservoirs is based on a knowledge of regional sandstone distribution, subsurface temperatures, porosity/permeability, formation pressure, salinity, and structure. All of these factors have been considered in detail in Louisiana Geological Survey (LGS)/Louisiana State University (LSU) reports to the U.S. Department of Energy (August 31, 1981; March 31, 1982) and to the Gas Research Institute (January 1982) and in the Proceedings of the Fifth Conference on Geopressured-Geothermal Energy (1981). Some of these findings are incorporated in this report for the convenience of the reader.

The broad regional data made possible the identification of geothermal corridors, areas in which favorable reservoirs are most likely to occur. These data also provided the information necessary for the assessment of the total in-place solution-gas resource. The details of resource assessment and the identification and study of prospect areas are discussed in full in the following sections.

CONTROLS ON DEVELOPMENT

D. G. Bebout and D. R. Gutierrez

Reservoir Thickness

Thick sandstone units occur throughout south Louisiana within the geopressured zone (Fig. 1) and range in age from Upper Cretaceous (Tuscaloosa) to middle Miocene. The location of these prospective geothermal reservoirs was determined by climate, location of major rivers, location of

GEOPRESSURED SANDSTONES INTERPRETED FROM WELL LOGS

EXPLANATION

- < 12,000 FEET
- 12,000-15,000 FEET
- > 15,000 FEET
- SALT DOME

October 1981

the source area, and contemporaneous structures at the time of deposition. However, it is obvious from all of the regional cross sections (Figs. 2-20) that in all geological formations sandstone units are more common and thicker in the hydro pressured zone and shallow geopressured zone and become less common and thinner in the deeper geopressured zone.

Geopressured sandstones occur downdip of the 40% contour line on the sandstone-percent maps of the Wilcox, Frio, and Miocene (lower, middle, and upper) (Figs. 21-25). Therefore, the geothermal prospects all occur downdip of the main sandstone depocenter. The geopressured corridors (Fig. 26) occur within the area of approximately 20% sandstone in each of the units listed above.

Structure

The predominant depositional processes in the main sandstone depocenter control the maximum lateral extent of a single sandstone unit; however, superimposed upon the depositional models are numerous contemporaneous (growth) faults (Fig. 27) which must also be assumed to be barriers to fluid flow. The major growth fault systems are complex and result in the subdivision of sandstone areas into units generally averaging less than 50 mi² (129.5 km²) in area. Detailed study of any area invariably results in the identification of many additional faults and further reduction in the size of the area of continuity.

Formation Pressure

The depth to the top of geopressure is defined operationally as the point at which the 0.7 psi/ft gradient is reached; this point in each well (shown by the solid arrows in Figs. 3-20) is picked where drilling mud

FIGURE 2. Location of regional dip and strike sections constructed for this study. Dip sections S-S', T-T', and U-U' were not completed for this report because of stratigraphic and structural complications offshore from southeasternmost Louisiana.

FIGURE 5. Dip section C-C'.

FIGURE 6. Dip section D-D'.

FIGURE 7. Dip section E-E'.

FIGURE 8. Dip section F-F'.

FIGURE 9. Dip section G-G'.

FIGURE 10. Dip section H-H'.

FIGURE 12. Dip section J-J'.

FIGURE 14. Dip section L-L'.

FIGURE 18. Dip section P-P'.

FIGURE 20. Dip section R-R'.

FIGURE 21. Sandstone percentage, Wilcox Group, south Louisiana.

FIGURE 22. Sandstone percentage, Frio Formation, south Louisiana.

FIGURE 23. Sandstone percentage, lower Miocene strata, south Louisiana.

FIGURE 24. Sandstone percentage, middle Miocene strata, south Louisiana.

FIGURE 25. Sandstone percentage, upper Miocene strata, south Louisiana.

FIGURE 26. Geopressured-geothermal corridors, south Louisiana. Locations of wells of opportunity and designed wells are also shown.

FIGURE 27. Major subsurface faults, onshore Texas and Louisiana Gulf Coast (modified from National Geophysical and Solar-Terrestrial Data Center, National Oceanic and Atmospheric Administration, 1979).

greater than 13 ppg was needed and where the shale resistivity decreases abruptly (Figs. 28-29). The map of the top of geopressure (Fig. 30) shows that this pressure change does not occur at a uniform depth. On the contrary, the top of geopressure varies considerably, depending upon the amount of porous and permeable sandstone present in the deeper parts of the section. The top of geopressure is deeper in areas where sandstones are abundant and shallower where shale predominates. Therefore, the general trends illustrated on the top-of-geopressure map are similar to those shown on the sandstone-percent maps.

Subsurface Temperature

Plots of bottom-hole temperatures recorded on well logs make possible the prediction of subsurface temperature trends with depth (Figs. 31-32). Also from these data, depths to 212°F (100°C) and 300°F (150°C) isotherms were plotted on the regional cross sections (shown by open arrows in Figs. 3-20); these plots indicate that the 212°F isotherm occurs near the top of geopressure, generally between the depths of -10,000 and -12,000 ft (-3048 and -3658 m). The 300°F isotherm occurs between -13,000 and -18,000 ft (-3962 and -5486 m). As a result of the decrease in the geothermal gradient from west to east Louisiana, the shallower occurrences of a given isotherm are in the west and the deeper occurrences, in the east.

Porosity/Permeability

Porosity decrease with depth is well-demonstrated by the plot of porosity with depth using diamond core analyses from Core Laboratories data (Fig. 33) for Louisiana. This plot also illustrates that, although there is general decrease with depth, there is a spectrum of porosities at any depth,

FIGURE 28. Shale-resistivity plots for Cameron, Calcasieu, and Acadia Parishes.

FIGURE 29. Shale-resistivity plots for St. Mary, LaFourche, Terrebonne, and Plaquemines Parishes.

FIGURE 30. Top of geopressure, onshore Texas and Louisiana Gulf Coast.

FIGURE 31. Temperature plots for Cameron, Calcasieu, Jefferson Davis, and Vermilion Parishes.

FIGURE 32. Temperature plots for St. Mary, St. James, St. John the Baptist, and Terrebonne Parishes.

FIGURE 33. Porosity of Oligocene and Miocene sandstones with depth in south Louisiana (compiled from diamond-core analyses).

probably because of differences in sandstone composition, burial history, and formation fluid composition and movement. Porosity plots by parish (Figs. 34-35) are probably more reliable, but data are sparse for many areas. Permeability plots by parish, shown in Figure 36, illustrate the erratic character of permeability values typical of most areas.

Salinity

Salinity increases with depth and is highest in the hydropressured zone, just above the geopressed zone. In the major hydrocarbon-producing zone just above the geopressed zone, salinity is generally 100,000 ppm or greater. These general trends were determined from the regional cross sections (Figs. 3-20), on which log-derived salinities have been calculated for all wells and throughout the section penetrated. A sample cross section contoured for salinity (D-D') is shown in Figure 37.

RESOURCE ASSESSMENT--IN-PLACE SOLUTION METHANE

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

One of the prime objectives in constructing the regional cross sections across the south Louisiana Gulf Coast was to aid in assessing the total solution-methane resource in place. The cross sections provide point sources of information from key wells as well as considerably more insight into the significance of each well through logical correlations with other wells on the section. While the sections were being prepared, many detailed studies of smaller areas were conducted simultaneously at LSU and other universities and private organizations throughout the Gulf Coast. Data from these detailed studies were also considered in determining the size of the resource. Obviously, it is essential that reasonable values be used for all

FIGURE 34. Porosity plots for Jefferson Davis, Acadia, Cameron, and Vermilion Parishes.

FIGURE 35. Porosity plots for Terrebonne, LaFourche, Jefferson, and Plaquemines Parishes.

FIGURE 36. Permeability plots for Cameron, LaFourche, Iberia, St. Mary, Vermilion, and Terrebonne Parishes.

FIGURE 37. Example of a regional dip section (D-D') with contours drawn (contour interval = 50,000 ppm TDS) to show subsurface distribution of salinity values in sandstone reservoir fluids. Salinity distribution shown is typical of other cross sections.

parameters affecting the size of the resource. Also, in areas of insufficient data it is necessary to make reasonable assumptions which are in accord with the structural and depositional processes operative in the Gulf coastal province.

The total area under consideration in south Louisiana includes more than 18,000 mi² (46,617 km²). The geopressed formations within this area are the Wilcox (1692 mi², or 4382 km²), Frio (5200 mi², or 13,467 km²), and Miocene (11,514 mi², or 29,819 km²). The parameters considered in this assessment are pressure, sandstone volume, porosity, temperature, and salinity (Table 1).

Pressure

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 pounds per square inch,
D is the depth in feet to the middle of the formation, and
p is the mud density (weight) in pounds per gallon.

The pressures for the wells in a parish were calculated, and the average for all these wells was used. Shale-resistivity plots (Figs. 28-29) from well logs, combined with mud weights, were used to identify the top of geopressure.

Sandstone Volume

The sandstone volume (reservoir bulk volume) was obtained from the net-sandstone maps by planimetering each contour. The area thus obtained was multiplied by the contour value in order to determine volume. It should be pointed out that this figure is a minimum because many wells did not penetrate

TABLE 1. Parameters used in assessing the solution-methane resource.

Parish	Porosity (%)	Bulk Volume (mi ³)	Pore Volume (mi ³)	Solubility CH ₄ (SCF/bbl)	Pore Volume x10 ⁹ (bbl)	In-Place CH ₄ x10 ¹² (SCF)
WILCOX	TOTAL	16.5	160	26	58	40.2
	Acadia	23	50.20	11.5	61	301.50
	Ascension	27	4.23	1.1	35	28.84
	Calcasieu	27	120.50	32.5	36.5	852.06
	Cameron	25	65.24	16.3	54	427.34
	Iberia	23	0.40	0.1	--	2.62
	Iberville	22	26.53	5.8	46	152.06
	Jefferson	25	62.75	15.7	46	411.61
	Lafayette	25	30.63	7.6	57	199.25
	Livingston	26	2.00	0.5	39.5	13.11
	St. Landry	25	3.75	0.9	33.5	23.59
Frio	St. Martin	25	30.84	7.7	48	201.87
	Vermilion	18	19.00	3.4	81	89.14
	TOTAL	24.8	416	103		129.08
MIOCENE	Assumption	20	10.5	2.1	59	55.05
	Cameron	25	74.5	18.6	41.5	487.60
	Iberia	20	39.4	7.9	42	207.10
	Jefferson	21	28.4	6.0	41	157.30
	Lafourche	23	74.8	17.2	46	450.90
	Plaquemines	24	136.7	32.8	47	859.85
	St. Bernard	25	48.3	12.0	25	314.58
	St. Charles	25	23.5	5.9	42	154.67
	St. James	27	3.1	0.8	34.5	20.97
	St. John					
	the Baptist	25	8.7	2.2	32	57.67
	St. Mary	20	114.7	22.9	56	600.32
	Terrebonne	20	101.6	20.3	56	532.16
	Vermilion	18	82.2	14.8	58	387.98
	TOTAL	21.9	746.4	163.5		202.4

the entire formation and no adjustment was made to account for the remainder of the section. In the calculation of Wilcox sandstone volume, an assumption of 500 ft (152 m) of net sandstone was made because of the lack of wells extending to the base of the Wilcox Group.

Porosity

The average porosity for each parish was determined by using the porosity/depth plot constructed for each parish (Figs. 34-35). Data on this plot included core analyses from diamond and sidewall cores and 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.

Temperature

Temperature plots have been prepared for each parish (Figs. 31-32) 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

The salinity of the formation was calculated using the method developed by Silva and Bassiouni (1981). The average formation-water salinity of a formation in each parish was determined by first obtaining an average salinity value for the formation sandstones in each well and then adding all of these salinity values within a parish; the resulting figure was then divided by the number of wells in that parish.

The solubility of methane in water is a function of formation pressure, temperature, and water salinity. In this report, methane solubilities were

computed by the empirical equation of Blount, Price, Wenger, and Tarullo (1979), which follows:

$$\begin{aligned}\log_e(\text{CH}_4) = & 3.6003 + 1.1176 \times 10^{-3} T \log_e P + 0.10002 Y \\ & -0.01634 T + 1.6574 \times 10^{-5} T^2 - 0.2828 \times 10^{-3} TY \\ & -0.01124 Y \log_e P + 2.1262 \times 10^{-5} YT \log_e P\end{aligned}$$

Where CH_4 = methane solubility, standard cubic feet per barrel,
T = temperature, degrees Kelvin,
P = pressure, pounds per square inch, 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 error is very small compared to the much larger errors inherent in other data which have gone into the final calculations presented here; therefore, this error has not been taken into account in this assessment.

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

The Wilcox corridor covers an area of 1692 mi^2 (4382 km^2). The stratigraphic section extends from -11,000 ft (-3353 m) to the deepest significant sandstone occurrence. In the estimation of total volume of in-place methane dissolved in formation waters, an assumption of an optimistic average thickness of 500 ft (152 m) of net sandstone was made. Because not enough wells penetrated to the base of the Wilcox, it was difficult to obtain a realistic volume of net sandstone. Based on the assumed value of 500 ft (152 m), the bulk volume of Wilcox sandstone was calculated to be 160 mi^3 (667 km^3), with an

average porosity of 16.5%. 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 mi² (13,467 km²). The total bulk volume of Frio sandstone below 8000 ft (2438 m) is estimated to be 416 mi³ (1732 km³). The total pore volume, which is assumed to be filled with water with no net pay of hydrocarbon, is estimated to 103 mi³ (429 km³), using an average porosity of 24% for the Frio corridor. Methane solubility values for formation waters of the Frio corridor range from 33.5 to 81 SCF/bbl, based on the empirical equation of Blount and others (1979). The total volume in place of solution methane in Frio reservoirs in Louisiana is 129.1 TCF.

The areal extent of the Miocene corridor is 11,514 mi² (29,819 km²). The lower Miocene extends over 6176 mi² (15,995 km²) and contains a total bulk volume of 426 mi³ (1775 km³). The total pore volume, which is assumed to be filled with water with no net pay of hydrocarbon, is estimated to be 87.4 mi³ (364 km³), using an average porosity of 20% for the lower Miocene. Methane solubility values for formation waters of the geopressed lower Miocene average 50 SCF/bbl, based on the empirical equation of Blount and others (1979). Therefore, the total in-place volume of methane for the lower Miocene in Louisiana is 118.7 TCF. The areal extent of the middle Miocene corridor is 5338 mi² (13,825 km²). The pore volume is 76.4 mi³ (318.4 km³), using an average porosity of 24%. Methane solubility values for formation waters of the geopressed middle Miocene average 38.8 SCF/bbl. The total in-place volume of methane is 83.7 TCF. A total volume of 202.4 TCF of in-place methane has been assessed for the total onshore Miocene.

TUSCALOOSA REGIONAL ASSESSMENT

M. D. Purcell and R. P. McCulloh

Introduction

This study was begun to evaluate the lower Tuscaloosa Formation on a regional scale for deep geopressured-geothermal potential in south Louisiana. The area studied extends from the Sabine River on the western side of the state eastward across Lake Pontchartrain through Chandeleur Sound; the northern and southern boundaries were determined by available deep Tuscaloosa control (Fig. 38). The Tuscaloosa is a lowermost Upper Cretaceous formation of wedge-like geometry, in which areas of massive sand accumulations were controlled by deltaic or nearshore depocenters on the Lower Cretaceous carbonate shelf (Funkhouser, Bland, and Humphris, 1980). The sandstones formed in these depocenters may have downdip equivalents laid down as density-flow deposits on the continental slope, as reported by Siemers (1978) and Foss (1979) for the Woodbine Formation in East Texas. While these could lie very deep, Berg (1982) suggests that turbidites account for much of the production in the Tuscaloosa trend. A series of dip and strike cross sections constructed with electric well logs (Figs. 39-43) shows substantial thickening of the lower Tuscaloosa section on the downthrown sides of growth faults.

Initial work showed that, in many places within the Tuscaloosa trend where the Tuscaloosa Formation lies below the regional top of geopressure, the formation itself is not overpressured, as defined by mud weights less than 13.0 ppg. The drastic pressure drop in the Tuscaloosa interval, which creates a zone of normal pressure within the geopressured zone, is attributable to reported Tuscaloosa sandstone porosities and permeabilities, which have been found to be extremely high for the depths involved (Thomson, 1979, 1980; Franks, 1980; Smith, 1980a, 1980b).

FIGURE 38. Index map of Tuscaloosa study area.

FIGURE 39. Location of dip and strike sections constructed for Tuscaloosa regional assessment.

FIGURE 40. Tuscaloosa dip section A-A'.

FIGURE 42. Tuscaloosa dip section C-C'.

FIGURE 43. Tuscaloosa strike section D-D'.

The depth to the top of the sandstone interval ranges from 10,000 ft (3048 m) in the eastern region to as great as 21,000 ft (6400 m) in the central region of the study area. Abnormally high permeabilities at these depths permit gas to exist as a separate phase in the Tuscaloosa trend (Gill, 1980). The need for lower permeability and/or greater aquifer confinement, to maintain geopressures and diminish the proportion of free gas and to permit production of reservoir fluids and their contained solution gas, originally suggested that a study of Tuscaloosa geopressured-geothermal potential concentrate on areas between producing gas fields. It was found, however, that producing areas could still hold high potential for solution gas. Early indications of very large quantities of dissolved methane in Tuscaloosa sandstone reservoir fluids were noted from testing done in the central portion of the Tuscaloosa trend. Tests of several aquifers at +20,000 ft (6096 m) in the False River-Judge Digby field areas of Pointe Coupee Parish, Louisiana, have revealed methane concentrations ranging from 80 to 496 SCF/bbl at flow rates up to about 7000 bbl/day (Wallace, 1983, personal commun.).

In order to permit an evaluation of geopressured-geothermal resource potential, the investigation sought to determine the areal distribution of the following parameters within the Tuscaloosa trend:

- 1) Massive sandstone having discernible shale interbeds, with a minimum net thickness of 200 ft (61 m), or a single massive sandstone unit 100 ft (30.5 m) thick or greater.
- 2) Sandstone exhibiting geopressures as identified from well log data (> 13.0 ppg mud weight).
- 3) Temperatures greater than 300°F (150°C) at the base of the lowermost Tuscaloosa sandstone.

Geopressured-Geothermal Potential

In the Tuscaloosa trend of Louisiana, identification of the geopressured zone on well logs is made difficult by widely varying formation pore pressures and by the large proportion of highly resistive limestone units in the section above (Austin Chalk) and below (Washita-Fredericksburg units) the Tuscaloosa interval. In most places, high pressures were encountered in the Eagle Ford Shale at the base of the Austin Chalk. The chalk itself is not geopressured, as defined above pressures, although some dissipation from the underlying shale through microfractures probably occurs (Gill, 1980).

The massive lower Tuscaloosa sandstone shows lower pressures than the overlying shale of the Eagle Ford Formation. The overpressures, which originated within the shales (Gill, 1980), have dissipated into the hydro pressured zone through the abnormally porous and permeable sandstone units. Cores from False River field in Pointe Coupee Parish have shown porosities exceeding 25% and permeabilities as high as 1200 md (Thomson, 1980). These anomalous porosities, found at depths greater than 20,000 ft (6096 m), are believed by some to be primary (Thomson, 1979, 1980) and by others, secondary (Franks, 1980; Smith, 1980a, 1980b).

The pressure drop encountered in the massive sandstone units is identified by mud weights recorded on electric well logs (Fig. 44). Heavier mud weights of up to nearly 18 ppg in the overlying geopressured shale section can drop to less than 10 ppg in the sandstone. The amount of pressure loss is dependent on the ability of the overpressures to leak into the normal or hydro pressured zone, a direct function of permeability and reservoir continuity. The cross sections indicate that higher pressures are retained in the expanded sections on the downthrown sides of growth faults (Figs. 40-43). Updip from these fault blocks, substantial pressure loss in places has created tongues, or wedges, of

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 SEC.48,T.4S.,R.2W.

FIGURE 44. Pressure drop in lower Tuscaloosa massive sandstone, as indicated by change in drilling mud weight to value characteristic of hydro pressured zone (less than 13.0 ppg).

hydropressure within the geopressured zone (Figs. 41-43, 45 and 46). Downdip in the trend, where the sandstone units become thin and the interbedded shales, more numerous, no pressure loss is evident, and the entire Tuscaloosa interval penetrated is geopressured. The areal extent of geopressured Tuscaloosa sandstone is therefore controlled by two boundaries: 1) arcuate growth faults defining the northern updip limit (except in the western part of the trend where the massive sandstone is absent) and 2) the pinch-out of sandstone units southward into the basin.

The regional distribution of the Tuscaloosa sandstone was determined by net sandstone isopach (Purcell and McCulloh, in prep.). The collective lobate geometry of the sandstone bodies distinguishes the individual depocenters where well control is good. The largest of these depositional lobes, with sandstone thickness exceeding 900 ft (274 m), lies in the central portion of the trend east of the present-day Mississippi River. Other areas with good sandstone development include the Moncrief field in St. Landry Parish and the North Lake Borgne-Chandeleur Sound region. The net sandstone mapping indicated that the Tuscaloosa hydropressure tongues (Fig. 46) are preferentially developed in these lobes.

To determine the areal extent of massive Tuscaloosa sandstone lying within the geopressured zone, a regional map was constructed depicting the hydropressure-geopressure boundary and the distribution of massive sandstone based on the initial definition (above) of a massive unit (Purcell and McCulloh, in prep.). The downdip lobate boundary of massive sandstone influences the downdip extent of the hydropressure-geopressure contact in the Tuscaloosa interval, although, as mentioned above, the precise updip extent of geopressure in the Tuscaloosa interval is determined by arcuate growth faults in the massive sandstone areas.

FIGURE 45. Schematic section showing distribution of hydropressures and geopressures in the lower Tuscaloosa of the Tuscaloosa trend, as discerned on the dip and strike sections (Figs. 40-43).

FIGURE 46. Areal distribution of hydropressure tongues in the Tuscaloosa Formation, Louisiana (includes only those areas where hydropressured Tuscaloosa sandstone is overlain by geopressed section).

By retarding pressured dissipation, the faults permit the hydropressure-geopressure contact to extend updip into the massive sandstone facies. In general, sandstone which is both massive and geopressured extends from the Moncrief field in St. Landry Parish eastward through Chandeleur Sound. Although some areas of this trend are only speculative, continued drilling in the eastern region will better define sandstone development and geopressure distribution. In the western region, no evidence of any major depocenter exists, thereby limiting the extent of the massive geopressured sandstone to only the central and eastern regions of the study area.

In order to identify the range of maximum reservoir fluid temperatures in the Tuscaloosa interval and to provide a general interpretation of temperature distribution, corrected bottom-hole temperatures for different logging runs were interpolated to the base of the lowermost Tuscaloosa sandstone and mapped (Purcell and McCulloh, in prep.). The map shows that temperature trends parallel regional strike and reflect the basic regional pattern of homoclinal dip which characterizes the stratigraphic units in this part of the Gulf Coast basin. Individual lowermost Tuscaloosa sandstone temperature values range from 200°F (93°C) to higher than 400°F (204°C). The temperature at the base of massive geopressured Tuscaloosa sandstone exceeds 300°F (150°C) throughout the study area.

Summary

Areas most prospective for geopressured-geothermal energy in the Tuscaloosa Formation, where massive Tuscaloosa sandstone lies within the geopressured zone and contains fluids with temperatures exceeding 300°F (150°C), are limited to the following locations in the Tuscaloosa trend of south Louisiana:

- 1) A strike-oriented band, approximately 40 by 5 mi (64 by 8 km), which lies between the Judge Digby, Port Hudson, Irene, and False River gas fields and includes the Moore-Sams and Profit Island fields in Pointe Coupee, West Baton Rouge, and East Baton Rouge Parishes.

- 2) An area of undetermined size (because of sparse well control) which extends east-southeast of Lake Borgne in the Chandeleur Sound region and averages about 6 miles (10 km) wide.
- 3) A small area which includes the northern portion of the Rigolets field at the north end of Lake Borgne in St. Bernard Parish.
- 4) A small area which includes part of the southern half of the Moncrief field in St. Landry Parish.

Most of these areas include both producing and non-producing parts of the trend. The distribution of geopressure in relation to potential Tuscaloosa reservoir sandstones is determined partly by anomalously high permeabilities. The most highly permeable sandstone with the thickest net sandstone values is invaded by tongues of normal pressure, which extend downdip from the hydropressured zone, where such sandstone is not bounded updip by growth faults. These local hydropressured tongues limit geopressured-geothermal potential to fewer and smaller areas than regional Tuscaloosa sandstone development and the regional top of geopressure would otherwise dictate.

DETAILED SITE-SPECIFIC GEOLOGICAL STUDIES

Through the regional studies conducted in order to assess the in-place solution-methane resource, several areas were delineated which merited additional study as future geopressured-geothermal test well sites. Detailed studies were completed for the Calcasieu, Bayou Hebert, and Houma embayment areas. The results of these studies are included here, along with the results of the detailed study of the Rockefeller Refuge prospect, which was conducted because of the need to incorporate into previous studies the results of the new test well, the DOE/TF&S No. 1 Gladys McCall.

Calcasieu Prospect

M. A. Pino

The Calcasieu prospect covers a 100-mi² (259-km²) area in southwest Louisiana (Fig. 47). This part of Louisiana can be subdivided into three distinct structural provinces: the Eocene fault trend, Oligocene domal trend, and growth fault area (Ocamb, 1961). This prospect is within the Oligocene domal trend. Much of the structure in this area is genetically related to the effects of salt movement. Paine (1968) reported on the depositional setting of the Hackberry wedge, and Friedel (1978) and Kurth (1981) evaluated the geopressured-geothermal potential. Five cross sections of the Calcasieu prospect were constructed with available well logs; the two dip sections and the southernmost strike section are shown in Figures 48 to 50.

The Hackberry embayment section is divided into two parts. The upper part is as thick as 3000 ft (9144 m); shales in this section contain outer-neritic microfossils. The lower section ranges in thickness from 50 to 700 ft (15 to 215 m) and consists primarily of sandstones. The lower Hackberry sandstones in Texas have been interpreted by some authors as density-flow deposits; Bornhauser (1960) interpreted those in the northwest Hartburg field (East Texas), and Berg and Powers (1980) interpreted those in southeast Texas as having been deposited in a submarine channel.

The study area is contained in the Oligocene domal trend; the D-D' cross section crosses three domes that act as a continuous salt ridge, and their associated faulting takes on a regional character. Electric log cross sections constructed for this study show lateral changes within the reservoir section in the lower Hackberry. Reservoir continuity is interrupted by several mappable faults (Figs. 48-51). Normal faults, the most common structures found in this study, show only slight growth both below and above the top of geopressure.

FIGURE 47. Location, well control, and cross sections, Calcasieu prospect.

FIGURE 48. Dip section A-A', Calcasieu prospect.

S. EAST
A'

19

22

PAN AMER. PET. CORP.
EASTLAKE TOWNSITE CO. NO. C-1
SEC. 14, T.10S., R.8W.

16

PAN AMER. PET. CORP.
LAKE CHARLES SUGAR CO. NO. 3
SEC. 25, T.10S., R.8W.

29

THE CALIF. CO.
POWELL LUMBER
SEC. 29, T.9S., R.8W.

28

SAMEDAN OIL CORP.
EDNA JACOB NO. 1
SEC. 29, T.9S., R.8W.

PAN AMER. PET. CORP.
SAM D. SONNIER NO. 1
SEC. 15, T.10S., R.8W.

N.WEST
B

89

FIGURE 49. Dip section B-B', Calcasieu prospect.

FIGURE 50. Strike section E-E', Calcasieu prospect.

FIGURE 51. Structure map of top of lower Hackberry, Calcasieu prospect.

The faults in this area are of two general types, those related to salt tectonics (crestal stretch faults) and those related to large-scale sediment movement (regional faults). The structure map on top of the lower Hackberry (Fig. 51) ranges in depth from 8150 ft (2484 m) in the northwestern part of the area to 14,100 ft (4298 m) in the southeastern part; this horizon probably shows the greater relief. Comparison of the structure contour map of the lower Hackberry (Fig. 51) with the net sandstone map (Fig. 52) shows larger quantities of sandstone (200 to 490 ft, or 60 to 150 m) in the channel areas, which show up as large elongate trenches, or cuts, on the structure map. The positions of the channel areas are shown by arrows in Figure 52.

The top of geopressure (Fig. 53) lies at an average depth of 9700 ft (2957 m) and is lithostratigraphically controlled. The lower Hackberry sandstones show a pressure gradient of 0.65 to 0.90 psi/ft, averaging 0.77 psi/ft. Temperatures are from 200° to 250°F (193° to 121°C), averaging 225°F (107°C). Salinity values calculated from well logs in the Calcasieu area range from about 42,000 to 170,000 ppm (Fig. 54) within individual sandstones in the lower Hackberry. The study also indicates good sandstone development, with favorable porosity (12 to 36%, averaging 24%) (Fig. 55) and permeability from 200 to 500 md. The net sandstone thickness map within the lower Hackberry (Fig. 52) shows reservoirs 50 to 490 ft (15 to 150 m) thick at 8500 to 14,100 ft (2591 to 4298 m).

As a result of this study, the structural-stratigraphic setting of the prospect has been delineated from a combination of several parameters. The reservoir with greatest geopressured-geothermal potential is located in the southeastern part of the Calcasieu field (Fig. 56). Parameters which characterize this area are as follows:

average depth, top of geopressure - - - - - 10,500 ft (3200 m)
geopressure gradient - - - - - 0.77 psi/ft

FIGURE 52. Net sandstone isopach map, lower Hackberry interval, Calcasieu prospect.

FIGURE 53. Depth to the top of geopressure, Calcasieu prospect.

FIGURE 54. Log-calculated salinity (ppm TDS x 1000) of lower Hackberry sandstone reservoir fluids, Calcasieu prospect.

FIGURE 55. Log-calculated porosity (%) of lower Hackberry sandstones, Calcasieu prospect.

FIGURE 56. Summary of parameters, Calcasieu prospect (evaluation priorities defined bottom center; HNS and LNS refer to high net sandstone and low net sandstone, respectively; LS and HS refer to low and high salinity, respectively; HPG and LPG refer to high- and low-pressure gradient, respectively; and HP, MP, and LP refer to high, medium, and low porosity, respectively).

aquifer temperature	- - - - -	250°F (121°C)
salinity regime (relatively low)	- - - - -	40,000-90,000 ppm
average sand thickness	- - - - -	200-450 ft (60-137 m)
porosity	- - - - -	adequate, averaging 24%
structure	- - - - -	large unfaulted blocks

Rockefeller Refuge (Gladys McCall Test Well)

D. G. Bebout and D. R. Gutierrez

The Technadril-Fenix and Scisson-Department of Energy (TF&S-DOE), No. 1 Gladys McCall well was drilled to a total depth of 16,510 ft (5032 m) in southeastern Cameron Parish in the Miocene geopressured-geothermal corridor (Fig. 26). The test well is less than one mile north of the Union Oil Co. of California, No. 1 Dr. M. O. Miller well, Well 12, on regional cross section D-D' (Fig. 6). The geologic section penetrated here consists of upper Miocene from 4000 to 6000 ft (1220 to 1830 m), middle Miocene from 6000 to 11,000 ft (1830 to 3353 m), and lower Miocene from 11,000 ft to a total depth of about 18,150 ft (5532 m).

Along regional cross section D-D' (Fig. 6), the operational top of geopressure occurs approximately at 11,000 ft (3353 m). However, the exception to the trend is at Well 12, near the test well site, where the operational top of geopressure is as deep as 15,000 ft (4572 m) because of the high volume of sandstone in the lower Miocene section.

The TF&S-DOE, No. 1 Gladys McCall test well is located between Wells 11 and 12 on regional cross section D-D', extremely close to Well 12 (Fig. 6). Wells in this immediate area contain the thickest sandstone units found in the geopressured zone of both Texas and Louisiana. These thick sandstones are even anomalous for the D-D' section because they occur where shale was expected to predominate.

Prior to the drilling of the TF&S-DOE, Gladys McCall well, there was considerable controversy concerning the correlations between the nearby

Getty-Buttes, No. 1 McCall, which reached only to 15,590 ft (4752 m), and the Union, No. 1 Miller. At depths less than 15,000 ft (4572 m), the correlations can be made essentially straight across from the McCall to the Miller (Fig. 57). However, at depths greater than 15,000 ft, correlations that are continued straight across result in the correlation of sandstone with shale and shale with sandstone. Although facies changes are common and expected in the lower Miocene, the magnitude of these changes seems anomalous. Therefore, it was thought probable that a major fault cuts the McCall well. Before the drilling of the new McCall well, it was believed that the fault cut the well at 14,970 ft (4563 m) and that the thick sandstone in the McCall actually correlated to the upper part of the thick lower sandstone of the Miller.

After the drilling of the deeper TF&S-DOE, McCall well to 16,510 ft (5032 m), correlation of the shales and Sandstone No. 3 from the McCall to the Miller and recognition of the marker foraminifer Siphonina davisii confirmed a different correlation (Fig. 58). The large fault is now believed to cut the McCall well at 16,320 ft (4974 m), just beneath Sandstone No. 3. At least 1300 ft (396 m) of section, present in the Miller, is missing in the McCall well. The shale and sandstone units above the fault in the McCall well thicken as a result of contemporaneous movement of the fault during deposition. This movement along the fault resulted in the development of reverse dip ("rollover") to the north into the fault, as shown by the correlation lines.

The dipmeter log taken in the McCall well shows variable-to-south dip from 14,400 to 15,100 ft (4389 to 4602 m); then, there is a strong north dip from 15,100 ft down to 16,320 ft (4974 m), where the fault is interpreted to cut the well. Below the fault, dip is again to the south or variable. The revised interpretation of the structure (Fig. 61, cross section B-B') was corroborated by independent studies of seismic data by S. Brunhild and of dip and strike

FIGURE 57. Logs of Gladys McCall design well and nearby oil and gas wells, showing similar section above 15,000 ft (4572 m) and highly variable section below 15,000 ft.

FIGURE 58. Same wells as those in Figure 57, showing correlations and structure as interpreted following completion of Gladys McCall design well.

electric log cross sections in the area of the McCall test well by D. Gutierrez (Figs. 59-60, 62).

Therefore, the thick Sandstone No. 2 in the McCall well correlates with the upper thick Sandstone No. 2 of the Miller well, but the former is thicker as a result of thickening into the fault. Although Sandstone No. 2 is broken by one or more small faults between these two wells, the displacement along these faults is small relative to the sandstone thickness, and the bulk of the sandstone unit is juxtaposed across the faults (Figs. 61). One of these faults, a small up-to-the-coast fault, probably cuts the Miller well at 14,910 ft (4545 m), thus resulting in Sandstone No. 1 being lower than its equivalent in the McCall well, where it is thicker and should be down along the large fault already described. Displacement along this smaller fault is only about 170 ft (52 m). Therefore, continuity of Sandstone No. 2 should not be interrupted by this fault between the two wells. Sandstone No. 3 has a very characteristic SP pattern and is easily correlated between the McCall and Miller wells. However, because it is relatively thin, it is probably not continuous between the two wells.

Sandstone No. 4, the lower, very thick sandstone in the Miller well, is missing in the McCall well because it has been faulted out at 16,320 ft (4974 m).

Fluids produced from the TF&S-DOE, No. 1 Gladys McCall test well will have temperatures of approximately 300°F (150°C) and salinities ranging higher than 50,000 mg/L TDS. Because of their moderately high salinity and complex chemical composition, the produced fluids will be injected into the subsurface. It has 50,000 mg/L TDS. Because of their moderately high salinity and complex chemical composition, the produced fluids will be injected into the subsurface. It has been determined that the shallow part (above 3550 ft, or 1082 m) of the previously drilled Getty-Buttes, No. 1 Gladys McCall well is in good condition for

FIGURE 59. Location, well control, and cross sections, Rockefeller Refuge/Gladys McCall prospect.

FIGURE 60. Dip section A-A', Rockefeller Refuge/Gladys McCall prospect.

NORTH
B

SUN
NO.1 STURLESE
SEC.22, T.26, R.2W.

DOE/TF & S
NO.1 GLADYS McCALL
SEC.27, T.100, R.2W.

UNION
NO.1 Dr. MILLER
SEC.24, T.100, R.2W.

ANSCHUTZ
NO.1 S.L. 6308
SEC.4, T.26, R.2W.

SOUTH
B'

FIGURE 61. Dip section B-B', Rockefeller Refuge/Gladys McCall prospect, showing structural interpretation revised from Figure 58 based on dipmeter log and seismic data.

FIGURE 62. Dip section C-C', Rockefeller Refuge/Gladys McCall prospect.

use as a disposal well. Interpretation of well logs on regional cross section D-D' (Fig. 6) indicates that the Pliocene sandstones in the 3000- to 3500-ft (914- to 1067-m) depth interval (Fig. 6) are sufficiently thick and porous for the disposal of large volumes of brine to be produced from the test well. At this shallow depth, displacement along growth faults is minimal. Therefore, excellent lateral continuity of the sandstones of the disposal zone should be expected.

Bayou Hebert Prospect

R. P. McCulloh and M. A. Pino

A previous study of the Bayou Hebert prospect by Bassiouni (1980) indicated only moderate pressure gradient (0.80 psi/ft) and temperature (230°F, or 110°C, at an average depth of 14,500 ft, or 4420 m). However, the study also indicated good sandstone development, along with favorable porosity (10 to 23%, $\bar{x}$ = 16%) and permeability (15 to 220 md, $\bar{x}$ = 45 md), and salinity of 35,000 to 130,000 ppm ($\bar{x}$ = 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.

The fault block evaluated here for geopressured-geothermal potential lies immediately northwest of Vermilion Bay in southwestern Louisiana (Fig. 63). Three main boundary fault zones give the block a triangular shape (Fig. 64). Electric log cross sections constructed for this study (Figs. 65-68) 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 (640 m) thick (Fig. 68).

The two dip sections indicate differential subsidence along the southern boundary fault zone; a 720-ft (219-m) interval of section is added between two marker beds on C-C' with no equivalent on D-D', while D-D' shows 2100 ft (640 m) of new section not represented on C-C' between a different pair of markers. Therefore, D-D' (Fig. 68), compared to C-C' (Fig. 67), shows about 1400 ft (427 m) of net subsidence downdip of the fault zone. 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 Figure 69. Both sections show an addition of 500 to 700 ft (150 to 213 m) of new section between a third set of markers.

Faults show discernible growth only below and slightly above the top of geopressure (Figs. 65-68), a situation which Dickey, Shriram, and Paine (1968) attributed to mutual stimulation between growth faulting and abnormal pressure genesis. Maps of net sand thickness within intervals immediately above and below the top of geopressure show that deposition in these intervals was controlled mostly by faulting (Figs. 70-71). 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 the switching of delta lobes.

The top of geopressure corresponds to the base of the main sand series of the Miocene, as described by Dickinson (1953) (Figs. 65-68), and lies at an average depth of 12,500 ft (3810 m) within the fault block (Figs. 65-69). Steeper geothermal gradients and deeper geopressures about the block on all sides (Fig. 69).

FIGURE 63. Location, well No. 1, and cross sections, Bayou Hebert prospect.

FIGURE 64. Growth faults near and below the top of geopressure in the Bayou Hebert prospect area, ruled (after Geomap).

FIGURE 65. Strike section A-A', Bayou Hebert prospect.

FIGURE 66. Strike section B-B', Bayou Hebert prospect.

FIGURE 67. Dip section C-C', Bayou Hebert prospect.

FIGURE 68. Dip section D-D', Bayou Hebert prospect.

SOUTH
D'

4
BRITISH AM. OIL
NO. 1. PRIMEAUX
SEC. 11, T. 40S., R. 4E.

5
DARTMOUTH
NO. 1. VERMILION BAY LA. CO.
SEC. 40, T. 40S., R. 4E.

6
LAMSON, BENNETT AND COLE
NO. 1. WISNER
SEC. 40, T. 40S., R. 4E.

7
PAN AMERICAN
NO. 1. VERMILION
SEC. 23, T. 40S., R. 4E.

8
TENNOCO (FIFTEEN)
CALDWELL LAND
SEC. 27, T. 40S., R. 4E.

9
CONTINENTAL OIL
NO. 1. VERMILION BAY
SEC. 26, T. 40S., R. 4E.

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FIGURE 69. Depth to the top of geopressure (ft), Bayou Hebert prospect. 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 70. Net-sandstone isopach for interval between two marker beds immediately above the top of geopressure, Bayou Hebert prospect. Contour interval = 100 ft (faults after Geomap).

FIGURE 71. Net-sandstone isopach for interval between two marker beds immediately below the top of geopressure, Bayou Hebert prospect. Contour interval = 100 ft (faults after Geomap).

Two intervals above 21,000 ft (6400 m) in the geopressured zone contain possibly prospective sandstone units. One has a 500-ft (152 m) massive sandstone unit indicated by the gamma ray log at a depth of 20,200 ft (6157 m) in the Superior No. 1 Hulin well (Fig. 68), 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 (61 m) 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 mi² (150 km²), so that the total reservoir volume is about 2.2 mi³ (9.2 km³) if the units are in hydrologic communication and average only 200 ft (61 m) 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 (150°C) isotherm lies well below these sandstones at depths of 15,000 to 19,000 ft (4572 to 5791 m) (Fig. 72). The 212°F (100°C) isotherm lies nearer the top of geopressure (Fig. 73) and more nearly approximates the temperature within shallow geopressured reservoirs.

Salinity values calculated from well logs 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, which show erratic vertical and lateral distribution in both hydropressured and geopressured horizons (Figs. 74-79), lack any consistent relationship with faults (Figs.

FIGURE 72. Depth to 300°F (150°C) isotherm (thousands of feet), Bayou Hebert prospect. Contour interval = 1000 ft (partly inferred from Geomap structure contours).

FIGURE 73. Depth to 212°F isotherm (thousands of feet), Bayou Hebert prospect. Contour interval = 500 ft (faults after Geomap).

FIGURE 74. Log-calculated salinity (ppm TDS x 1000) of fluids in sandstones between two marker beds immediately above the top of geopressure, Bayou Hebert prospect. Contour interval = 10,000 ppm.

FIGURE 75. Log-calculated salinity (ppm TDS x 1000) of fluids in sandstones between two marker beds immediately below the top of geopressure, Bayou Hebert prospect. Contour interval = 10,000 ppm.

FIGURE 76. Profiles of log-derived parameters for strike section A-A', Bayou Hebert prospect.

FIGURE 77. Profiles of log-derived parameters for strike section B-B', Bayou Hebert prospect.

FIGURE 78. Profiles of log-derived parameters for dip section C-C', Bayou Hebert prospect.

FIGURE 78. Continued.

FIGURE 79. Profiles of log-derived parameters for cross section D-D', Bayou Hebert prospect.

74-75). Shale resistivity, log-calculated porosity, and hydrostatic pressure show similar erratic vertical distribution, but do not consistently correlate with salinity (Figs. 76-79).

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 geopressed-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 may yet represent but a fraction of the total, and alone could substantially fragment the total volume of shallow contiguous geopressured reservoirs.

Houma Embayment Prospect

E. C. Kusters

The Houma embayment is located in the vicinity of the town of Houma, Terrebonne Parish, southeastern Louisiana, with the center of the embayment in T17S R16E. The basin is developed in the middle-Miocene trend (Fig. 80). The area was selected for detailed study based on the results of an extensive electric log search covering all of south Louisiana (Fig. 1). All wells used for the study are listed in the appendix at the end of this report.

The prospective section in the Houma embayment contains a foraminifer fauna (Fig. 81) that closely resembles the Harang fauna (Pope and Smith, 1948) and is interpreted to represent outer-neritic/upper-slope (330- to 1640-ft, or 100- to 500-m, water depth) environments. For example, Cibicides opima, the major

FIGURE 80. Location of Houma embayment study area.

MIOCENE				
	DUCK LAKE	C		Bigenerina "2" nodosaria
				Textularia "W" Stapperi
		E	HARANG	Bigenerina humblei
				Cristellaria "I" assemblage
				Cibicides (Carstensi) opima
		F		Amphistegina "B" fauna
				Robulus "43" (L) = Rob macomberi
		G		Operculinoides (Camerina "I")

FIGURE 81. Stratigraphic column applying to Houma embayment area.

marker fossil in these beds, is interpreted to represent deep-water conditions on the upper slope.

Well logs from 77 wells located within and around the major fault blocks were studied (Fig. 82); one strike section (Fig. 83) and five dip sections, of which three are included in this report (Figs. 84-86), were constructed. Two areas (fault blocks) within the main fault block studied are considered relatively favorable for future consideration (Fig. 82). Net-sandstone maps of two units (Figs. 87-88) and a structure map of a resistivity marker near the top of the lower sandstone unit, the Hollywood sandstone (Fig. 89), were constructed.

The general structural setting is shown in Figure 90 in schematic dip section. The structural history of the Houma embayment was first described by Sloane (1966). The embayment is bounded on the north by a zone of arcuate growth faults (Fig. 82), the downdip side of which rapidly downdropped and was contemporaneously filled with marine sediment. Near the southern edge of the embayment, an up-to-the-coast fault brings the Cibicides opima marker up to approximately the same depth as in the area north of the northern boundary fault zone. Faults A and B together show a maximum displacement of more than 4000 ft (1219 m) (Figs. 84-86), and classical thickening of the shale wedge is observed. The resistivity marker near the base of the Hollywood shale shows an abrupt deepening of the basin towards the southeast, beyond the area mapped on Figure 89.

The period of maximum deposition, subsidence, and fault movement started at Cibicides opima time and ended at Bigennerina humblei time (Sloane, 1966). Figure 90 shows the typical sequence of the embayment, which corresponds to the representative well log of Sloane (1966). The lowermost shale and sandstone sequences are discontinuous along dip (Figs. 84-86), but very continuous along

FIGURE 82. Location, well control, cross sections, and faults (after Geomap), Houma embayment prospect.

FIGURE 83. Strike section Z-Z', Houma embayment prospect.

EAST
Z'

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FIGURE 84. Dip section A-A', Houma embayment prospect.

FIGURE 85. Dip section C-C', Houma embayment prospect.

FIGURE 86. Dip section E-E', Houma embayment prospect.

FIGURE 87. Net-sandstone isopach of sandstone unit A, Houma embayment prospect. Contour interval = 50 ft (faults after Geomap).

FIGURE 88. Net-sandstone isopach of "Hollywood sands," Houma embayment prospect. Contour interval = 100 ft (faults after Geomap).

FIGURE 89. Structure of a resistivity marker near the top of the Hollywood sandstone and base of the Hollywood shale. Contour interval = 500 ft (faults after Geomap).

FIGURE 90. General structural setting, Houma embayment area.

strike (Fig. 83). The Cibicides opima marker, below the Hollywood sandstones, is only reached north of faults A and B and south of fault D (Fig. 90). The Hollywood sandstones, which occur at the base of the section studied, can be divided into two units: a lower discontinuous unit and an upper thick, continuous unit. Above the Hollywood sandstones is the Hollywood shale wedge which reaches a thickness of up to 2500 ft (762 m) in the center of the embayment. Sandstone unit A (Fig. 90) was deposited on top of the Hollywood shale; the top of geopressure is generally located below this sandstone sequence. There are two depocenters, and a downdip thinning of the unit is observed. The log patterns display more fining-upward sequences updip and more coarsening-upward sequences downdip. Because these sandstones are located just below the Bigennerina humblei marker bed, which marks the end of the transgression (Sloane, 1966), it seems likely that they represent an outbuilding delta system with two major lobes. On top of the shale are various sandstones and shales. Generally, sandstones below the Cristellaria "I" assemblage marker are called the Krumbhaar sandstones and include significant shale interbeds. Bigennerina "2" nodosaria and Textularia "L" mark the transition to the upper Miocene at an average depth of 7800 ft (2377 m).

The Hollywood sandstone log patterns and distribution show remarkable similarities to that of the shelf-edge slump masses on the modern Mississippi delta front (Coleman and Prior, 1980) (Fig. 91). According to Coleman and Prior, many growth fault structures are related to similar slump deposits, a hypothesis also proposed by Sloane (1966). This mechanism would also explain the observed rollover structure and thinning of the sandstones in a downdip direction. In addition, there is evidence for thinning of the sandstones and thickening of the underlying shales because the erosional force of the slump blocks decreased downdip. The distribution of the upper Hollywood sandstones

SUBAQUEOUS SLUMPS

0 5 Mi.

- Sd., graded bedding
- Sh., burrowed
- Sd., ripple drift, x-lam., sharp base
- Sd., sm. x-lam.
- Cl. w/shell, burrowed
- Sd., ripple drift, sharp base, burrowed top
- Sd., ripple drift, sharp base, fractured, burrowing at top, st. stringers
- Cl.-st., burrowed, shell
- Ripple drift, sharp base, graded bedding

FIGURE 91. Sedimentary characteristics of slump deposits offshore from a deltaic sequence (from Coleman and Prior, 1980).

(Fig. 88) indicates a source to the northwest; the difficulty of correlations in this interval in the abruptly-deepening southeast part of the embayment suggests interfingering with sediment from a northeastern source.

The top of geopressure occurs near the 212°F (100°C) isotherm (Figs. 92-93) and approximately at the top of the Hollywood shale (Figs. 83-86, 90). To the east, the top of geopressure is much deeper. In general, the Hollywood sandstones show fluid temperatures ranging from 221° to 257°F (105° to 125°C). The geothermal gradient constructed from data from 21 wells deeper than 9000 ft (2743 m) averages 2.5°F/100 ft (4.6°C/100 m), with a correlation of $r = 0.81$ (Fig. 94, Table 2).

Twenty seven salinity calculations were made from electric logs of the Hollywood sandstone. The calculated values range from 32,000 to 160,000 ppm, with a mean of 91,000 ppm (Figs. 95-96, Table 3). Permeabilities from sidewall cores are generally higher than 20 md (Fig. 97).

Summary of Site-Specific Studies

R. P. McCulloh and M. A. Pino

The site-specific studies indicate a general consistency of physical parameters pertinent to the geopressed-geothermal potential of the four areas studied. Thicknesses of geopressed sandstone reservoir units average about 300 ft (91 m), with a range of 130 to 450 ft (40 to 137 m); salinity of contained fluids can be quite variable but averages about 100,000 ppm TDS; porosity, from both sidewall and conventional core, averages 24%; and permeability, also from both types of core, can be highly variable with depth in all prospects with a range of less than 20 to more than 200 md. Pressure gradients in the four areas are similar and average 0.84 psi/ft; geothermal gradients for parishes in which prospects lie average 1.7°F/100 ft. The

TABLE 2. Data used for calculation of the geothermal gradient
for depths greater than 9000 ft.

<u>Well No.</u>	<u>Depth (ft)</u>	<u>Corrected temp. (°F)</u>
26	11,370	271
	12,110	274
	13,820	270
	15,150	284
30	10,400	198
	11,240	213
	13,070	259
	13,500	262
21	11,065	202
	15,314	273
	16,006	302
	16,503	310
20	11,100	211
	13,170	230
	14,430	265
	15,030	268
34	11,000	199
	13,120	153
	15,000	270
50	11,100	195
	13,300	250
	14,800	266
51	10,500	182
	11,000	203
	12,030	215
	13,060	250
	13,520	238
	14,510	255
	15,000	249
38	11,130	209
	13,560	252
	15,290	266
55	12,590	217
	14,210	247
	16,500	291
8	11,550	174
	13,900	222
	14,870	234

TABLE 2 (cont.)

<u>Well No.</u>	<u>Depth (ft)</u>	<u>Corrected temp. (°F)</u>
36	11,500	180
	14,270	221
	15,770	256
37	11,090	168
	11,390	164
	11,500	199
	11,940	210
38	11,120	176
	13,560	220
	15,240	236
54	10,860	206
	11,980	230
	12,620	230
63	10,820	196
	10,900	195
	11,700	206
	12,300	232
	12,900	234
73	11,270	202
	12,610	243
	13,710	264
22	11,200	201
	11,330	202
	11,580	197
	11,850	211
	12,470	217
	12,990	240
	13,220	233
23	11,850	229
	12,100	243
31	10,510	199
	11,100	199
	13,200	241
20	11,100	211
	13,180	230
	14,420	265
	15,090	268
19	11,250	225
	15,060	270
	15,450	281
	15,700	286
	16,500	308

TABLE 3. Salinity calculations in the
Hollywood sands, units I and II.

Unit I

<u>Well No.</u>	<u>Depth (ft)</u>	<u>Salinity (ppm)</u>
5	14,050	130,000
	14,250	160,000
19	13,280	100,000
	13,520	110,000
	13,780	87,000
20	13,130	112,000
	13,530	110,000
21	13,020	100,000
	13,470	98,000
36	13,740	32,000
39	13,880	63,000
51	13,200	95,000
	13,480	98,000
	13,680	80,000
59	12,150	115,000
	12,280	105,000
	12,430	105,000
61	12,130	95,000
	12,230	72,000
	12,435	77,000
52	11,150	80,000
	11,670	120,000
33	13,060	92,000
	13,190	90,000
	13,350	115,000
	13,500	113,000

Unit II

<u>Well No.</u>	<u>Depth (ft)</u>	<u>Salinity (ppm)</u>
8	13,950	130,000
36	14,550	82,000
38	14,130	120,000

FIGURE 92. Depth to the top of geopressure (ft), Houma embayment area. Contour interval = 500 ft (faults after Geomap).

FIGURE 93. Depth to the 212°F (100°C) isotherm (ft), Houma embayment area. Contour interval = 500 ft (faults after Geomap).

GEO THERMAL GRADIENT FOR THE HOUMA EMBAYMENT FOR DEPTHS GREATER THAN 9000 FEET
 REGRESSION- $\rightarrow Y=40X + 3610$, CORRELATION- $\rightarrow R=.81$, GRAD.- $\rightarrow 2.5$ DEG PER 100 FT

FIGURE 94. Geothermal gradient for depths greater than 9000 ft (2743 m), Houma embayment area.

SALINITY VS DEPTH FOR 27 CALCULATED SALINITIES IN THE HOLLYWOOD SANDS

FIGURE 95. Log-calculated salinity of Hollywood sandstone at various depths, Houma embayment area.

PERCENTAGE NUMBER OF DATA PER 10,000 PPM INTERVAL (REGARDLESS OF DEPTH)

MEAN=91.800 , MEDIAN=95.000

CUMULATIVE PERCENTAGE VS SALINITY PLOT

FIGURE 96. Frequency distribution (top) and cumulative frequency curve (bottom) for log-calculated salinity values, Hollywood sandstone, Houma embayment area.

COMPARISON OF POROSITIES & PERMEABILITIES FROM SIDE-WALL CORES FROM WELL #27
BULLSEYE IS POROSITY, * IS PERMEABILITY

FIGURE 97. Porosity and permeability of sidewall cores from well 27 (Fig. 82), Houma embayment area.

Parcperdue and Sweet Lake test well sites, in Vermilion and Cameron Parishes, respectively, show very similar physical parameters, except that geopressured sandstone is thinner (50 ft) at Parcperdue.

The main differences among the four prospects studied are not related to the above physical parameters, but to the geologic setting and the depths to geopressured sandstone reservoirs, summarized schematically in Figure 98. The depths of potentially prospective geopressured sandstone reservoirs range from as little as 8000 ft (2438 m) in the Calcasieu area to more than 15,000 ft (4572 m) at Rockefeller Refuge/Gladys McCall; Bayou Hebert and the Houma embayment encompass a spectrum of depths in the lower half of this range, and Bayou Hebert also has one sandstone unit of unknown extent below 20,000 ft (6096 m). The prospects studied show a "main sand series" (Dickinson, 1953), generally underlain by "alternating sand and shale facies" (Thorsen, 1963). The most important differences in geologic setting involve 1) whether the geopressured zone extends upward into the main sandstone series or is restricted to the alternating sandstone and shale facies and underlying section and 2) differences in distribution and continuity of sandstone units in the alternating sandstone and shale facies. The only prospect in which the geopressured zone appears to include the base of the main sandstone series is the Rockefeller Refuge/Gladys McCall, and this situation probably accounts for the unusually large quantity of sandstone in the geopressured zone there. In the other prospects, the top of geopressure lies not far beneath the base of the main sandstone series, suggesting lithostratigraphic control. The differences among these other prospects are primarily differences of sandstone distribution in the alternating sandstone and shale facies, and differences in the degree of fault or facies control of sandstone discontinuities.

It is important to note that such sandstone units which may appear to correlate across faults in Figure 98 do not necessarily do so. In Bayou Hebert,

CALCASIEU

ROCKEFELLER REFUGE/ GLADYS MCCALL

BAYOU HEBERT

HOUMA EMBAYMENT

EXPLANATION

5000 ft

NO HORIZONTAL SCALE

FIGURE 98. Geologic setting in each of the four prospect areas studied in detail.

for example, the two geopressured sandstone units shown on the upthrown side of the main fault zone do not correlate with the two on the downthrown side; rather, their stratigraphic positions on the downthrown side lie beneath the total depths of available wells in what is probably the "predominantly shale facies" of Thorsen (1963). (The Liebusella paleo marker was extrapolated here because enough correlative section was penetrated to determine expansion indices and prorate the distance to it). Another example, in the Calcasieu area, is the geopressured sandstone unit in the farthest-updip fault block, which is stratigraphically lower than the similar-looking unit in adjacent downdip fault blocks. Thus, as has been emphasized previously, any test well site in a particular prospect must not be assumed to encompass more than a single known fault block, regardless of whether or not prospective sandstone units are contiguous across faults.

REFERENCES

- Bassiouni, Z., 1980, Evaluation of potential geopressure geothermal test sites in southern Louisiana: La. State Univ., Dept. Petr. Engineering, Baton Rouge, La., U.S. Dept. Energy Contract No. DE-AS05-76ET28465, 70 p. and apps.
- Bebout, D. G., and A. L. Bachman, eds., 1981, Geopressured-geothermal energy--U.S. Gulf Coast: Proceedings of the fifth conference: La. Geol. Survey, La. State Univ., Baton Rouge, La., 343 p.
- Bebout, D. G., D. R. Gutierrez, and N. Y. Salem, 1982, Physical properties of reservoir fluids--Final report, February 1980-January 1981, extended to August 1981: La. Geol. Survey, La. State Univ., Rept. to Gas Research Inst., Contract No. 5014-321-0276, 53 p.
- Bebout, D. G., R. G. Loucks, S. C. Bosch, and M. H. Dorfman, 1976, Geothermal resources--Frio Formation, upper Texas Gulf Coast: Univ. Texas at Austin, Bur. Economic Geol., Circ. 76-3, 47 p.
- Bebout, D. G., Z. Bassiouni, D. R. Carver, C. G. Groat, R. H. Pilger, Jr., and F. M. Wrighton, 1982, Technical support for geopressured-geothermal well activities in Louisiana: Annual report for the period November 1, 1980, to October 31, 1981: La. Geol. Survey, La. State Univ., Rept. to U.S. Dept. Energy, Div. Geothermal Energy, Contract No. DE-AC08-81NV10174, rept. no. DOE/NV/10174-1, 378 p.
- Berg, O. R., 1982, Seismic detection and evaluation of delta and turbidite sequences: Their applications to exploration for the subtle trap: Am. Assoc. Petr. Geol. Bull., vol. 66, no. 9, p. 1271-1288.
- Berg, R. R., and B. K. Powers, 1980, Morphology of turbidite-channel reservoirs, lower Hackberry (Oligocene), southeast Texas: Trans., Gulf Coast Assoc. Geol. Soc., vol. 30, p. 41-48.

- Blount, C. W., L. C. Price, L. M. Wenger, and M. Tarullo, 1979, Methane solubility in aqueous NaCl solutions at elevated temperatures and pressures, in M. H. Dorfman and W. L. Fisher, eds., Proc., 4th U.S. Gulf Coast geopressured geothermal conference: Univ. Texas at Austin, vol. 3, p. 1225-1262.
- Bornhauser, M., 1960, Depositional and structural history of northwest Hartburg field, Newton County, Texas: Am. Assoc. Petr. Geol., vol. 44, p. 458-470.
- Coleman, J. M., and D. B. Prior, 1980, Deltaic sand bodies--A 1980 short course: Am. Assoc. Petr. Geol. Education Course Note Series no. 15, 171 p.
- Dickey, P. A., C. R. Shriram, and W. R. Paine, 1968, Abnormal pressures in deep wells of southwestern Louisiana: Science, vol. 160, no. 3828, p. 609-615.
- Dickinson, G., 1953, Geological aspects of abnormal reservoir pressures in Gulf Coast Louisiana: Bull., Am. Assoc. Petr. Geol., vol. 37, no. 2, p. 410-432.
- Foss, D. C., 1979, Depositional environment of Woodbine sandstones--Polk County, Texas: Trans., Gulf Coast Assoc. Geol. Soc., vol. 29, p. 83-94.
- Franks, S. G., [1980], Origin of porosity in deeply-buried Tuscaloosa sandstone, False River field, Louisiana [abs.], in Soc. Econ. Paleontologists and Mineralogists, Gulf Coast Sec., 2nd annual research conference on geology of the Woodbine and Tuscaloosa Formations--Program and abstracts, Houston, Tx.: p. 20-21.
- Friedel, George F., III, 1978, Structural and geothermal relationships in the Lake Charles area of southwestern Louisiana: M.S. thesis, Univ. Southwestern La., Lafayette, La., unpub., 62 p.
- Funkhouser, L. W., F. X. Bland, and C. C. Humphris, Jr., 1980, The deep Tuscaloosa gas trend of S. Louisiana: Oil and Gas Jour., vol. 78, no. 36, p. 96-101.
- Gill, J. A., 1980, Multiparameter log tracks Tuscaloosa/Woodbine pressures: Oil and Gas Jour., vol. 78, no. 44, p. 55-64.

- Kurth, R. J., 1981, Subsurface evaluation of the geopressured-geothermal Chloe prospect, Calcasieu Parish, Louisiana: M.S. thesis, Univ. Southwestern La., Lafayette, La., unpub., 89 p.
- Nat. Geophysical and Solar-Terrestrial Data Center, Nat. Oceanic and Atmospheric Admin., 1979, Geopressured-geothermal energy in reservoir fluids of the northern Gulf of Mexico basin, in L. J. P. Muffler, ed., Assessment of geothermal resources of the United States--1978: U.S. Geol. Survey Circ. 790, map 3, scale 1:1,000,000.
- Ocamb, R., 1961, Growth faults of south Louisiana: Trans., Gulf Coast Assoc. Geol. Soc., vol. 11, p. 139-173.
- Paine, W. R., 1968, Stratigraphy and sedimentation of subsurface Hackberry wedge and associated beds of southwestern Louisiana: Bull., Am. Assoc. Petr. Geol., vol. 52, no. 2, p. 322-342.
- Pope, D. E., and D. J. Smith, 1948, The Harang fauna of Louisiana: La. Dept. Conservation, La. Geol. Survey, Geol. Bull. No. 26, 80 p.
- Price, L. C., C. W. Blount, D. MacGowan, and L. Wenger, 1981, Methane solubility in brines with application to the geopressured resource, in D. G. Bebout and A. L. Bachman, eds., Proc., 5th conference on geopressured-geothermal energy--U.S. Gulf Coast: La. Geol. Survey, La. State Univ., Baton Rouge, La., p. 205-214.
- Purcell, M. D., and R. P. McCulloh, in prep., Distribution of geopressure in the Tuscaloosa trend, Louisiana: La. Geol. Survey, Baton Rouge, La.
- Siemers, C. T., 1978, Submarine deposition of the Woodbine-Eagle Ford interval (Upper Cretaceous), Tyler County, Texas: Trans., Gulf Coast Assoc. Geol. Socs., vol. 28, p. 493-533.
- Silva, P., and Z. Bassiouni, 1981, Accurate determination of geopressured aquifer salinity from the SP log, in D. G. Bebout and A. L. Bachman, eds.,

- Proc., 5th conference on geopressured-geothermal energy--U.S. Gulf Coast:
La. Geol. Survey, La. State Univ., Baton Rouge, La., p. 193-196.
- Sloane, B. J., 1966, The structural history of the Houma embayment: Trans., Gulf Coast Assoc. Geol. Soc., vol. 16, p. 249-260.
- Smith, G. W., [1980a], Secondary porosity in the "19,800 foot" Tuscaloosa sandstone, False River field, Pointe Coupee and West Baton Rouge Parishes, Louisiana [abs.], in Soc. Econ. Paleontologists and Mineralogists, Gulf Coast Sec., 2nd annual research conference on geology of the Woodbine and Tuscaloosa Formations--Program and abstracts, Houston, Tx.: p. 28-30.
- _____, [1980b], Sedimentology of the "19,800 foot" Tuscaloosa sandstone, False River field, Pointe Coupee and West Baton Rouge Parishes, Louisiana [abs.], in Soc. Econ. Paleontologists and Mineralogists, Gulf Coast Sec., 2nd annual research conference on geology of the Woodbine and Tuscaloosa Formations--Program and abstracts, Houston, Tx.: p. 30-31.
- 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 Inst., San Antonio, Tx., U.S. Energy Research and Development Admin. Contract No. E(11-1)-2687, 75 p.
- Thomson, A., 1979, Preservation of porosity in the deep Woodbine/Tuscaloosa trend, Louisiana: Trans., Gulf Coast Assoc. Geol. Soc., vol. 29, p. 396-403.
- _____, [1980], Preservation of porosity in the deep Woodbine/Tuscaloosa trend, Louisiana [abs.], in Soc. Econ. Paleontologists and Mineralogists, Gulf Coast Sec., 2nd annual research conference on geology of the Woodbine and Tuscaloosa Formations--Program and abstracts, Houston, Tx.: p. 32-34.
- Thorsen, C. E., 1963, Age of growth faulting in southeast Louisiana: Trans., Gulf Coast Assoc. Geol. Soc., vol. 13, p. 103-110.

Wallace, R. H., Jr., 1983, Personal commun.: Hydrologist, U.S. Geol. Survey, Bay St. Louis, Miss.

Wrighton, F. M., D. G. Bebout, D. R. Carver, C. G. Groat, and A. E. Johnson, Jr., 1981, Technical support for geopressured-geothermal well activities in Louisiana: Final report for the period September 27, 1978-December 31, 1980: La. State Univ., Energy Programs Off., Advances Studies and Research, Rept. to U.S. Dept Energy, Div. Energy Technology, Contract No. DE-AS05-78ET27160, rept no. DOE/ET.27160, 211 p.

APPENDIX

Wells Used in Houma Embayment Area

Well no.	Township and Range	Operator	Well	TD (ft)	Paleo inf.
1.	T 16 S - R 15 E, sec. 108	Florida Gas	#1-Wilson	14,021	
2.	- - - - - , sec. 108	Florida Gas	#2-Wilson	16,200	
3.	- - - - - , sec. 110	McMoran Exploration Co.	E.W. Brown, Jr., #B-1	12,613	
4.	T 16 S - R 16 E, sec. 59	The Texas Co.	W/C #1 Jacques M.	15,390	X
5.	- - - - - , sec. 19	Exchange Oil and Gas	#1 Southdown Sugars	14,478	X
6.	- - - - - , sec. 9 (N-18)	Placid Oil	#1 Prentice	18,687	X
7.	- - - - - , sec. 12	Forest Oil	#1 Belle Grove	12,120	X
8.	- - - - - , sec. 13	N.A.R. et al.	#1 Pelto	14,871	
9.	- - - - - , sec. 9	Carol Hunt Sands	#1 Caldwell	12,082	
10.	- - - - - , sec. 5	Placid Oil	#1 Robichaux	17,311	
11.	- - - - - , sec. 67	Union Oil of Calif.	#1 Prairie Land Co.	12,236	
12.	- - - - - , sec. 13	Humble	#1 McCollum	15,000	X
13.	- - - - - , sec. 26	Bintcliffe	#1 Cocke	12,804	
14.	- - - - - , sec. 24	Quintana	#1 Daigle	13,035	
15.	- - - - - , sec. 41	Cities Service (00169)	#1 Southdown Sugars	11,915	X
16.	T 16 S - R 17 E, sec. 90	Carthay	#1 Savane	14,125	
17.	T 17 S - R 15 E, sec. 49	Glasscock	#1 CL & F	14,096	X
18.	- - - - - , sec. 57	Seaboard Oil	#1 CL & F	12,732	X
19.	- - - - - , sec. 26	Shell	#1 Faultkenburg	17,187	
20.	- - - - - , sec. 5	Quintana	#1 Kleinschmidt	15,248	
21.	- - - - - , sec. 6 or 7	Quintana	#3 Southdown Sugars	16,644	X
22.	- - - - - , sec. 58	Glasscock	# C-1 CL & F	13,220	
23.	- - - - - , sec. 50	Southport	D-2 CL & F	12,060	
24.	- - - - - , sec. 46	Shell	B-1 CL & F	14,175	
25.	- - - - - , sec. 40	Shell	#1 Kuntz	15,759	
26.	- - - - - , sec. 41	Mosbacher	#1 Kuntz	15,137	
27.	- - - - - , sec. 35	Shell	#20 Pelican	13,600	
28.	- - - - - , sec. 23	Shell	# B-43 Matthews	15,219	
29.	- - - - - , sec. 48	Shell	A-2 CL & F	13,386	
30.	- - - - - , sec. 36	Shell	# 20 Pelican	13,492	
31.	- - - - - , sec. 47	Quintana	#1 CL & F	13,205	
32.	T 17 S - R 16 E, sec. 32	D & L et al.	#1 White	14,005	X

Well no.	Township and Range	Operator	Well	TD (ft)	Paleo inf.
33.	- - - - - , sec. 37	Pennzoil	A-1 Antill	15,390	
34.	- - - - - , sec. 35	Pennzoil	#1-Antill	15,007	X
35.	- - - - - , sec. 36 (N-21)	Shell	#1-Antill	19,000	
36.	- - - - - , sec. 70	Exxon	#1 Pelto	15,866	
37.	T 17 S - R 16 E, sec. 18	Arkansas fuel	#1 McCollum	11,938	X
38.	- - - - - , sec. 48	Exchange	#1 Cox	15,300	
39.	- - - - - , sec. 69	Austral	#1 Pelto	15,521	
40.	- - - - - , sec. 49	Tenn. Gas	#1 Trans. Breaux	11,186	
41.	- - - - - , sec. 88	Shell	B-1 Riggs <u>et al.</u>	9,758	
42.	- - - - - , sec. 85	Union Texas	#5 Wylie	12,000	
43.	- - - - - , sec. 80	Arkansas fuel	#1 McCollum	12,320	
44.	- - - - - , sec. 72	Arkansas fuel	U 1/3 Southdown Sugars	13,853	
45.	- - - - - , sec. 13	Caroline Hunt Sands	#1 Chouffe <u>et al.</u>	12,101	
46.	- - - - - , sec. 94	Arkansas fuel	H-1 Southdown Sugars	13,114	
47.	- - - - - , sec. 60	Brewster Bartle	#1 Southdown Sugars	13,112	
48.	- - - - - , sec. 62	Brewster Bartle	#2 Southdown Sugars	12,192	
49.	- - - - - , sec. 82	Trice Prod Co.	A-2 Southdown Sugars	14,928	
50.	- - - - - , sec. 38	Pennzoil	#1 Hubert	14,800	
51.	- - - - - , sec. 42	Sun Oil	#1 Blanchard	13,093	
52.	- - - - - , sec. 84	Ted Weiner	#3 Wylie	11,900	
53.	- - - - - , sec. 83	Union Oil of Calif.	#2 Southdown Sugars	12,052	
54.	- - - - - , sec. 43	Whitestone	#1 Blanchard	12,766	
55.	- - - - - , sec. 75	General American	#9 Southdown Sugars	16,510	
56.	- - - - - , sec. 95	Quintana	#1 Southdown Sugars	14,790	
57.	- - - - - , sec. 67	Cities Service	#2 Pelto	12,585	
58.	- - - - - , sec. 71	Amarillo	#1 Aminoil <u>et al.</u>	12,620	
59.	- - - - - , sec. 91	Union Texas	#1 Robichaux <u>et al.</u>	12,525	X
60.	- - - - - , sec. 89	Union Texas	#3 Wylie	13,250	X
61.	- - - - - , sec. 52	Rutherford	#1 Cox	12,475	
62.	- - - - - , sec. 52	Union Texas	#1 Cox	12,230	
63.	- - - - - , sec. 93	Shell	A-2 Riggs <u>et al.</u>	12,889	
64.	- - - - - , sec. 49	Damson	#1 Breaux <u>et al.</u>	13,000	
65.	- - - - - , sec. 64	Superior	B-1 Southdown Sugars	13,750	
66.	- - - - - , sec. 81 (N-20)	Pennzoil	#2 Pelto	16,000	
67.	- - - - - , sec. 81	Arkansas fuel	#1 Southdown Sugars	12,583	
68.	T 17 S - R 17 E, sec. 63	Quintana	#1 Southdown <u>et al.</u>	16,500	

<u>Well no.</u>	<u>Township and Range</u>	<u>Operator</u>	<u>Well</u>	<u>TD (ft)</u>	<u>Paleo inf.</u>
69.	- - - - - -, sec. 4	McCarter et al.	#1 Codiere	17,500	
70.	- - - - - -, sec. 103	Mecom	Southdown Sugars (00215)	12,642	
71.	- - - - - -, sec. 4	Arkansas fuel	#1 Lirette U-1	13,400	
72.	- - - - - -, sec. 28	Quintana	#1 Savage	14,441	
73.	T 18 S - R 15 E, sec. 3	Union Oil	#1 CL & F	13,732	
74.	- - - - - -, sec. 7	Pure Oil	#2 CL & F	11,960	X
75.	T 18 S - R 17 E, sec. 16	Getty Oil	#1 Schoolboard	15,825	X
76.	T 17 S - R 15 E, sec. 30	Pennzoil	Pelican "B" #1	14,521	
77.	- - - - - -, sec. 35	Pennzoil	Pelican "A" #8	14,537	

ROCK MECHANICS AND SUBSIDENCE MODELING

D. R. Carver and J. Janssen

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

Initially, Carver devoted his time to the vast literature on theoretical rock mechanics. He became convinced early in his association with the project 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. He reviewed essentially all of the fundamental papers on rock mechanics as they pertained to rock deformation and reservoir drive. The results of his study entitled "A Note on Effective Stresses" were published in the Proceedings of the Fifth Conference on Geopressured-Geothermal Energy, U.S. Gulf Coast, which was held at LSU on 13-15 October 1981. This paper is theoretical and should be of interest to specialists in rock mechanics.

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 in earlier speculative studies.

Carver and 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.

Janssen used classical rock deformation theory to formulate a computer program for predicting surface subsidence in a reservoir of any shape and thickness due to a uniform pressure depletion. This program was applied to the Parcperdue reservoir with an assumed pressure drop of 3000 psi. It predicted a maximum surface subsidence of only 0.004 ft. This study was also reported in the conference proceedings cited above.

Carver and Janssen then applied the program, which was modified to take into account variations in thickness of an aquifer, to the Lafourche Crossing site. With an average depth of 14,000 ft and a pressure drawdown of 3000 psi, a maximum subsidence of 1.05 in. was calculated at a point directly over the center of the reservoir. The predicted subsidence extended well beyond the boundaries of the reservoir and was 0.1 in. at a point 2.5 mi from the eastern tip.

Carver and Janssen then refined the computer program to predict subsidence due to a nonuniform pressure drawdown in an aquifer. In this modified model, pressure drawdown was taken to be greatest at the borehole and falling off to zero at the most distant edge of the reservoir. To express this in terms which can be incorporated into the computer program, a pressure drawdown curve equation, $P = C \times (1 - 2R/L + R^2/L^2)$, was used. In this equation, R is the distance from a given point to the borehole, and L is the distance from the borehole to the point of greatest distance in the reservoir. The constant C is dependent on the amount of pressure which is to be depleted from the reservoir.

To test this model, a reservoir which was 4 mi², 50 ft thick, and at a constant depth of 7000 ft was numerically described. A well was placed at the center of this block, and the pressure was depleted a maximum of 3000 psi. This resulted in a maximum subsidence of about 5 in. at the well-head location at the surface. This subsidence fell off to zero approximately 4 mi from this central location.

Janssen then approached the problem from a geological viewpoint. He made an empirical study of density, velocity, and porosity relationships in sandstones. Data from Oligocene to Pliocene sediments ranging in depth from 3000 to 17,000 ft were compared to show the range and variation of these parameters with depth and one another, and results compared with experimentally proven rock properties to evaluate the dominant physical and chemical factors affecting the sediments with increasing depth of burial. For comparison, a study of the velocity, density, and depth relationships in shales was included.

In all cases, the relationships between the parameters are nonlinear. Sonic transit time is seen to decrease at a less rapid rate with depth due to the rate of increase in the elastic constants of the rock becoming less as compression increases at a relatively constant rate. A tendency for the transit time to increase at depth in some of the sandstone units is related to a decrease in the effective pressure on the quartz grains caused by geopressured pore fluids and possibly by increased porosity resulting from greater silicate solubility. Bulk density increases at a more rapid rate with depth because the increase in temperature and pressure has a greater effect on the strength of the quartz grains, leading to increased compaction. Unlike a homogeneous solid, velocity increases with increasing bulk density in the sandstones. This phenomenon is due to the decrease in porosity on the velocity dominating the increase in bulk density. Clean sandstone porosity decreases at a more rapid rate with depth, and this trend correlates well with the bulk density-depth trend, indicating that the physical and chemical factors influencing them are the same.

This work is described in full in Janssen's master's thesis entitled "Bulk density, velocity, and porosity relationships in Tertiary sandstones of southwest Louisiana" (LSU, Baton Rouge, 1983).

RESERVOIR ANALYSIS AND SIMULATION

Z. Bassiouni and P. L. Silva

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 accurate representation of water salinity. The SP method tends to underestimate the 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 the 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 exhibit dilution and contamination characteristics due to mixing with condensation water or drilling fluids. However, such discrepancy continues to exist when reliable water samples are available.

The purpose of the study conducted by the Department of Petroleum Engineering at LSU 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.

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

Traditional Approach

The method traditionally used to calculate R_w from the SP log is based on the well known equation¹

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

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 NaCl 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 Simard² 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.³ Equation (2) has been extensively used to estimate R_w from SP values.

Kharaka and co-workers⁴ reported detailed chemical analysis of several formation water samples from 7 oil and gas fields in the Lafayette, La., area. These chemical analyses were determined using a new, reliable technique.⁵

These waters are predominantly NaCl with a concentration of Ca and Mg less than 5% by weight. The water resistivity values of these samples were calculated using the technique proposed by Ucock, Ershaghi and Olhoeft.⁶ 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 NaCl solutions.
2. The shale is a perfect membrane, i.e., one through which only cations can pass.

The effect of salts other than NaCl was investigated.^{7,8} This effect was found to be relatively small for brines containing less than 5% by weight of salts other than NaCl 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.^{2,9,10} 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

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

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 purposes, 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.

Using the correlation of Figure 5 the R 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,

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.

despite the fact that some of the data points were obtained in shaly formations.

Application of the New Correlation to Geopressured Wells

The new correlation was used to calculate salinity values in 6 geopressured formations encountered in wells of opportunity. For comparison purposes, 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

<u>Well</u>	<u>SALINITY, TDS</u>		
	<u>Chemical Analysis</u>	<u>Old Techn.</u>	<u>New Techn.</u>
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#1, a	122,564	44,580	92,560
5. E. Delcambre#1, b	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 $\pm 21,500$ ppm were obtained when the new correlation was employed. On the other hand, the traditional approach yielded an average error of -39% and

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

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

a standard error of $\pm 47,300$ ppm. The statistical parameters have to be carefully considered because of the limited number of data points available.

Conclusions

The traditional SP equation $SP = -K \log(a_w/a_{mf})$ 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, Figure 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.

References

1. Wyllie, M. R. J.: "A Quantitative Analysis of the ElectroChemical Component of the SP Curve," Jour. Pet. Tech. Vol. 1, 1949.
2. Goudouin, M., Tixier, M. P., and Simard, G. L.: "An Experimental Study of the Influence of the Chemical Composition of Electrolytes on the SP Curve," Jour. Pet. Tech., Feb. 1957.
3. Schlumberger Well Surveying: "Log Interpretation Charts."
4. Kharaka, Y. K., Brown, P. M., and Carathers, W. W.: "Chemistry of Waters in the Geopressed Zone from Coastal Louisiana -- Implications for the Geothermal Development," Geothermal Resources Council Transactions, Vol. 2, July 1978.
5. Presser, T. D., and Barnes, I.: "Special Techniques for Determining Chemical Properties of Geothermal Waters," U.S. Geological Survey Water Resources Inv. 22-74.
6. Ucock, H., Ershghi, J., and Olhoeft, G. R.: "Electrical Resistivity of Geothermal Brines," Jour. Pet. Tech., April 1980.
7. Pedro Silva: "Accurate Determination of Formation Water Resistivity from the SP Log in the Gulf Coast Area," M.S. Thesis, LSU, August 1981.
8. Pedro Silva and Zaki Bassiouni: "A New Approach to the Determination of Formation Water Resistivity from the SP Log," SPWLA 22nd Annual Logging Symposium, June 1981.

9. Wyllie, M. R. J. and Southwick, P. F.: "An Experimental Investigation of the SP and Resistivity Phenomena in Dirty Sands," Trans. AIME, Vol. 201, 1954.
10. Hill, H. J. and Milburn, J. D.: "Effect of Clay and Water Salinity on Electrochemical Behavior of Reservoir Rocks," Trans. AIME, Vol. 207, 1956.

SYSTEMS ANALYSIS AND SCIENTIFIC SUPPORT

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Introduction

This report is submitted in fulfillment of the reporting requirement of the Systems Analysis and Scientific Support (S.A.S.S.) function of the subject DOE contract. The S.A.S.S. function has been active both under the current contract and preceding contracts funded by DOE since 1977. Since the S.A.S.S. function, along with a number of other functions, is not designated for continued support after the current contract period, it seems appropriate to review briefly the history of this function prior to reporting the activities of this final contract year.

Review of Previous Activities

(1977-1978)

Systems analysis activities in the geopressured/geothermal area at LSU were initiated under an ERDA contract awarded in 1977 to Dr. Bert Wilkins, LSU Department of Chemical Engineering. The purpose of this first contract was to conduct a preliminary systems study (Operations Research study) of the potential for commercial development of the geopressured/geothermal resource in Louisiana, with a specific goal of developing a projected time schedule for the probable rate of future development of energy from the resource. The ERDA RFP requested estimates of energy rates to be made available, such as "electric power generation on stream" and "gas delivered to pipe lines" for future years, based on various scenarios.

This preliminary study, which was carried out in parallel with a similar study funded by ERDA at the University of Texas for the Texas geopressured/geothermal resource, resulted in first-year reports which contained rough estimates of the future rate of GP/GT energy development, but the focus of the conclusions and recommendations was upon the high degree of uncertainty connected with the available data and, therefore, on the projections made from them. The study also identified a number of potential impediments to the development of the resource in Louisiana, tagging them for further study: legal, socio-economic, environmental, political were the major impediments. The report agreed with others written at that time on the subject that actual test (design) wells and an increased effort to carry out geological assessments were clearly needed to provide more reliable information about the resource. Otherwise, no reliable systems analyses could be expected.

(1978-1979)

A second contract was granted at LSU in June 1978 by DOE to build a strong Operations Research and Systems Analysis interdisciplinary team to conduct studies, gather together available data from various sources, and continue work on the systems analyses of the resource begun by the preliminary study. Some goals of the second year were to remove some of the uncertainties connected with the identification of the commercial potential of the resource, evaluate the significance of the impediments to its development, and propose governmental actions which might stimulate commercial development of the resource in the future. The systems analysis team was gradually formed during 1978-79, reaching a complement of eight professionals (A.E. Johnson, Jr., et al.) consisting of engineers, a lawyer, an economist, a sociologist, and a geographer.

Three "workshops" were planned and conducted by the LSU systems analysis team during that year to gather together experts on specific geopressure/geothermal-related topics to discuss and evaluate both the impediments to development of the resource and the uncertainties connected with its assessment. The three workshop areas were environmental aspects, legal and political aspects, and resource assessment aspects. Reports and proceedings of each of the three workshops were compiled, published, distributed to interested parties, and included in the annual report to DOE. Major problems in each area were identified, and many of them were later targeted for further study by DOE in the form of research contracts to universities and private organizations.

Also during the second year the systems analysis team designed and developed the initial version of a techno-economic geopressured site simulation model (GPPROG) for use in determining the commercial and economic potential of a geopressure/geothermal resource, primarily through net present value (NPV) and discounted cash flow (DCF) analysis. During the development of this model, it was recognized that the ability to predict the quantity of methane contained in a geopressured brine (scf/bbl) was severely limited, because available published data (from a variety of researchers) had not been incorporated by anyone into one "global" correlation suitable for predicting the methane content of a saturated brine as a function of temperature, pressure, and salt content. Accordingly, a project was initiated to develop such a global correlation to be used by the techno-economic model, thereby reducing one major source of uncertainty. A project was initiated during this year to evaluate the potential socio-economic impacts of geopressured/geothermal energy development in coastal Louisiana as part of the overall study of

impediments to commercial development of the resource. The final report for the second-year contract (DOE/ET/27085-1) gave the status of all of these activities at the end of the second year, including conclusions and recommendations concerning the impediments and the commercial viability of the resource (based on studies of high potential prospects made with the techno-economic model). A total of eight papers based on the second-year activities were delivered by the systems analysis team at various geopressured/geothermal meetings and were included in the Appendix of the report for (1978-79). Recommendations for future work in each of the various areas studied by the systems analysis team were submitted as part of the annual report.

(1979-1980)

In the third year of systems analysis activity at LSU, DOE decided to fund all geopressured/geothermal activities at LSU under one "umbrella" contract to facilitate program management and coordination of activities. The size of the S.A.S.S. team was maintained approximately constant during the third year, but the level of effort was reduced somewhat, primarily because some of the areas no longer appeared to warrant intensive study; the level of effort in others actually increased, however.

During the third year, the development of a methane solubility correlation was completed, utilizing all available published data at that time, including that of Blount (Idaho State). A comprehensive computer sub-program (solute) based upon the resulting correlation, was incorporated into the techno-economic model. The model itself was used to evaluate additional high potential prospects in Louisiana and to evaluate the first design well, the Pleasant Bayou well (in Texas). A major

revision of the model was initiated to incorporate the Monte Carlo technique into it as an option. This revision was designed to permit inclusion of the uncertainties associated with the input data to the model, such as reservoir parameters (permeability, porosity, sand thickness, salinity, etc.) and economic parameters (investment costs, operating costs, fuel prices). Although not completed during the third contract year, the Monte Carlo revision was well on the way towards completion at year's end. The socio-economic impact studies were revised, brought to completion, and terminated during this year. As before, a number of papers were prepared later as a result of the year's activities for presentation at the fifth geopressured/geothermal conference held at LSU in October 1981.

(1980-1981)

For this fourth year of DOE sponsorship of systems analysis activity, a reduction in the overall effort to be expended was implemented. Except for the Monte Carlo revisions to the techno-economic model initiated the previous year, no major new direction was undertaken in the systems analysis effort. Instead, emphasis was placed upon expanding the existing data base (for the techno-economic model) of prospects, regional data, and design or well of opportunity (WOO) reservoir data so that new evaluations with the model could be made, particularly with the Monte Carlo revision. Work was also expended towards improving the data base of cost and price information to account for the perceived uncertainties in these inputs with the Monte Carlo approach.

Several of the members of the systems analysis team reduced their level of participation to a minimal advisory capacity, available for

answering requests for information or advice, but not conducting any organized research. A set of four papers based largely on the previous year's effort was given by the team at the October 1981 conference. These included an analysis of the Pleasant Bayou Design well made with the techno-economic model, a complete report and comparison of the methane solubility correlation with other available correlations, an economic analysis of various alternate schemes for managing the removal of brine from a well to enhance the economic potential, and a report on the economic value of secondary working fluid schemes for generating electricity from the thermal energy of a geopressured well. The Monte Carlo version of the techno-economic model was completed during this period, and evaluations were made of the high potential prospects, including the design wells under development. These analyses were published as an M.S. thesis by Adnan Abdulrahman, Department of Chemical Engineering, Louisiana State University, December 1981.

Activities During 1981-1982

At the beginning of the current contract year, it was clear that little additional systems analysis development activity was warranted. The assessments of impediments, with conclusions and recommendations, had been completed, and no revisions were contemplated. The analysis tool which had been developed over the previous years did not need further refinement, in light of the results of the analyses that had been completed on high potential prospects and prospective design wells. Accordingly, the proposal for this year's activities consisted of "primarily a maintenance and updating function, with a secondary function of providing an analysis and evaluation service to DOE at any time new

information is provided from the test-well program or from the resource assessment program". To provide only this maintenance and updating function, the funding requested from DOE represented a major reduction (by more than 70%) from previous years' operating budgets. A group of five tasks was proposed to carry out the reduced scope of the S.A.S.S. function. However, during the contract year funding was reduced again by approximately one third, at DOE's request.

It became clear, however, as the contract year developed, that it should not be difficult to accommodate the need to shrink the budget from the standpoint of the workload, as much of the work originally envisioned as needed for the maintenance and updating functions was failing to materialize. However, because of the relative inflexibility of commitments made based on funding sources, personnel could not be reduced below two part-time faculty participants and two graduate assistants. These individuals had made commitments to participate during the final contract year based on the initial proposal, and alternate sources of funds could not readily be made available once the academic year had begun. It was decided, however, that the best use of the funding would be to initiate a sixth ad hoc task (a revision of the reservoir model) to utilize the available talents of the participants effectively. This decision and subsequent progress on this task was reported in the monthly progress reports submitted during the year. The work which has been accomplished to date on this task is reported in this final report; it represents a substantial majority of the effort expended by the S.A.S.S. team during this contract period.

The remainder of this section is a review of the activities and final status of each of the tasks undertaken as part of the S.A.S.S. function

during the current contract period, that is, the five tasks originally proposed and the sixth ad hoc task undertaken after the contract period had begun.

Task 1: Maintain and update data base with information which becomes available from the resource assessment projects, add any new site-specific prospects or fairways which are completed, and add new regional information as it is completed.

The data base which is referred to in this task is that which is incorporated into the techno-economic model, GPPROG. The data base consists primarily of basic parametric data on each geopressed reservoir of interest, whether it be a prospect, a design well, a well of opportunity, or a region (parish). In addition to parametric data on reservoirs, the data base also contains parametric data connected with investment costs, operating costs, and fuel prices with appropriate methods for projection into the future. This task function was concerned with adding to the data base new information which became available during the contract period from the LSU resource assessment function, which conducted both prospect analyses and regional resource analyses. As of the time of this report writing effort, all new information appropriate for potential techno-economic analysis from this source has been accumulated and entered into the data base. In general, however, the new information which was made available as a result of the final year resource assessment function was incomplete in coverage with regards to input requirements for techno-economic modelling. The resource assessment program, which has concentrated this year on completing the regional analysis of the eastern section of Louisiana, has identified no new high

potential prospects suitable for techno-economic analysis. The data from the regional assessments, although suitable for estimating total amounts of brine and gas in place for a region, does not lend itself towards estimation of average individual reservoir sizes and size distributions or of averages and distributions for the other parameters of individual reservoirs within a region. As a result, the data which has been added to the data base under the task 1 function was inappropriate for making new or revised techno-economic analyses of high potential prospects or of regions.

Task 2: Evaluate new prospects and fairways using the techno-economic model and all its options.

During the first part of this contract year, the most recently identified high potential prospects at that time were evaluated by the Monte Carlo option of the techno-economic model and reported in detail in the M.S. thesis of Adnan Abdulrahman. A summary of these evaluations was included in the annual report for the 1980-1981 year. In brief, these studies showed that for the highest potential prospects, a high probability of achieving a satisfactory economic return (15% ROI) was realized, but that there were in reality very few of these highest potential prospects to be found in south Louisiana. Other prospects studied, which were not high potential, were found to have a relatively low probability of achieving a satisfactory return. The primary causes for the scarcity of high potential prospects were the small sizes of continuous reservoirs and the generally high salinity of the brine, which together prevented the returns from a venture from being anywhere close to replacing the rather large investments required. As stated, since completing these studies with the Monte Carlo option in the fall of 1981,

there have been no new high potential prospects identified and recommended by the resource assessment function. This lack of new high potential prospects seems to verify the conclusion that the potential (over the twenty-year horizon used in these studies) for the Louisiana geopressured resource to become a viable or significant alternate energy source is quite low, barring some very unexpected change in the value of natural gas compared to other energy and equipment costs from that used in the data base of these studies.

Task 3: Add to the data base the information which becomes available from the well testing program.

This task was carried out during the contract period, but as was true for Task 1, the new information actually added to the data base was sparse, quite limited in scope, and generally unsuitable for providing a basis for techno-economic analyses. The primary sources of the information for this task were the test well program and the wells of opportunity program, which can provide reservoir information about specific sites being investigated. Typically, the new data made available from test wells or wells of opportunity has been the result of short-range tests, which give well pressures and flow rates, plus measured gas to water ratios. Unfortunately, short-range tests do not provide much basis for reducing the uncertainties connected with reservoir sizes, effective permeabilities, sand thicknesses, etc., which determine the ultimate recoverability of brine and gas.

• Task 4: Evaluate each design well and appropriate well of opportunity as enough new information becomes available in the data base.

No new evaluations of either design wells or well of opportunity were performed under this task. The overall difficulties and slow-downs encountered in the design well programs plus the short-lived tests themselves, resulted in incomplete data being made available, unsuitable for producing any useful new techno-economic analyses. Similarly, the data from the wells of opportunity, also of short-range nature, as explained in the discussion of Task 3 above, made it inadvisable to perform any studies based on their results. On the other hand, any design well or well of opportunity could have been analyzed with the techno-economic model by making subjective estimates where necessary for the various parameters of the reservoir and of the parameter distributions; but performing such studies would have been an unwarranted exercise as no new useful information would have been generated by such studies. Suffice it to say that none of the last wells in question seem to be "high-potential", based on the data which have been made available. The Monte Carlo studies made by Abdulrahman of high potential prospects were based on the best available estimates at that time. No further studies are warranted until new prospects or less uncertain data about the old prospects become available. It was, of course, hoped that the test well program would help reduce the uncertainties in the site-specific parameters of typical prospects. To some degree this has been accomplished for some parameters, but from the standpoint of achieving a substantially improved techno-economic systems analysis, there are still, unfortunately, sensitive parameters with large uncertainties. Accordingly, it was decided that the efforts of the S.A.S.S. group could be more effectively spent on the ad hoc task 6 than on task 4 activities.

Task 5: Respond to DOE (and other) requests for expertise and consulting advice of a legal, socio-economic, economic, engineering, or venture analysis nature on an ad hoc basis.

From this task description, it is clear that not much personnel effort was likely to be required to fulfill it. There have been during the year, as in previous contract years, informal inquiries from various sources to the individuals who have previously served as part of the systems analysis team during its peak effort period. As we intended by the task statement, all such inquiries were handled by the individuals concerned without requiring any substantial research effort; on the contrary, responses were usually based upon the experience and knowledge which had been accumulated during the course of the previous four years of systems analysis on the Louisiana geopressured resource. Such advice will no doubt continue to be made available by each of these individuals in the future, regardless of the existence of a DOE contract at LSU on geopressured energy.

Task 6: Modify the reservoir model of the techno-economic model GPPROG to provide the capability to analyze "watered out" gas reservoirs, subjected to brine production to enhance the recoverability of the gas.

As previously described, this task was added to the task list as an ad hoc function to utilize the systems analysis team in a more productive manner than would otherwise have been possible from conducting tasks 2 or 4 with an incomplete data base. This project is one which is also sponsored as a task under an existing Gas Research Institute (GRI) contract at LSU; therefore, by adding the project to the task list of this DOE contract, it

was possible to conduct the research at a higher level of effort than would have been possible under the GRI contract alone and thereby achieve the desired end result sooner than would have otherwise been possible.

The objective of this research effort was to develop a one-dimensional, circular, bounded or unbounded reservoir model which could be used to simulate the production of gas from a geopressured reservoir driven by a moderately or strongly encroaching aquifer. It is of interest to develop such a simulator because it has been recommended that the gas recovery from such a gas field can be improved substantially by removing water (brine) from the surrounding aquifer at rates which will retard the advance of the aquifer into the gas reservoir. This would allow the reservoir to be depressured without trapping residual gas in the invaded region, thereby resulting in a higher gas recovery than would have been achieved from the original reservoir without brine production. Note that gas recovery is also increased by the amount of solution gas which is recovered from the produced brine. Whenever the drive of an aquifer is moderate or strong, then a large region in the original gas reservoir becomes invaded by the brine, trapping residual gas, most of which does not get recovered before the reservoir "waters out".

It was desirable to develop this simulation capability so that existing gas reservoirs which are identified as "prospects for enhanced gas recovery by brine production" can be simulated to determine the amount of enhanced gas recovery possible from using either existing abandoned wells as brine removal points (a relatively inexpensive route) or by drilling new well(s) (a more expensive alternative) for the purpose of removing brine at the most propitious locations and/or rates. In any case, the simulator would permit the assessment of the possibilities of

enhanced gas recovery by this method for any proposed site-specific gas reservoir.

The development of the modified reservoir subprogram became an M.S. research project for Mr. Stephen J.P. Oliver, Department of Chemical Engineering graduate student, and his major professor, Dr. A.E. Johnson, Jr. Modifications to the techno-economic model routines dealing with the economic calculations became a project under the direction of Dr. Fred M. Wrighton. At this time, both parts of the project are in the final stages of completion. The reservoir model has been completed and is undergoing testing, using an existing gas reservoir, with historical data, as a basis for the tests. Also the modifications to the techno-economic model have been designed and are essentially implemented so that the combined package can be used in the near future (under the GRI contract, of course) to evaluate a number of potential enhanced gas recovery prospects. The remaining sections of this report describe in some detail the revised reservoir model and computer subprogram that was developed in this research and the current status of the applications of the model.

A Model and Computer Program to Simulate Gas Reservoirs Subjected to Enhanced Recovery by Producing Brine from the Encroaching Aquifer

Introduction

Since the early 1970's, when gas supply peaked at 22×10^9 cubic feet per year, the U.S. gas reserves and gas production have been declining. Current domestic production is about 14×10^9 cubic feet per year.

Gas reserves are often classified into associated and non-associated gas. Associated gas is gas which is initially dissolved in oil and is liberated from this oil as the oil is produced, while non-associated gas

is that which exists in the gas phase in the reservoir. Enhanced recovery of associated gas is generally a result of enhanced recovery of the oil and, although a substantial fraction of the gas supply, is not the subject of this report.

The conventional recovery efficiency of non-associated gas is heavily dependent upon the type of natural drive mechanism that prevails within the reservoir. The two major drive mechanisms are depletion drive and water drive. Depletion drive signifies a closed reservoir which allows gas production at the expense of ever-decreasing pressures in the reservoir. The pressure eventually reaches such a low value that it becomes economically infeasible to recover additional gas. Recovery efficiencies for depletion drive gas reservoirs are generally about 70%, falling well below this figure as formation permeability decreases.

Water drive gas reservoirs are characterized by natural water encroachment into the reservoir as gas is produced, and by reservoir pressures that remain high throughout their production history. The wells are abandoned when the encroaching water reaches the producing wells and causes gas flow to decrease or even cease. Recovery efficiencies for water drive reservoirs can be as high as those for depletion drive reservoirs, but quite often water drive efficiency is lower (about 50%).

The displacement of gas by water in porous media is far from complete, resulting in a large by-passed gas volume behind the flood front. Gas is by-passed both on the microscopic and the macroscopic scale. The former makes up the residual gas saturation and exists in portions of the formation that have been swept by water; the latter is formed when some portions of the reservoir have not been swept by water at the time of abandonment.

Residual gas is formed on a microscopic scale when filaments of gas which connect particular groups of gas-filled pores with the continuous gas phase become discontinuous due to the advance of water from adjacent pores. The entrapment of residual gas is illustrated in Figure 1. The particular paths taken by the advancing water front and the sequence in which particular pores are flooded are determined by the pressure that draws water into each pore, and the resistance to flow encountered in the process.

Thus, in a water drive reservoir, the unrecovered gas will exist as a high-pressure, immobile, discontinuous gas phase. One possibility for enhancing the gas recovery from this type of reservoir is to produce water from the watered out areas, or from the associated aquifer at high rates. The major effect is to reduce or even reverse water encroachment and thereby reduce reservoir pressure. By lowering reservoir pressure, the discontinuous, immobile gas phase can expand to such an extent that it becomes mobile and can flow to the producing wells. It is also possible that small amounts of gas dissolved in the water will evolve from solution and thereby add to the available gas. In essence, the production of large volumes of water changes the drive mechanism from a relatively inefficient water drive to one that approaches that of a depletion drive. In the right kind of reservoir, this can result in significant additional gas production. This concept has been discussed in detail by Christian (1) and by Cook and Greet (2).

Not all water drive gas reservoirs will be susceptible to this potential enhanced recovery method. Reservoir parameters, such as permeability and reservoir size, and aquifer extent, are suspected as being important in determining the possible utilization of this enhanced

FIGURE 1. - Gas trapped by advancing water in porous media.

recovery method, but little work has been done to establish meaningful relationships. Therefore, the study in hand has two main purposes:

1. To investigate the most important parameters affecting the economic potential of the recovery method and
2. to develop a quick and cheap method for analysing potential reservoirs where this method can be used.

The Program

The prime objective of the programming side of the problem is to minimize the usage of computer time. This inevitably rules out the implementation of a complex multi-dimensional finite difference model. Instead, the program is based on a modified material balance, as applied to a "tank-type" mode, first reported by Lutes and Chang (3), and subsequently used in their investigation of accelerated blowdown of a strong water drive gas reservoir. The nub of this modified balance is the existence of a large pressure drop in the water-invaded region, and a small (even negligible) pressure drop in the uninvaded region. Thus, the residual gas, trapped behind the invading water front, is at a much higher pressure than the gas flowing to the producing well. The presence of a pressure gradient in the invaded region and trapped gas within this region must be accounted for in any representational model. Consequently, different gas volume factors should be used to assign standard volumes (SCF) to the trapped and untrapped gas. The conventional material balance equation

$$G B_{gi} = (G - G_p) B_g + W_e \quad (1)$$

was therefore modified to include a trapped gas term as follows:

$$G B_{gi} = (G - G_p - G_t) B_g + G_t B_{gt} + W_e \quad (1a)$$

Where

- G = original gas in place, SCF
 G_p = cumulative gas production at time t , SCF
 G_t = volume of gas in invaded region at time t , SCF
 B_{gi} = original gas volume factor, bbl/SCF
 B_g = gas volume factor from uninvaded region, bbl/SCF
 B_{gt} = gas volume factor for trapped gas, bbl/SCF
 W_e = cumulative water influx at time t , bbl

The reservoir model corresponding to Eqa. 1a. and the uninvaded regions is illustrated in Figure 2.

The water influx term W_e is described by the Hurst-van Everdingen unsteady state water influx solution for a radial aquifer (3). The program contains tables taken from Hurst and van Everdingen's paper and performs a double interpolation in these tables (with respect to time, t , and with respect to the ratio of aquifer to reservoir radius, r_d) to solve for the water influx:

$$W_e = C \sum_{j=1}^n \Delta P_j Q [t_{D(n)} - t_{D(j-1)}]$$

- c = $1.12 h \phi_a c_{f+w} r_R^2 f_R$ (bbl/Psi)
 h = net thickness of formation, ft
 ϕ_a = aquifer porosity, fraction
 c_{f+w} = rock plus water compressibility, psi^{-1}
 r_R = effective reservoir radius, ft
 f_R = fraction of reservoir periphery in contact with aquifer
 ΔP_j = $\begin{matrix} (P_{j-2} - P_j)/2 & j > 1 \\ (P_o - P_j)/2 & j = 1 \end{matrix}$ = reservoir pressure change for the j th time step, psi

WHERE,

r_2 = DISTANCE FROM CENTER OF RESERVOIR TO ORIGINAL GAS-WATER CONTACT, FT.

r_1 = DISTANCE FROM CENTER OF RESERVOIR TO GAS-WATER CONTACT AT SOME ELAPSED TIME t , FT.

P_2 = PRESSURE AT r_2 AT TIME t .

P_1 = PRESSURE AT r_1 AT TIME t .

FIGURE 2. - Reservoir model with terms for modified material balance.

$Q_{tD} = Q_{tD}(t_D, r_D)$ = dimensionless water influx function

$r_D = r_a/r_R$ = ratio of aquifer to reservoir radius

$t_{D(j)} = \frac{.00633 k_w t_j}{\phi_a \mu_w c_{f+w} r_R^2}$

k_w = water permeability in aquifer, md

μ_w = water viscosity, cp

t_j = time at end of jth time interval, day

The procedure for predicting reservoir pressure and water influx based on Eq. 1a. and Eq. 2 for any given time step is summarized below:

1. Compute the original reservoir radius

$$r_2 = [(G B_{gi} \times 5.615) / (\pi h (1 - S_{wi}) \phi)]^{1/2} \quad (3)$$

where

h = reservoir net thickness, ft

S_{wi} = connate water saturation, fraction

ϕ = average porosity of the formation, fraction

2. Estimate the pressure P_2 at the original reservoir boundary.
4. Calculate the radius of the uninvaded zone:

$$r_1 = [r_2^2 - \frac{W_e \times 5.615}{(1 - S_{gr} - S_{wi}) \phi \pi h}]^{1/2} \quad (4)$$

where S_{gr} is the residual gas saturation.

5. Calculate the pressure P_1 at the invading water front assuming radial flow:

$$P_1 = P_2 - \frac{q \mu_w \ln \left(\frac{r_2}{r_1} \right)}{0.00708 k_w h} \quad (5)$$

where

$$q = \Delta W_e / \Delta t, \text{ res bbl/day}$$

$$\Delta W_e = \text{net water influx for time step } \Delta t, \text{ res bbl}$$

$$\Delta t = \text{time step duration, day}$$

$$k_w = \text{effective permeability to water within reservoir limits, md}$$

6. Calculate the average pressure $\bar{P}$ in the water invaded region from the following equation:

$$\bar{P} = P_2 - \frac{2 q \mu_w}{0.00708 k_w h} \left[\frac{1}{4} - \frac{r_1^2 \ln \left(\frac{r_2}{r_1} \right)}{2 (r_2^2 - r_1^2)} \right] \quad (6)$$

7. Calculate the trapped gas volume G_t from:

$$\begin{aligned} G_t &= \int_{r_1}^{r_2} \frac{\phi S_{gr} 2\pi r h}{B_{gt} 5.615} dr \\ &= \frac{A}{2} \left(P_2 - \frac{B}{2} \right) (r_2^2 - r_1^2) + AB \frac{r_1}{2} \ln \left(\frac{r_2}{r_1} \right) \end{aligned} \quad (7)$$

where

$$A = \frac{2\pi h S_{gr} \phi}{(5.615)(0.00502) Z T}$$

$$B = \frac{q \mu_w}{0.00708 k_w h}$$

$$B_{gt} = 0.00502 \frac{Z T}{\bar{P}}$$

$$T = \text{absolute temperature, } ^\circ\text{R}$$

$$Z = \text{compressibility, fraction}$$

8. See Eq. 1a. for W_e .

Compare W_e calculated from Step 3 with that calculated from Step .8

If the two W_e 's are not within a specified tolerance, go to Step 2 and estimate another P_2 and repeat the procedure.

The above procedure assumes that the gas reservoir behaves like a tank and that:

- Pressure is uniform throughout the uninvasion region of the reservoir.
- The van Everdingen-Husrt unsteady state water influx equation satisfactorily describes aquifer behavior.
- Residual gas saturation is constant throughout the water-invasion region.
- The radial flow equation can be used to describe the pressure distribution in the water-invasion region.

In order to maintain the geometry of the system, that of a circular reservoir surrounded by a concentric annular aquifer, water production is assumed to take place at fixed radii from the central gas-producing well. These water production 'rings' may be situated either within reservoir limits or in the associated aquifer. Since the program completes each timestep upon successful convergence of the outer boundary pressure, if water production rings are situated in the aquifer, then the outermost of these is taken as a pseudo-reservoir boundary. This has implications that will be discussed later. If water production rings are found in the aquifer, then the program may be seen to operate in two halves: namely a zone where water saturates the formation 100%, and another where there will be a residual gas saturation; thus the importance of having available the relative permeability curves for the system comes into play.

Example relative permeability curves measured (4) for an imbibition process (water invading a water-wet porous rock containing gas) are shown in Figure 3. Point A corresponds to conditions in the aquifer where the permeability to water is equal to the absolute permeability. Point B corresponds to conditions in the water-invasion portion of the reservoir behind the flood front. Point C corresponds to conditions ahead of the

FIGURE 3. - Example relative permeability curves for gas and water.

flood front in the uninvaded portion of the reservoir; this point is of little consequence in the convergence routine in the program since no gas-flow equations are used. This is the case due to a negligible pressure drop in the uninvaded region. For the most common condition of a strongly water-wet reservoir, the region of two-phase flow at the flood front is a relatively narrow band. Indeed, the model assumes a "piston-like" displacement process and all that this entails; a subsequent assumption being that the gas producers will change from 100% gas production to 100% water production.

Water production can be scheduled, in which case artificial lift may be required, or the wells may be allowed to flow at full potential for the particular bottom-hole pressure. If artificial lift is required, then the program will calculate the pumping requirements for input into the economic model. The water production is subtracted from the water influx, and hence the influx to the next ring is computed. An average flowrate between successive rings is calculated and consequently the pressure at the next ring is calculated using the standard radial flow equation (ignoring changes in the density of the water):

$$P_{n-1} = P_n - \frac{q \mu \ln(r_n/r_{n-1})}{0.00708 k_w h}$$

Where

q = flowrate of water between rings in timestep, bbl/day

k_w = effective permeability to water in annulus, md

Also included in the program is the effect of gas coming out of solution due to the pressure decline with time. In order to program the latter, several assumptions had to be made:

1. at any temperature and pressure the connate water is saturated with gas,
2. water that has encroached into the reservoir is indistinguishable from the connate water,
3. encroaching water is considered as saturated at the average pressure at the reservoir boundary during the timestep,
4. exsolved gas in the aquifer is considered to occupy a negligible volume and, therefore, its effect is ignored, and
5. exsolved gas in the reservoir is assumed to percolate forward instantaneously to the uninvaded region.

The assumptions, as outlined above, can only be supported by tentative argument; however, previous workers have reported using the same assumptions, even though it is by post facto design. This rules out the consideration that the water may not be saturated or, indeed, that a saturation gradient is soon established in the aquifer water.

In order to take into account this effective increase in gas in the reservoir, the material balance equation is further modified to the following form to solve for the water influx:

$$W_e = G B_{gi} - (G - G_p - G_t - G_e) B_g - G_t B_{gt}$$

Where the term G_e is the exsolved gas (SCF). This extra term is really a trapped gas term, but a distinction is made in the program since this gas did not exist as free gas up until the timestep under consideration.

It should be noted here that this gas is assumed to percolate forward to the gas producer, although it may be envisaged as flowing to one of the water producers. Here lies a major limitation of the program: it is a mass-balance and therefore takes no account of any two-phase flow phenomena. It is well known that two-phase flow will be taking place at

the water producers (as well as gas wells), especially if the invading front is being held stationary at a radius where water production equals the influx from the previous radius. However, this is ignored inasmuch as the gas can only flow in one direction. This is also true if the production rate is such that the invading front is made to recede.

The solution for the outer boundary pressure converges using a secant method, in which the water influx term in equation 2 has been corrected for water production; that is, the reservoir is effectively viewed as extending only as far as the water production ring that has most recently been passed by the invading front.

Implementation

Experimental runs have been made using a 'typical' gas reservoir, with parameters as shown in Appendix 1. The purpose of these runs was to see if the reservoir would behave as would be expected in response to specific production schedules. The results so far have been very encouraging, and the program does indeed simulate, in general terms, what would be expected. Firstly, the recovery is improved by water production at any radius within or without the original reservoir boundary. If a very high water rate production rate is maintained at the original reservoir radius, then the reservoir behaves as if under depletion drive. Secondly, if the gas production rate is reduced (or stopped), a pressure buildup is seen throughout the reservoir, resembling that for a pressure buildup test. Indeed, the reservoir can also be repressured by water injection at the rings (a negative production rate), though extensive runs have not been made since it is felt this to be an unlikely requirement of the program.

As mentioned earlier, if a water production ring is situated in the associated aquifer, it is taken to be a "pseudo-reservoir" outer boundary. The program takes no account of the compressibility of the water between this radius and that of the actual reservoir boundary. This is done since it is not foreseen that this annulus will be large, and thus the effect of water expansion will be small compared with the influx from the aquifer. As suggested by Lutes and Chiang, the whole concept is best suited for reservoirs undergoing strong water drive.

Sensitivity runs are now under way, looking at the effect of perturbations in reservoir parameters using data from a real case. In order to make these input data compatible with the "mass-balance" concept of the model, the free gas produced at the water wells is summed and assumed to be produced at the centrally located gas producer. The pressures predicted by the model are then compared with the pressure history data from the reservoir itself. The sensitivity of the programme is studied by analyzing what changes in reservoir parameters (especially permeabilities) cause the best pressure fit to be obtained.

In conclusion, the correct results from these runs indicate that this is a valid method for screening prospects for the enhanced recovery technique, without resorting to an expensive three-dimensional finite difference simulation. However, the success of trying to model two or more wells in close proximity has yet to be studied, though it may be suspected that the model may fail in this case, due to flow interference, which must detract considerably from the assumption of radial symmetry throughout the reservoir.

References

1. Christian, L.D., "Recovery of Gas from Water Drive Gas Reservoirs", U.S. Patent No. 4, 149, 598 (April 1979).
2. Cook, H.L. and Greet, B.C., "Method for Increasing the Recovery of Natural Gas from a Geopressured Aquifer", U.S. Patent No. 4,042,034 (August 16, 1977).
3. Lutes, J.L. and Chiang, C.P., "Accelerated Blowdown of a Strong Water Drive Gas Reservoir", SPE paper No. 6166, 1976.
4. Hurst, W. and van Everdingen, A.F., "The Application of the Laplace Transformation to Flow Problems in Reservoirs" Trans., AIME (1949), 186, 305-322.
5. Mathews, C.S., "Existence and Flow Behavior of Gas at Low Saturation in Geopressured Formations - Final Report", DOE Report ZHCP/T2259-05, Dist. Category 4C-66a (April 1979).

Appendix I

Input Data

Current version of the program is a "stand alone" one, requiring input data presenting the problem to be read in. The data is read in using the NAMELIST format of FORTRAN. A list of variables is assigned a name and all input values must be associated with this namelist. All input variables have been assigned default values in the program itself, thus setting up a "base case". The procedure for reading in changes to the base case is as follows:

1. Column one (1) must be blank,
2. Columns two (2) must contain "&" followed directly by the namelist name,
3. The variables to be changed are then entered in the form var1=a, var2=b, and so on. When the variables to be changed have been entered, the last one is followed by a space and then '&END'.
4. All lines must start in column two (2) and variable names or values cannot be split over two (2) lines.
5. Any variable not entered in a read statement assumes its default value.
6. Even if no data is to be changed, the namelist name must appear (preceded by a "&") and followed by a space, then '&END'.

Example:

```
COLS123456789
```

```
&SHOW IOPTA=2, IOPTC=3 &END Only the variables IOPTA and
```

IOPTC are changed from the default values.

The Input Namelists

1. Namelist &SHOW: This namelist contains options for running the program in various modes, type of output, and debugging routines. ALL values in this namelist are INTEGERS.

a) IOPTA:

The program can run using two methods for calculating the water influx from the Hurst-Van Everdingen solution. One assumes a constant timestep, the other a varying one. IOPTA=1 tells the program that the timestep is constant, and is the default value. If the program changes the timestep for any reason (cf PLIMIT) then IOPTA is AUTOMATICALLY set to two (2). It is suggested that the user does not change IOPTA.

b) IOPTB:

In the course of a timestep the program may detect that the water front has reached the gas-producing well. However, the radius of the uninvaded zone, from the previous timestep may be quite large, and the user may require better "definition" before the front reaches the central well. IOPTB allows the user to control the timestep change option. IOPTB=1 tells the program to cut the timestep in half if the front reaches the well or the pressure in the uninvaded region falls below the allowable limit (cf PLIMIT). The default value is two (2). If the user does change the value to one (1), and the program does change the timestep, then IOPTA is changed automatically.

c) IOPTC:

This option is probably the one that must be selected with the most care. IOPTC can take on one (1) of three (3) values, namely 1, 2, or 3.

i) IOPTC = 1:

In this mode the program will calculate the maximum possible flowrate that EACH of the water producing wells can maintain over each timestep. If this flowrate is larger than the maximum allowable the rate is set equal to the allowed maximum (cf ALLOWD). Also, if the flowrate is so high that the well can produce more water than has encroached from the aquifer, the cumulative production is set equal to the water influx, and the rate recalculated for output purposes.

ii) IOPTC=2:

In this mode the program is told that it must meet a production schedule, input by the user (cf WPRATE(NN,I)). If the reservoir pressure is too low, then the program outputs the required head and horsepower for the pump. However, if this rate is too large, i.e., not enough water has encroached, then the program defaults as for IOPTC=1.

iii) IOPTC=3:

In this mode the program meets the production schedule wherever possible, but if it cannot, then it will flow the maximum possible; i.e., no pumps are used. Defaults are as for IOPTC=1,2.

d) IFREQ:

This controls the frequency of the output data. If IFREQ is equal to 'n', data for every 'n'th timestep, starting at the 'n'th, is shown. If IFREQ is equal to one (1), then every timestep is printed out. The latter is the default value.

e) IGOON:

IGOON=1 tells the program that another run is imminent; i.e., the next run is really a continuation of the last, except only one (1), or a few of, the variables have been changed. This is useful if, say, a study of aquifer size was to be carried out. All input data would remain the same and only the radius of the aquifer would be changed. The default value is two (2), i.e. 'this is the only run'. IGOON is reset each run, and must be set to one (1) each time there is a successive run.

f) IPLOT:

This parameter controls the plotting routine. If set equal to one (1), plots of radius of the uninvaded zone, cumulative gas production, etc. vs. time are created and sent to the Benson Plotter. The default value is two (2), and IPLOT is reset to this for every run; thus if IGOON has been set to one (1), then IPLOT must be entered on the next set of input cards if a plot is required for the next run.

g) IMDEBUG:

This parameter is for debugging purposes only. It is set to two (2), and should only be changed to one (1) if the user desires to look at the "intermediate" calculations in the program. The user is warned that doing so will produce rather a lot of paper output.

h) IDBUG2:

IDBUG=1 will cause the value of the dimensionless water influx term from the Hurst-Van Everdingen solution to be printed at each timestep. Again the user is advised to leave this parameter set at its default value of two (2).

2. Namelist &TIMES:

a) TOTIME:

This is the total time for which the reservoir is to be studied in days. Its default value is 1000 days. The user's attention is drawn to the fact that all real numbers MUST be entered in the D format. Thus the way to enter 1000. is 1.D03, or 10.D02, or 1000.D00; the D must appear for each real number.

b) TIMDIV:

This is the timestep which is to be used in the program. It must be an integral fraction of TOTIME. It's default value is twenty (20) days.

3. Namelist &RESDAT:

a) OGIP:

This is the original gas in place in standard cubic feet (SCF). Its default value is 3.D09.

b) PHIR:

Reservoir porosity, dimensionless fraction. Default value is 0.25D0.

c) SWI:

Connate water saturation in the reservoir, dimensionless fraction. Default value is 0.35D0.

d) SGR:

Residual gas saturation, dimensionless fraction. Default value is 0.35D0.

e) PINIT:

Initial reservoir AND aquifer pressure, psia. Default value is 3.D03.

f) HR:

Net pay thickness in reservoir, feet. Default value is 5.D01.

g) MUG:

Gas viscosity, assumed constant, centipoise. Default value is 3.D-2.

h) DEPTH:

This variable is dimensioned to assign a depth to each producing well. Data should be entered as DEPTH(NN) = 'value'. Default value for each is 1.D03 feet.

4. Namelist &CMPRES:

a) CW:

Compressibility of brine, assumed constant, in microsip (reciprocal psi). Default value is 3.D0.

b) DF:

Compressibility of formation, assumed constant, in microsip. Default value is 5.D0.

5. Namelist &PERMS:

a) KABS:

Absolute permeability of formation in millidarcy. Default value is 1.D02 md.

b) KRG:

Relative permeability of gas at initial water saturation, dimensionless fraction. Default value is 9.D-01.

c) KRW:

Relative permeability of water at residual gas saturation, dimensionless fraction. Default value is 3.D-01.

6. Namelist &AQFER:

a) RA:

Radius of aquifer in feet, default value is 1.D04.

b) HA:

Thickness of aquifer in feet, default value is 5.D01.

c) PHIA:

Porosity of formation in aquifer region, dimensionless fraction.

Default value is 25.D-02.

d) FR:

Fraction of aquifer in contact with the reservoir, dimensionless fraction. Default value is 1.D00.

e) TEMP:

Temperature of system in Rankine. Assumed to be same in aquifer as in reservoir, and constant. Default value is 63.D01.

f) SALT:

Salinity of brine in lb salt per lb water, dimensionless fraction. Default value is 0.0D0.

7. Namelist &GSCHED:

This is a good place in which to explain the production scheduling, which applies to the last three (3) namelists. The rate of production of water or gas is in bbls or SCF per day, quite straightforward. The associated time is the time through which the rate will prevail. Thus, if rate 1 is to last for "x" days, then time 1 is set equal to "x". If a certain rate is to prevail for the entire reservoir study time, then the time parameter must be set to a large value.

a) NRATES:

The number of gas production rates, an INTEGER value. Default value is 1. Maximum number of 10.

b) GPRATE:

Gas production rate in SCF per day. Default value is 2.D06 for the one rate.

c) TGRATE:

The time for which the rate is operational. Default value is 1.D04, i.e., the time under consideration for most cases (c 30 years).

d) PLIMIT:

The pressure below which the reservoir will no longer produce gas from the gas well due to "loading up". Default value is 15.D02 psia.

8. Namelist &RSCHED:

Since the reservoir radius is not known, if a well on the edge of the reservoir is designated as a water producer, a schedule for it must be input separately.

a) NRES:

Number of production rates; default is 1.

b) WPRES:

Production rate in bbls per day. Default value for the one (1) rate is 0.0D0.

c) TWRES:

Time for which each rate is operational in days; default for the one (1) rate is 1.D10.

9. Namelist &WSCHED:

a) NWELL:

Number of water production radii, excluding the reservoir radius, even if there is water production at this radius. NWELL is really the number of radii to be read in. The reservoir radius is found internally and automatically inserted into the correct array, along with its production schedule; hence the need for namelist &RSCHED. Default value is three (3), maximum number is 10.

b) RW:

The radius of any water production wells in feet. These MUST be entered in order of decreasing size. Failure to do this will lead to a program error with some very cryptic diagnostics. Default values for the three (3) radii are 3., 2., and 1. feet; i.e., the water front will reach these radii at the end the run, and consequently they affect the run little.

c) NWRATE:

Number of rates for each well. Default value is 1 one (1), maximum is 10. Thus the doubly dimensioned array NWRATE will contain 400 elements.

d) WPRATE:

Water production rate in bbls per day for each of the water production wells, e.g. WPRATE (n,j) contains the 'j'th rate for the well at the 'n'th radius. Default values are 0.0D0.

e) TWRATE:

The time for which the above rates are operational, days. Default values are 1.D11.

f) DPIPE:

The pipe diameter, in feet, through which the water is to be produced; a value for each well must be input. Default values are 0.6667D0.

g) DELIVP:

The surface delivery pressure for the water-producing wells, psia. This is made a variable and not set to atmospheric pressure since it may be required that the water be delivered to a separation unit at some high pressure. Default value is 2.D01.

h) ALLOWD:

The maximum possible flow rate at ANY radius, bbls per day. This is set, according to past experience, at 4.D04. However, if there are, say, 'n' wells at the same radius, then ALLOWD should be set to 4n.D04 for that radius.

Appendix II

Sample Output from Computer Program to Simulate Watered Out Gas Reservoirs Subjected to Enhanced Recovery Procedure

Input Data

Table A. This is a computer listing of the input data file, which utilizes the Namelist option of FORTRAN.

```
4DEBUG 4END
4SHOW IOPTB=1,IOPTC=2,IFREQ=3,IGCON=2,ISOL=2 4END
4PLOTS 4END
4TIMES TIMDIV=60.8000,TOTIME=6080.000 4END
4RESDAT IOPTAC=2,OGIP=35939.8242006,SGR=0.18000,
PINIT=5.003,HA=30.000,DEPTH=1.003 4END
4ZFACTR SGRAS=0.65000,IOPTZ=2 4END
4CMPRES CF=3.65000,CW=5.000,AVGHUW=0.277000 4END
4PERMS KRW=0.38116000,KABS=1.001,AQKABS=1.001 4END
4AQFER RATIO=9.60159000,HA=30.000,TEMP=71.001 4END
4GSCHED NRATES=1,PLIMIT=5.001,
TGRATE(1)=6080.000,GPRATE(1)=1.0007 4END
4RSCHED NRES=1,WPRES(1)=1.003,TWRES(1)=6080.000 4END
4NSCHED NNEWELL=0,ALLOWD(1)=1.011 4END
```


Appendix II (continued)

Table B
First Page Output

TOTAL STUDY TIME 6080.000000 DAYS.
A TIME STEP OF 60.800000 DAYS IS USED.

ORIGINAL GAS IN PLACE.....35939.824200 MMSCF
AREAL EXTENT OF RESERVOIR..... 693.657300 ACRES
INITIAL PRESSURE..... 5000.000000 PSIA
TEMPERATURE..... 250.000000 FAHRENHEIT
SPECIFIC GRAVITY OF GAS..... 0.650000
INITIAL GAS VOLUME FACTOR..... 0.000730 BBL/SCF
INITIAL COMPRESSIBILITY FACTOR. 1.019992

RESERVOIR POROSITY..... 0.250000
CONNATE WATER SATURATION..... 0.350000
RESIDUAL GAS SATURATION..... 0.180000

NET PAY THICKNESS..... 30.000000 FT
ORIGINAL RESERVOIR RADIUS..... 3101.405206 FT

ROCK COMPRESSIBILITY..... 3.650000 MICROSIP
WATER COMPRESSIBILITY..... 5.000000 MICROSIP
INITIAL WATER VISCOSITY..... 0.277000 CP
GAS VISCOSITY..... 0.030000 CP

ABSOLUTE PERMEABILITY..... 10.000000 MD
RELATIVE WATER PERMEABILITY.... 0.381160
RELATIVE GAS PERMEABILITY..... 0.200000

AQUIFER POROSITY..... 0.250000
AQUIFER THICKNESS..... 30.000000 FT
FRACTION OF CONTACT..... 1.000000

AQUIFER/RESERVOIR RADIUS RATIO. 9.601590

PROGRAMME HAS COMPLETED RUN. TERMINATION OCCURRED AFTER 55 TIME STEPS.

Appendix II (Continued)

Table C
Second Page Output

WELL LOCATED AT 3101.4052 FT
DIAMETER OF WELL 0.6667FT

TIME (DAYS)	BOTTOM HOLE PRESSURE (PSIA)	WATER PRODUCTION RATE (MMBLS/DAY)	CUMULATIVE WATER PRODUCTION (MMBLS)	CUMULATIVE GAS PRODUCTION (MMSCF)	HORSEPOWER SUPPLIED TO FLUID (HP)	HEAD TO BE SUPPLIED BY PUMP (PSIA)	RADIUS OF UNINVADED ZONE (FT)
*****	*****	*****	*****	*****	*****	*****	*****
0.0	5000.0000	0.0	0.0	0.0	.0	.0	3101.4052
182.4000	4687.4133	1.0000	0.1735	0.0	.0	.0	3028.4685
364.8000	4461.4834	1.0000	0.3559	0.0	.0	.0	3052.5743
547.2000	4278.6023	1.0000	0.5383	0.0	.0	.0	3005.0905
729.6000	4124.9154	1.0000	0.7207	0.0	.0	.0	2947.7613
912.0000	3993.0935	1.0000	0.9031	0.0	.0	.0	2882.7983
1094.4000	3876.7949	1.0000	1.0855	0.0	.0	.0	2810.2052
1276.8000	3769.1089	1.0000	1.2679	0.0	.0	.0	2730.7513
1459.2000	3667.9447	1.0000	1.4503	0.0	.0	.0	2645.2538
1641.6000	3574.8842	1.0000	1.6327	0.0	.0	.0	2552.5911
1824.0000	3485.9593	1.0000	1.8151	0.0	.0	.0	2452.4008
2006.4000	3399.9315	1.0000	1.9975	0.0	.0	.0	2343.9646
2188.8000	3314.2930	1.0000	2.1799	0.0	.0	.0	2226.0467
2371.2000	3229.0931	1.0000	2.3623	0.0	.0	.0	2097.1778
2553.6000	3141.8760	1.0000	2.5447	0.0	.0	.0	1954.8106
2736.0000	3049.4073	1.0000	2.7271	0.0	.0	.0	1795.0035
2918.4000	2947.8767	1.0000	2.9095	0.0	.0	.0	1611.1232
3100.8000	2827.7228	1.0000	3.0919	0.0	.0	.0	1390.4121
3237.6000	2732.6696	1.0000	3.2287	0.0	.0	.0	1184.0755

TIMES AT WHICH THE INPUT GAS PRODUCTION RATES
WERE NOT POSSIBLE. ALL RATES IN SCF/DAY.

TIME	POSSIBLE	SCHEDULED
3222.400000	.0	.1000000+08
3237.600000	.0	.1000000+08
3241.400000	.0	.1000000+08

Appendix II (continued)

Table D

Third Page Output

TIME (DAYS)	RADIUS OF UNINVADED ZONE (FT)	TOTAL GAS PRODUCED (MMSCF)	GAS FROM GAS WELL (MMSCF)	GAS FROM WATER WELLS (MMSCF)	PRESSURE IN UNINVADED ZONE (PSIA)	GAS TRAPPED IN INVADED ZONE (MMSCF)	RECOVERY (%)	CUMULATIVE WATER PRODUCTION (MMBBL)	TOTAL WATER PROVIDED BY AQUIFER (MMBBL)
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
0.0	3101.4052	0.0	.0	0.0	5000.0000	0.0	0.0	0.0	0.0
182.4000	3088.4065	1824.0000	1824.	0.0	4685.1390	79.5219	5.0752	0.1735	0.3321
364.8000	3052.9749	3648.0000	3648.	0.0	4447.1126	283.7917	10.1503	0.3559	0.9437
547.2000	3005.0905	5472.0000	5472.	0.0	4242.7291	541.5144	15.2255	0.5383	1.6982
729.6000	2947.7613	7296.0000	7296.	0.0	4058.0670	829.2966	20.3006	0.7207	2.5537
912.0000	2882.7983	9120.0000	9120.	0.0	3887.6540	1132.3659	25.3758	0.9831	3.4831
1094.4000	2810.2052	10944.0000	.10940+05	0.0	3722.1772	1446.8104	30.4509	1.0855	4.4806
1276.8000	2730.7513	12768.0000	.12770+05	0.0	3558.9618	1763.4310	35.5261	1.2673	5.5313
1459.2000	2645.2538	14592.0000	.14590+05	0.0	3393.0437	2073.3804	40.6012	1.4503	6.6202
1641.6000	2552.5911	16416.0000	.16420+05	0.0	3222.9102	2377.4777	45.6764	1.6327	7.7525
1824.0000	2452.4008	18240.0000	.18240+05	0.0	3044.9048	2670.1836	50.7515	1.8151	8.9239
2006.4000	2343.9646	20064.0000	.20060+05	0.0	2854.7837	2946.4811	55.8267	1.9975	10.1320
2188.8000	2226.0467	21888.0000	.21890+05	0.0	2645.4047	3199.5132	60.9018	2.1799	11.3772
2371.2000	2097.1778	23712.0000	.23710+05	0.0	2413.6848	3423.7200	65.9770	2.3623	12.6584
2553.6000	1954.8106	25536.0000	.25540+05	0.0	2144.5706	3610.1353	71.0521	2.5447	13.9786
2736.0000	1795.0035	27360.0000	.27360+05	0.0	1820.7488	3735.8013	76.1273	2.7271	15.3428
2918.4000	1611.1232	29184.0000	.29180+05	0.0	1405.1766	3775.3039	81.2024	2.9095	16.7605
3100.8000	1390.4121	31008.0000	.31010+05	0.0	818.1806	3669.4463	86.2776	3.0919	18.2494
3237.6000	1184.0755	32376.0000	.32380+05	0.0	127.0479	3427.6341	90.0839	3.2287	19.4339

Bibliography

1. F.P. Brinkman, Increased Gas Recovery from a Moderate Water Drive Reservoir, SPE Paper #9473, 1980.
2. T.P. Chesney, R.C. Lewis, M.L. Trice, Jr., Enhanced Gas Recovery from a Moderately Strong Water Drive Reservoir, SPE Paper #10117, 1981.
3. EXXON P. Co., EXXON Watered-out Gas Reservoir Project - North Alazan Field, Private Publication.
4. M.P. Finch, J.A. Marek, The Long-range Planning Function as Related to Katy Field Gas Sales, J. Petroleum Technology, (PP145-148) Feb. 1972.
5. E.C. Geer, H.L. Cook, Enhanced Gas Recovery from Geopressured Aquifers, SPE Paper #7541, 1978.
6. E.C. Geer, J.C. Sharer, Unconventional Geopressured Gas Recovery, Economics and Research, 7th Energy Technology Conference, 1977.
7. J.D. Huppler, Scheduling Gas Field Production for Maximum Profit, J. Soc. Pet. Engrs., (PP279-294) June 1974.
8. R. M. McKinley, Wellbore Transmissibility from Afterflow-dominated Pressure Buildup Data, J. Petroleum Technology, (PP863-872) July 1971.
9. G. Matthes, R.F. Jackson, S. Schuler, O.P. Marudiak, Reservoir Evaluation and Deliverability Study, Bierwang Field, West Germany, J. Petroleum Technology, (PP23-300) Jan. 1973.

INFORMATION SYSTEM

Fred M. Wrighton, Linda K. Veal, Ho Chang

Introduction

The Information Systems component of the DOE contract no. DE-AC08-81NV10174, "Technical Support for Geopressured-Geothermal Well Activities in Louisiana" was largely a service function. It was recognized in previous research efforts of the magnitude of the geopressured research activity that a central source of information and management of that information would be beneficial. The project was designed to provide support to faculty investigators and other researchers at LSU in conducting their research. This support has been provided over the contract period (1980-1982); the following sections of this report will describe the activities and computer files developed during the period.

Information Needs Assessment

In-House Resources

Geopressured energy has been a resource of interest to LSU since the mid-1970s; being actively involved in the basic research, a substantial amount of information and data accumulated campus-wide. Through this project an assessment was made of all in-house documents which included a campus-wide search and solicitation of literature and on-going research. Literature found within the project coordination office (Office of Advanced Studies-Energy

Programs Office) was used as a base to develop a traditional research library, along with a compilation of all LSU geopressured-geothermal project literature.

Interviews with researchers and faculty investigators were conducted to assess the information needs of the project staff. The researchers expressed a need for a simple but functional library and cataloging system whereby literature could be retrieved with the minimum of reference information. A review of literature was made of existing subject categories and classification schemes; this review resulted in a compilation of terms associated with the geopressured-geothermal energy resource and the design of a geopressured classification scheme. The classification scheme was originally designed with emphasis on geopressured as the major resource and geothermal as the minor resource. After working with this scheme of subject categories, an indepth review was made of the DOE Energy Information Data Base: Energy Categories (1980). In the second year of research, a refinement of the system was initiated to incorporate the subject categories included in DOE Energy Categories (Geothermal Energy), as listed in Appendix A.

In addition to the need for a traditional type library and a computerized bibliography a need for data files was identified also. The environmental monitoring component produced a substantial amount of data from the DOE Test Well Program in Louisiana. The amount of data required the design and programming of a computer file that could be used by the environmental specialists to analyze the sample data. With these needs specified similar information systems were reviewed to see if any would meet these needs.

Review of Similar Information Systems

The assessment of the information needs of project researchers generated a focus for the design of the information system; a review of similar systems and the management of their respective data bases was conducted to further that design. As a result of this review, three systems were selected for possible implementation to meet the specific requirements identified. Each system and its relevance to the project was investigated and evaluated in terms of end-use and researcher's needs.

Geopressured-Geothermal Information System (GGIS): This system was designed and compiled by the Center for Energy Studies (CES) at the University of Texas at Austin from 1978 through 1980; a three year compilation of citations on geopressured geothermal energy resources for an eighteen year period. The GGIS is an interrelated system of computer files for the maintenance of a data base that contains such data as: (1) a computerized bibliography (2) a geopressure Thesaurus (3) a well-log trace data base (4) a well-log and header data base and software package (5) and a software package for analysis of digitized traces.

The geopressure Thesaurus proved to be the key document in the GGIS for the development of the LSU system, but was not referenced until it was made available to us in our second year of research. The final analysis of the GGIS and its relevance to the LSU system was that all products and services appear to be unique to CES or the activities in the state of Texas with the exception of the Thesaurus and the computerized Bibliography. The Thesaurus is a useful research tool that can be referenced by all researchers, whereas the Bibliography is a file of all existing citations on geopressured energy obtained from a number of databases searched, with the availability of the

document indicated on the file with some available from CES.

Lawrence Berkeley Laboratory-Geothermal Database: The Geothermal Database was developed at the Lawrence Berkeley Laboratory and sponsored by DOE as a component of the National Geothermal Information Resource project. The scope of this project was to provide data and other information for the development and utilization of geothermal energy. This evaluation resulted in the creation of a Geothermal Resource Areas Database (GRAD). GRAD was designed to answer questions about the progress of geothermal energy development and includes such data and subject areas as: names and addresses, leases, area descriptions, geothermal wells, power plants, direct use facilities, and environmental and regulatory aspects of development.

The GRAD system provided some insight into the development and design of the LSU Information System by demonstrating how needs were developed into interactive files and the relevance of all facets of the geothermal resource to the development of an unconventional energy source. These and other concepts were considered and utilized in the design of a Geopressured Geothermal Information Center for the Louisiana well activities research.

Department of Energy/RECON: The DOE/RECON system was reviewed and found to be the most comprehensive search tool available. RECON is an interactive online information retrieval system developed to provide rapid and easy access to energy-related databases produced or obtained by the Technical Information Center (TIC). The system can be accessed through telephone hookups with Teletype-compatible terminals by using the GTE Telenet network or by dialing directly. RECON has approximately thirty (30) files available which are mostly bibliographic in content and can be searched by author, title words, abstract words, report numbers, etc. Project personnel were trained to search RECON and continued interaction with the system lead to the refinement of the

Information Center for Geopressured Geothermal (ICGG). Programming was initiated to make ICGG files accessible on RECON and are presently being evaluated by TIC. (DOE/TIC, 1980 and Kawakami, 1980)

Database Management Software Packages and Hardware

The Information Center for Geopressured Geothermal (ICGG) conducted a review of existing information systems and their associated database management software packages, as well as other packages that would compliment the design of the LSU information systems. As a result of this review, relative information was extracted from the literature and incorporated with an analysis of needs and the design of the ICGG. Software packages were selected in conjunction with the creation, structure and function of data files; these packages and the management of the database are discussed in this and the following sections.

CFAMULUS

The FAMULUS software package was adopted as a programming tool for the the storage and retrieval of bibliographic and directory data . FAMULUS software package provides programming for the 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 is an adaptation of the FAMULUS software modified at LSU as a conversational program for small files. It offers various information retrieval facilities such as indexing, automatic sorting of files into alphabetical order and searching in response to specific

requests. The system is sufficiently general in design to permit various applications, specifically the maintenance of private bibliographies or abstract files.

SAS

This system, the Statistical Analysis System (SAS) is a computer system for data analysis created to organize data by utilizing programming tools that provide for (1) information storage and retrieval (2) data modification and programming (3) report writing (4) statistical analysis and (5) file handling. SAS products can be integrated with the basic system to provide one total system that will produce graphics, statistical tables and statistical analysis. Data values are read in almost any form from cards, disk or tape and are then organized into a SAS data set; which can be combined with other SAS data sets through the file-handling operations.

SAS statements and functions are available for modifying and handling data whereby the system becomes a data base management system. Report writing features offered can be preformatted by utilizing standard SAS procedures or users can design and produce printed reports in any desired form. Statistical analysis procedures range from simple descriptive statistics to complex multivariate techniques. These SAS features offers ICGG statistical analysis procedures to manipulate surface and ground water quality data and climatological data collected at the DOE test well sites in Louisiana.

Hardware

A review of computer hardware was conducted after a needs assessment and design was completed. Factors relevant to the selection of hardware for ICGG were contingent upon the ability to interact with other systems, such as the

LSU computer system and the DOE/RECON system. The LSU system network is supported by an IBM 370/3033 computer with 16 megabytes of memory. The DOE/RECON system is also supported by an IBM 370/3033 at the Oak Ridge National Laboratory (ORNL) by the Computer Sciences Division of Union Carbide Corporation, Nuclear Division.

The IBM 3101 Display Terminal and 3102 Printer were selected as compatible hardware for ICGG and its associated interactive systems because of such standard operating characteristics as:

- o Character or block transmission mode
with multiple interface types
- o Communication interface baud rate:
110 to 9600 bps
- o Support of ASCII code (95 printable
ASCII characters)
- o Prints 80 characters per line, 40
characters per second.
- o Non-impact, serial matrix, thermal printer

ICGG interacts with the LSU system through the time sharing option (TSO) and with the DOE/RECON system through the Telenet data telecommunications network of the GTE Telenet Corporation. Interactive computing is executed through the use of a Bell data set 212A modem capable of transmitting and receiving data at two distinct bit rates over the switched telephone network (300 to 1200 bps).

Description of Data Files

The information system is comprised of three data files: (1) Geopressed-geothermal bibliography (GTGPLIB), (2) Researchers' Directory (GEORED), and (3) Environmental well data and analysis (GEOWAT), each are accessible on-line as datasets. Each data file is managed by one of the two software packages previously discussed; access to these files are described in the user's guide file and Appendices B (CFAMULUS) and C(SAS). These files are each a collection of related records consisting of bibliographic, numeric, textual and directory data. A basic unit of information is a record or citation; data is stored in this format and organized for sorting by field or element. Data elements are categories of information within a record; each data file has a unique set of elements by which records are manipulated and retrieved.

Data files created for the ICGG database are outlined here to show the design and structure of the system.

I. Bibliography Data File

Dataset Name: GTGPLIB

Source: Information Center for Geopressed Geothermal
Center for Energy Studies
Louisiana State University
Baton Rouge, LA 70803

Description: The bibliographic file contains all literature housed at LSU in a special collection of the geopressed resource in the Gulf Coast Region. This includes relevant conference literature, LSU geopressed research, unclassified technical reports, journal articles, monographs and other publications.

Subject Coverage:

- o Resource Assessment
- o Geologic Studies
- o Legal and Institutional Aspects
- o Economic Studies
- o Environmental Impacts
- o Fluid Disposal, Surface and Subsurface
- o Proposals and Research Programs
- o Drilling and Completion Technology
- o Gas Processing
- o Geothermal Research and Thermal Applications
- o State and Federal Regulations
- o Well Testing
- o Water Chemistry and Geochemistry
- o Design Wells
- o Wells of Opportunity
- o Watered-Out Gas Reservoirs

Size: 300 citations

Software: CFAMULUS

Example Citations: GTGPLIB

SUBJ RESERVOIR ENGINEERING/RESERVOIR MECHANICS, GEOLOGIC STUDIES
TITL THE FLOW OF GAS-LIQUID MIXTURES THROUGH UNCONSOLIDATED SANDS
AUTH WYCKOFF, R.D. AND H.G. BOTSET
PUBL TAKEN FROM PHYSICS, VOLUME 7. SEPT. 1936, GULF RESEARCH AND DEVELOPMENT, J
ULY, 1936
NOTE 20P.: TABLES
NMBR 622, WYC

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, GRA
PHS. LOGS, TABLES SYMBOLS AND SELECTED REFERENCES
NMBR 623, H10

SUBJ GEOLOGIC STUDIES, RESOURCE ASSESSMENT
TITL FRIO SANDSTONE RESERVOIRS IN THE DEEP SUBSURFACE ALONG THE TEXAS GULF COAST
: THEIR POTENTIAL FOR PRODCUTION OF GEOPRESSURED-GEOPRESSURED ENERGY
AUTH BEBOUT, D. G., R.G. LOUCKS, AND A.R. GREGORY
PUBL BUREAU OF ECONOMIC GEOLOGY, UNIVERSITY OF TEXAS AT AUSTIN, AUSTIN, TEXAS,
1978
NOTE REPORT OF INVESTIGATIONS NO. 91., 5, 93P.: FIGURES 106, TABLES
NMBR 624, BE

SUBJ DEVELOPMENT STRATEGY, RESOURCE ASSESSMENT
TITL OPERATIONS RESEARCH AND SYSTEMS ANALYSIS OF GEOPRESSURED-GEOTHERMAL ENERGY
IN LOUISIANA - FINAL REPORT, JUNE 1, 1978 - AUGUST 31, 1979
AUTH JOHNSON, ADRAIN, E....ET AL
PUBL DEPT. OF NATURAL RESOURCE, STATE OF LOUISIANA, BATON ROUGE, LA., 1979
NOTE HDOE/ET/27085-1, 4, 289P.: TABLES, FIGURES
NMBR 662, JOH

SUBJ DEVELOPMENT STRATEGY, RESOURCE ASSESSMENT
TITL OPERATIONS RESEARCH AND SYSTEMS ANALYSIS OF GEOPRESSURED/GEOTHERMAL RESOU
RCES IN TEXAS - FINAL REPORT
AUTH LESSO, WILLIAM G....ET AL
PUBL CENTER FOR ENERGY STUDIES, UNIVERSITY OF TEXAS AT AUSTIN, AUSTIN, JANUARY
1980
NOTE 3, 104P.: TABLES, FIGURES
NMBR 662, LES

II. Geopressured Researchers Directory File

Dataset Name: GEORED

Source: Information Center for Geopressured Geothermal
Center for Energy Studies
Louisiana State University
Baton Rouge, LA 70803

Description: GEORED is a data file of active geopressured researchers along with their address, affiliation, phone number and area of expertise or research. Entries were extracted from conference proceedings, professional contacts, mailing list and solicitations. This file functions as a quick reference source for technical support of Geopressured well activities.

Subject Coverage: This data file is a compilation of active researchers and experts in the field or study of the geopressured resource. Their areas of expertise coincides with subject categories referenced in the bibliographic file. (see app. A for subject categories)

Size: 174 records

Software: CFAMULUS

Example Record: GEORED

RESEARCHER DIRECTORY

- 1 NAME AGNEW, JAMES D.
TITL SENIOR STAFF SEISMOLOGIST
AFIL WOODWARD-CLYDE CONSULTANTS
ADDR 2822 O'NEAL LN, P.O. BOX 66317, BATON ROUGE, LA 70896
EXPT INSTALLMENT AND MANAGEMENT OF SEISMOGRAPHS
PHON (504) 291-1873
- 2 NAME ALEXANDER, J.H.
AFIL SYSTEMS, SCIENCE & SOFTWARE
ADDR P.O. BOX 1620, LA JOLLA, CA 92038
PHON (714) 453-0060
- 3 NAME ANDERSON, A. E.
TITL ASSISTANT MANAGER - OPERATIONS
AFIL CONOCO, INC.
ADDR P.O. BOX 53041, LAFAYETTE, LA 70505
PHON (318) 237-3900
- 4 NAME ANGIN, MEREDITH JOAN
TITL PROJECT MANAGER
AFIL ELECTRIC POWER RESEARCH INSTITUTE
ADDR 3412 HILLVIEW AVENUE, P.O. BOX 10412, PALO ALTO, CA 94306
PHON (415) 855-2594
- 5 NAME ASHMAN, T.R.
AFIL CENTER FOR EARTH SCIENCES AND ENGINEERING, UNIV OF TEXAS AT AUSTIN
ADDR 10100 FURNETT RD. BUILDING 17, AUSTIN, TX 78758
EXPT COMPACTION MEASUREMENTS
PHON (512) 471-3434
- 6 NAME AUSTIN, CARL
TITL DEVELOPMENT ENGINEER
AFIL HALLIBURTON SERVICES
ADDR P.O. BOX 1431, CRO, DUNCAN, OK 73536
PHON (405) 251-3760
- 7 NAME BACHMAN, ANN
AFIL PETROLEUM TRAINING SERVICE, UNIVERSITY OF SOUTHWESTERN LOUISIANA
ADDR P.O. BOX 42411, LAFAYETTE, LA 70504
PHON (318) 231-6232
- 8 NAME BASSIOCHI, ZAKI
TITL ASSOCIATE PROFESSOR PETROLEUM ENGINEERING
AFIL PETROLEUM ENGINEERING DEPT., LOUISIANA STATE UNIV.
ADDR 3526 CIBA LOUISIANA STATE UNIV., BATON ROUGE, LA 70803
PHON (504) 388-5215
- 9 NAME BAYLISS, GEOFFREY S.
AFIL GEOCHEM LABORATORIES - HOUSTON
ADDR 1143 BRITTONS, HOUSTON, TX
EXPT ORGANIC CHEMISTRY
PHON (713) 467-7011

III. Water Quality and Climatological Data File

Dataset Name: GEOWAT

Source: Information Center For Geopressed Geothermal
Louisiana Geological Survey
Louisiana State University
Baton Rouge, LA 70803

Description and Subject Coverage: In support of environmental monitoring of the DOE Louisiana test well sites, GEOWAT was created to store and analyze sample observations of water quality sampling stations and climatological data. The file is a partitioned data set with each partition or member containing monthly observations from a water quality sampling station at a test well site. There are 18 members that contain 36 variables per record for the test well sites: Gladys McCall, Sweet Lake, and Parc Perdue. Other members are created from the climatological data and contains such variables as: precipitation, temperature, sample dates and times. Examples of GEOWAT are illustrated in Appendix D.

Size: 352 records

Software: SAS

Acquisition and Maintenance of Material

The ICGG maintains a collection of materials and literature that is representative of the geopressured resource but not exhaustive. Literature in this collection has been obtained from many different sources and thus established an unconventional method for acquisition and maintenance. Initially, a small collection existed from previous research projects; this collection was cataloged and shelved using the revised Dewey Classification Scheme. Acquisition of materials continued through various methods and procedures, such as:

- 1) Government Publications: some documents were ordered as requested, others were received on a timely basis via a mailing list. Many of these kinds of documents were donated from personal collections, the State library and the University library.
- 2) Journal and Magazine Articles: these materials were clipped as needed or were retrieved from various research leads. Articles were secured as needed from a leads file or through a computerized search.
- 3) Books and Monographs: acquisition of such were made by special request only and donations.
- 4) Microfilm and Fiche: these materials were not maintained in the collection because of the governmental depository maintained by the university library.

Maintenance of such documents included the cataloging and shelving or housing of materials, as well as data entry into the bibliographic data file. Geopressured literature (600's) was cataloged by a project staff member, at

this point subject categories were assigned as well as call numbers.

Documents were then physically prepared for shelving (i.e. book pockets, cards, accession numbers, card number, etc.) by student workers. Book preparation was supervised by the project staff as well as entry cards for the card catalog.

Cataloging procedures were established and student workers were trained and supervised to carry out a portion of this task (lettering of books and the typing of entry cards) as described in Appendix E. The preparation of catalog cards was initiated by a project member and completed by student workers. In the process of preparing books for the shelves, cards were made for both the card catalog and the shelf list. The shelf list is a record of all documents in the collection, arranged in the order of the books on the shelves. The card catalog utilized by the ICGG consists of three entry cards excluding the shelf list, arranged in alphabetical order by author (main entry card), title and subject (secondary entries). Citation formats for the bibliographic file were extracted from the shelf list cards as well as data for entry into the dataset, GTGPLIB.

Data compiled for entry in the computer files coincided with the emphasis and demand of the project as a unit, thereby establishing a diverse update procedure for each data file. The bibliographic file (GTGPLIB) is updated monthly via new documents accessed into the shelf list card file. As new cards are created for the shelf list file, copies are made for data entry and filed for entry by graduate students. The card file is maintained by student workers and the computerized file by graduate students that program and maintain all data files. Initially, the researchers' directory file (GEORED) was compiled through mail solicitations of known geopressured researchers and

organizations. This effort created our basic mailing list which was further expanded and developed. GEORED was updated monthly and reviewed for changes occurring in the industry, such as the affiliation of researchers and areas of research. The water quality and climatological file (GEOWAT) was updated on a monthly basis as well. Data was collected from three well sites at a number of locations by private laboratories (Kemron and Petroleum Labs., 1980-1982) and submitted to LSU for storage and analysis. Climatological data was extracted and compiled from the Louisiana Climatological Reports (1980-1982) by the environmental monitoring staff and submitted for data entry.

Other Activities and Disposition of Computer Files

There were other activities supported under this component beyond the information systems effort per se. The technoeconomic site simulation model has been maintained by the ICGG and modifications to the reservoir simulation component of the model are described in the chapter of this report entitled, "Systems Analysis and Scientific Support". Generic economic studies were conducted, two of which can be found in the proceedings of the Fifth Geopressed-Geothermal Energy Conference held at LSU (Johnson, Abdulraham, Wrighton, 1981 and Wrighton, 1981). A third study entitled "Drilling Costs by Depth: The Past and The Future in South Louisiana (Wrighton, 1981) has been produced as a working paper and has not been published. The results of this study were utilized to incorporate a subroutine in the technoeconomic site simulation to estimate the cost of drilling production wells and disposal wells for a

geopressured energy development. The computer files developed during the course of this project will be maintained or integrated as a subfile in other systems. The water quality file, GEOWAT, has been transmitted to the Louisiana Geological Survey, Survey personnel have been trained to use it and it will be utilized and updated in the continuation of the Environmental Monitoring activities during FY-83. The bibliographic file, GTGPLIB, has been reprogrammed to meet the format specifications of the U.S. Technical Information Center (TIC) for inclusion in the energy information collection (Kawakami, 1980). TIC will review the data file and may include, GTGPLIB, in their Energy Information DataBase system so that it will be available for future users. At the Center for Energy Studies (CES), this file will become the geopressured sub-part of a larger energy bibliographic file. The geopressured researcher's directory file, GEORED, will be incorporated as a subcomponent of the CES energy researcher's directory file. The products of the work conducted within the information systems component of the geopressured contract at LSU will continue to be available to researchers in the geopressured area through the Center for Energy Studies and the Louisiana Geological Survey.

References

- Bebout, D. G., Z. Bassiouni, F. M. Wrighton, et al, 1982, Technical Support for Geopressured Geothermal Well Activities in Louisiana, Annual Report; DOE/NV/10174: Baton Rouge, Louisiana Geological Survey, Louisiana State University, 305 p.
- Bost, David E., ed, 1980, Energy Information Database, Energy Categories; DOE/TIC-4584-R4: Oak Ridge, Tennessee, United States Department of Energy, Technical Information Center, 65 p.
- Burden and Yerkic, 1969, FAMULUS Software Package; Berkeley, California, United States Forest Service, Pacific Southwest Forest and Range Experiment Station.
- Coyne, J. G. and Nancy E. Hardin, 1981, Energy Data Base, DOE/RECON User's Manual; DOE/TIC-4586-R1: Oak Ridge, Tennessee, United States Department of Energy, Technical Information Center.
- Department of Energy, Technical Information Center, 1980, Energy Information Database: DECOL Manual (Descriptive Cataloging On-Line); DOE/TIC-4602: Oak Ridge, Tennessee, United States Department of Energy, Technical Information Center, 247 p.
- Geopressured-Geothermal Information System (GGIS), 1981, Geothermal Studies, in Jennifer Evans, ed., Energy Studies Newsletter, Vol. 6, No. 5, May/June 1981: Austin, Texas, Center for Energy Studies, University of Texas at Austin, p. 4-5.
- Helwig, Jane T., 1978, SAS (Statistical Analysis System) Introductory Guide; Cary North Carolina, SAS Institute Inc., p. 83.
- Hill, Thomas K. and Kamy Sepehrnoori, 1981, Geopressured Geothermal Bibliography, Volume I, Citation Extracts; DOE/ET/27018-1: Austin, Texas, Geopressured Geothermal Information System, Center for Energy Studies, University of Texas at Austin, p. 815.
- Johnson, Adrian, A. Abdulraham, and Fred Wrighton, 1981, Economic Evaluation of the Pleasant Bayou Design Well and other Geopressure Prospects and Regions, in D. Bebout and A. L. Bachman, eds., Proceedings of the Fifth Conference-Geopressured Geothermal Energy, U.S. Gulf Coast: Baton Rouge, Louisiana, Louisiana Geological Survey, Louisiana State University, October 13-15, 1981, p. 109-110.
- Kawakami, Noboru, ed., 1980, DOE Energy Information Data Base, Magnetic Tape Description; DOE/TIC-4581-R4: Oak Ridge, Tennessee, DOE, Technical Information Center.
- Kemron Environmental Services, 1980-1982, Monthly Surface and Ground Water Analysis, Sweet Lake and Gladys McCall Test Well Sites; Baton Rouge, Louisiana, Kemron Environmental Laboratory.

Lawrence, J. D., Keith Leung, and Winifred Yen, 1981, A User's Guide to the Geothermal Resource Areas Database; LBL-11492: Berkeley, California, National Geothermal Information Resource, Lawrence Berkeley Laboratory, University of California, p. 61.

National Climatic Center, 1980-1982, Climatological Data: Louisiana, Monthly Issues, Parc Perdue, Sweet Lake and Gladys McCall Test Well Sites; Asheville, North Carolina, Department of Commerce.

Petroleum Laboratories, Inc., 1980-1982, Monthly Surface and Ground Water Analysis, Parc Perdue Test Well Site; Lafayette, Louisiana, Petroleum Labs.

Ray, Alice Allen, ed., 1982, SAS User's Guide: Basics; Cary, North Carolina, SAS Institute Inc., P. 923.

Wrighton, Fred M., 1981, An Economic Overview of Geopressured Solution Gas, in D. Bebout and A. L. Bachman, eds., Proceeding of the Fifth Conference-Geopressured Geothermal Energy, U.S. Gulf Coast: Baton Rouge, Louisiana Geological Survey, Louisiana State University, October 13-15, 1981, p. 45-48.

_____, 1981, Drilling Cost by Depth: The Past and the Future in South Louisiana (working paper); unpublished paper supported by DOE Contract #DE-AC08-81NV10174: Baton Rouge, Louisiana, Energy Programs Office (Center for Energy Studies) Louisiana State University.

Appendices

Information Systems Component

Information Center for Geopressured Geothermal

- A. Revised Subject Categories with DOE Energy Categories.
- B. Adaptation of FAMULUS User's Guide Information Storage and Retrieval with CFAMULUS, Data Sets: GTGPLIB and GEORED.
- C. User's Guide for the Information Center for Geopressured Geothermal Database, Data Set: GEOWAT.
- D. Examples of GEOWAT.
- E. Cataloging Procedures.

APPENDIX A

Revised Subject Categories with DOE Energy Categories

APPENDIX A

ICGG Subject Categories (Revised)

INFORMATION CATEGORIES: GEOPRESSURED

BIBLIOGRAPHY AND GEOPRESSURED

RESEARCH FILES

- 601 - Bibliographies
- 676 - Design Wells
- 662 - Development Strategy
- 635 - Dispersed Gas
- 670 - Drilling and Completion Technology/Well Testing
- 650 - Economic Studies
- 674 - Enhanced Gas Recovery
- 663 - Environmental Impacts
- 605 - Federal Regulation
- 611 - Fluid Disposal-Subsurface
- 612 - Fluid Disposal-Surface
- 634 - Gas Processing
- 624 - Geologic Studies
- 623 - Geophysical Techniques
- 690 - Geothermal Research
- 661 - Legal/Institutional
- 642 - Patents
- 695 - Power Generation
- 602 - Proposals
- 671 - Pump Technology
- 600 - Reference
- 603 - Research Programs
- 622 - Reservoir Engineering/Reservoir Mechanics
- 621 - Reservoir Properties/Gas Content
- 620 - Resource Assessment
- 673 - Scaling/Corrosion/Materials
- 651 - Socioeconomic Impacts
- 606 - State Regulation
- 631 - Subsidence/Seismicity
- 696 - Thermal Applications
- 632 - Water Chemistry/Geochemistry
- 677 - Water-Out Gas Reservoirs
- 675 - Wells of Opportunity

Revised Subject Categories with
DOE Energy Categories

<u>ICGG Call Nos.</u>	<u>Subject Categories</u>	<u>DOE Category Nos.</u>
600	Reference	150000
601	Bibliographies	150001
602	Proposals	150002
603	Research Programs	150003
620	Resource Assessment	150100
	USA	150101
	Non-USA	150102
624	Geologic Studies	150200
	USA	150201
	Non-USA	150202
	Exploration and Exploration Technology	150300
623	Geophysical Techniques	150301
632	Water Chemistry/Geochemistry	150302
	Exploratory Drilling and Well Logging	150303
675	Wells of Opportunity	150304
676	Design Wells	150305
677	Watered-Out Gas Reservoirs	150306
661	Legal and Institutional	150400
605	Federal Regulations	150401
606	Louisiana (state) Regulations	150402
642	Patents	150405
655	SocioEconomic Impacts	150407

650	Economic Studies and (Financial Aspects)	150500
	Environmental Aspect and Waste Disposal	
663	Environmental Impacts	150600
611	Fluid Disposal, Subsurface	150601
612	Fluid Disposal, Surface	150602
631	Subsidence/Seismicity	150605
695	Power Generation (Geopressured and Geothermal)	150800
	Geothermal Engineering	150900
670	Drilling and Completion Technology/Well Testing	150901
671	Pump Technology	150901
634	Gas Processing (Fluid Transmission)	150902
673	Corrosion, Scaling, Materials	150903
622	Reservoir Engineering/Reservoir Mechanics	150904
674	Enhanced Gas Recovery (hydraulic fracturing, reservoir stimulation, extraction technology)	150906
696	Thermal Applications (Direct Energy Utilization)	151000
690	Geothermal Research (Geothermal Data and Theory)	152000
622	Development Strategy- Geopressured	152100
621	Reservoir Properties/Gas Content (Properties of Aqueous Solutions)	152101
635	Dispersed Gas (Rock-Water-Gas interactors, gas scattered throughout a reservoir)	152103

APPENDIX B

**Adaptation of FAMULUS and CFAMULUS User's Manual
by the Information Center for Geopressed Geothermal**

**Information Storage and Retrieval
for the Data Sets: GTGPLIB (Bibliography)
GEORED (Directory)**

TECHNICAL SUPPORT FOR GEOPRESSURED GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

INFORMATION SYSTEM COMPONENT

Information Center for Geopressured Geothermal

Adaptation of FAMULUS and CFAMULUS

User's Manual by The Information Center for
Geopressured Geothermal: Information Storage
and Retrieval for the Data Sets:

'EPWRIG.GTGPLIB' (Bibliography)

'EPWRIG.GEORED' (Directory)

July 1981
Revised June 1982

Prepared By: Ho Chang, Graduate Assistant
Linda K. Veal, Research Associate
Center for Energy Studies
Louisiana Geological Survey
Louisiana State University
Baton Rouge, Louisiana 70803

Table of Contents

1. Introduction	
2. File Organization	
3. Basic Operations and Information Storage	
4. Data Format	
5. Creating an Original FAMULUS File	
6. Information Retrieval in CFAMULUS	

1. Introduction

The Information Center for Geopressured Geothermal (ICGG) adopted the FAMULUS (CFAMULUS) software package as a programming tool for the storage and retrieval of bibliographic and directory data. FAMULUS provides programming for the 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 was adapted at LSU by Dr. Norm Howden, LSU, School of Library Science and Wetlands Resources, as a conversational program for small files. It 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 software's ability to collate and extract information, CFAMULUS can also be applied as a tool for research upon the data which it stores.

2. File Organization

A complete collection of information is held by FAMULUS on magnetic tape or disk and can be referred to as a file, or a data set. A file consists of an unlimited number of records or citations; a record or citation is a basic unit of information and 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 characters in length.

Every record in a file must have the same field structure, but every field need not be a part of every record (a field is the unit of information used to sort the file). Fields for data sets "EPWRIG. GTGPLIB" and 'EPWRIG. GEORED' are illustrated below:

2.1 Bibliographic File

Data set 'EPWRIG. GTGPLIB' is subdivided into six (6) fields:

1. SUBJ (subject)	4. PUBL (publisher)
2. TITL (title)	5. NOTE (note)
3. AUTH (author)	6. NMBR (number)

2.2 Researchers Directory

Data set 'EPWRIG. GEORED' is subdivided into six (6) fields:

1. NAME (name)	4. ADDR (address)
2. TITL (title)	5. EXPT (expertise)
3. AFIL (affiliation)	6. PHON (phone)

Field labels, as listed above, may be up to four characters in length, and must begin with an alphabetic character; the remaining characters must be either alphabetic or numeric. Lower case characters and special characters such as punctuations are not used.

3. Basic Operations and Information Storage

FAMULUS consists of a number of programs which perform the basic operations of the system; these operations can be classified into three main areas (1) data management (2) file manipulation and (3) information retrieval. Data is entered directly into a disk file while in the EDIT mode (EDIT creates an original file or revises the data and/or format of an existing FAMULUS file).

The EDIT program accepts data and creates a file on magnetic tape or disk; within the FAMULUS system, these files are referred to as internal files and is the form in which data is generally stored and processed. A second data management function of the EDIT program utilized by ICGG is to make additions, deletions and amendments to internal files.

Records are entered and stored in the bibliographic and directory files in random order. Manipulation of these files can be achieved through the SORT program, which creates a new file in proper alphabetical sequence on any given field. The SORT program rearranges the file according to a collating sequence as defined in the "FAMULUS User's Manual", Burden and Yerkic, 1969, using any field or combination of fields as the sort key. Another file manipulation function is the MERGE program; it combines two compatible files which have been previously sorted on the same field into a single file in correct alphabetical order. These programs of file manipulation allows retrieval of data from the GTGPLIB and GEORED data sets in any given field or combination of fields.

FAMULUS provides various methods of retrieving information from created data files, from these files retrieval can be comprehensive or selective. A comprehensive listing of all records in a file can be produced by executing the GALLEY program (GALLEY prints a FAMULUS file in one of two formats; standard or print by fields format). Used in conjunction with the SORT program, GALLEY can print separate author, title, or classified catalogs of bibliographic files. The KWIC program produces a Key Word In Context (KWIC) listing of selected fields of records in a file, it can generate an index of a FAMULUS file printing an alphabetical list of field contents.

The SEARCH program is another method of retrieval utilized by the ICGG information system to perform on-line searching of the contents of its FAMULUS/CFAMULUS file. As the basic method of retrieval from the bibliographic file (GTGPLIB) and the directory file (GEORED), the SEARCH program allows the user to retrieve specific items of information from a file according to a search formula constructed using Boolean logic. This capability is included to allow the user instant and accurate responses to specific queries. The SEARCH function or CSEARCH for "Conversational" SEARCH, searches a file for citations which satisfy a user-written search formula. CSEARCH and the application of this function within the ICGG information system is described in Section 6 of this manual.

4. Data Format

FAMULUS files 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 data into card format, since the EDIT program expects the input to be in card format. The ICGG information system utilizes the card format for data entry into the GTGPLIB and GEORED data sets.

Card Format

Field labels are entered in columns 1-4 of the first card in a field. Continuous cards for the field do 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, data entry begins in either column 6 or 7. If the last word of the preceding card ended in column 80, one blank is needed to

separate two words; therefore, begin in column 7. If the word is broken in the middle, or if column 80 is blank separating 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 entered 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 label is not required.

Each record is followed by a blank card which separates it from the next record. If the blank card is left out, the second record will 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 the bibliographic file and directory file 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. pleasant 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
```

```
READY
edit 'epwrig. geored' da nonum
EDIT
i
INPUT
name agnew, james d.
titl senior staff seismologist
afil woodward-clyde consultants
addr 2822 o'neal ln, p.o. box 66317, baton rouge, la 70896
expt installment and management of seismographs
phon (504) 291-1873
```

5. Creating an Original FAMULUS File

The input files 'EPWRIG.GTGPLIB' or 'EPWRIG.GEORED' must be transformed 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 HARDCOPY LISTING OF THE FAMULUS FILE?

n

DO YOU WANT A VOCABULARY LIST?

n

READY

6. Information Retrieval in CFAMULUS (C: conversational).

The CFAMULUS program providing for interactive searching is named CSEARCH. This program provides the following general categories of services:

- (1) printing of specified fields of specified citations,
- (2) indexing in specified fields single words by citation and field,
- (3) input and correction of queries, and
- (4) searching of specified fields for citations satisfying a query containing logical operators.

When execution of the CSEARCH program begins, the FAMULUS id of the file will be displayed as will the number of citations in the file and the field labels used. Then a "?" will be displayed; indicating that the program is awaiting the entry of a command from the terminal. After each command is entered, the program will respond and then await the next command. It should be noted that CSEARCH recognizes lower case and upper case alphabetic input received from the terminal. Thus CSEARCH commands may be entered in any combination of upper and lower case letters desired: these will be converted to upper case; search formulas, however, will not be converted and care must be taken when constructing the formula.

All commands accepted by CSEARCH begin with the command name abbreviation. If more information is required, it will be included within parentheses after the command name abbreviation.

CSEARCH Commands.

- a) id Identification - the file identification will be displayed.
- b) f Fields - the field labels used in the file will be displayed.
- c) # no. of citations - the number of citations in the file will be displayed.
- d) pf (fldlist) Print Fields - This command specifies the fields that are to be displayed by the CSEARCH program in response to any request to display one or more citations. The fields to be displayed are those in the

6. Information Retrieval in CFAMULUS (C: conversational).

The CFAMULUS program providing for interactive searching is named CSEARCH. This program provides the following general categories of services:

- (1) printing of specified fields of specified citations,
- (2) indexing in specified fields single words by citation and field,
- (3) input and correction of queries, and
- (4) searching of specified fields for citations satisfying a query containing logical operators.

When execution of the CSEARCH program begins, the FAMULUS id of the file will be displayed as will the number of citations in the file and the field labels used. Then a "?" will be displayed; indicating that the program is awaiting the entry of a command from the terminal. After each command is entered, the program will respond and then await the next command. It should be noted that CSEARCH recognizes lower case and upper case alphabetic input received from the terminal. Thus CSEARCH commands may be entered in any combination of upper and lower case letters desired: these will be converted to upper case; search formulas, however, will not be converted and care must be taken when constructing the formula.

All commands accepted by CSEARCH begin with the command name abbreviation. If more information is required, it will be included within parentheses after the command name abbreviation.

CSEARCH Commands.

- a) id Identification - the file identification will be displayed.
- b) f Fields - the field labels used in the file will be displayed.
- c) # no. of citations - the number of citations in the file will be displayed.
- d) pf (fldlist) Print Fields - This command specifies the fields that are to be displayed by the CSEARCH program in response to any request to display one or more citations. The fields to be displayed are those in the

fldlist which must be a list of one or more valid field labels separated by spaces. Any request to print a citation before a pf command has been entered will result in the display of all fields present in a citation. This command may be entered as often as desired; each new command invalidate the preceding pf command. CSEARCH will accept pf () as being equivalent to a pf command in which fldlist contains all the field labels in the file.

- e) pf Print Fields - CSEARCH lists the fields it will display in response to any request to print a citation.
- f) pc(citlist) Print Citations - This command causes the citations specified in citlist to be displayed. For each citation to be displayed only those fields specified as print fields by the pf command will be listed. An entry in citlist may be either a single number or a range of numbers. A range is indicated by separating the numbers by a hyphen. All numbers appearing in citlist must be between one and the number of citations in the file, inclusive. Also, in any range specification the first number must be less than or equal to the second number. If there is more than one entry in citlist the entries must be separated by spaces. The citations to be displayed are those whose numbers appear in citlist or whose numbers fall between the two numbers in a range specification in citlist. Regardless of the order of the citation numbers in citlist. CSEARCH lists them in increasing order by citation numbers.
- g) sf(fldlist) Search Fields - This command specifies the fields that are to be searched by CSEARCH in response to any command requiring a search of the file. The fields to be searched are those in fldlist which must be a list of one or more valid field labels separated by spaces. Any command requiring a search before an sf command has been entered will result in a search of all fields. This command may be entered as often as desired; each new command invalidates the preceding sf command. CSEARCH will accept sf() as being equivalent to an sf command in which fldlist contains all field labels used in the field.
- h) sf Search Fields? - CSEARCH will list the fields it will search in response to any command requiring a search of the file.
- i) v(wd) Verify - this command requests that CSEARCH check the file for occurrences of wd in the fields specified by the sf command. Its response will be to display wd and the number of citations in which wd occurs in at least one of the search fields. The argument wd is presumed to be a word, but in fact it can be any string of no more than 40 characters containing no spaces or

right parentheses. CSEARCH will accept v() as equivalent to v(wd) where wd is the last entry CSEARCH located in the index; other commands causing an index search are lf, lc, ic, if, s, and e. Instead of displaying the number of citations in which wd occurs in a search field, CSEARCH lists those search fields in which wd occurs in at least one citation in the file.

- j) lc(wd) Locate Citations - This command is the same as v(wd) except that instead of displaying the number of citations in which wd occurs in a search field, CSEARCH lists the numbers of the citations in which it occurs in at least one of the search fields.
- k) if(wd) Index by Fields - This command is the same as v(wd) except that instead of displaying the number of citations in which wd occurs in a search field, CSEARCH lists each search field which contains it in some citation and displays after each such label the numbers of the citations containing wd in that field.
- l) ic(wd) Index by Citation Numbers - This command is the same as v(wd) except that instead of displaying the number of citations in which wd occurs in a search field, CSEARCH lists the number of each citation containing wd in some search fields containing it in that citation.
- m) Edit - (see the description of the s command.)
- n) s Search - The search and edit commands both initiate a search of the file. This process is performed in two steps. First, CSEARCH allows the entry of the query and when that is complete, the search is performed for that query. The only difference between the s and e commands is that an s command implies that a new query is to be entered while an e command implies that the query used in the last search is to be modified and used again. The response to an s command is to initiate the CSEARCH input mode and the response to an e command is to initiate the CSEARCH edit mode; these modes are described below.
- o) cn Citation Numbers? - After a search has been performed using an s or an e command, the number of citations satisfying the search will be displayed.
- p) ph Print Hits - After a search has been performed by an s or an e command, a ph command will cause all citations satisfying the query to be displayed. Only those fields as specified by the pf command will be displayed.
- q) End - This command causes CSEARCH to terminate execution.

Query Format. A query may contain the following elements:

- (1) words,
- (2) logical and operators (ϵ),

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- (3) logical or operators ($/$),
- (4) logical not operators ($_$),
- (5) left-right parentheses pairs,
- (6) spaces,
- (7) (+) the plus sign at the end of a string allows a stem search.

A "word" is any non-empty string of characters delimited by any two of the following characters: $;$, $:$, ϵ , $/$, $_$, $(,)$, or space. If a word exceeds 40 characters, it will be truncated on the right to 40 characters and a message will be displayed. A "phrase" is two or more words separated only by spaces. Each query must form a valid logical expression with words and phrases as operands, logical and logical or as binary operators, and logical not as a unary operator. Left/ right parentheses pairs may be inserted anywhere that the contained portion of the query is still a valid logical expression. The only required use of spaces is to separate the words of a phrase. Conversely the only position in which spaces are prohibited is within a word. CSEARCH considers any string of two or more consecutive spaces to be equivalent to one space.

In evaluating a logical expression, logical not has the highest priority, then logical and, and finally logical or. If this priority of operations does not yield the desired query, parentheses may be used to change the order of operations performed since any expression within parentheses is evaluated independently of that portion of the query outside the parentheses.

Input Mode

CSEARCH retains a query in 80 character "lines". The maximum number of lines a query can occupy is 32767; however, since storage is obtained dynamically for the lines, a lower limit will be determined by available memory. The query is scanned for elements a line at a time with CSEARCH adding one space to the end of each line; thus no word may be split between two lines. The lines held in memory are numbered consecutively from one by ones. These line numbers are not attached to specific lines however; an insertion or deletion of a line will cause all subsequent lines to be renumbered. These line numbers are not part of the query but are available for reference to specific lines by edit mode subcommands.

The input mode is entered as a result of an s command or by transfer from the edit mode (see below). When CSEARCH is in the input mode, it will display the line number which will be assigned to the next line of the query that is entered; this will be followed by a "?" and then CSEARCH will wait for the entry of a line at the terminal. If 1 to 80 characters are entered, these will be assumed to be the next line of the query and CSEARCH will respond with the number of the next line followed by a "?". If more than 80 characters are entered, CSEARCH will retain only the first 80 characters as the next line of the query; a message and the line retained will be displayed and then CSEARCH enters the edit mode. If a null line is entered, CSEARCH enters the edit mode.

Edit Mode. The EDIT mode allows for verification and correction of the lines currently being retained as the query. When CSEARCH is in the EDIT mode, it displays "e?" and waits for a subcommand. One possible subcommand is to enter a null line; this will be accepted as a command to return to input mode to add lines after the last line currently held.

The format of the EDIT mode subcommands is different from the format of the CSEARCH commands. Each subcommand still begins with a subcommand abbreviation; but if any options are required, they follow the abbreviation with spaces as separators. In the description of the edit subcommands given below, ln#1 and ln#2 represent line numbers. If both ln#1 and ln#2 are specified in one subcommand, then ln#1 must be less than or equal to ln#2. Note that the d and i subcommands can cause renumbering of some lines if they cause deletion or insertion of lines before the last line currently held.

Edit Mode Subcommands.

- a) l List - All lines currently being retained are displayed.
- b) l ln#1 List - The single line with line number ln#1 is displayed.
- c) l ln#1 ln#2 List - All lines starting with the line having number ln#1 through the last line having a line number less than or equal to ln#2 are displayed.
- d) d Delete - All lines currently held are deleted.
- e) d ln#1 Delete - The single line with line number ln#1 is deleted.
- f) d ln#1 ln#2 Delete - All lines starting with the line having number ln#1 through the last line having a line number less than or equal to ln#2 are deleted.
- g) i Input - CSEARCH returns to input mode to all lines after the last line currently held. (This is equivalent to entering a null line.)
- h) i ln#1 Input - CSEARCH returns to input mode to begin inserting lines after the line with line number ln#1. If ln#1 is zero, the lines entered in INPUT mode will be inserted before the first line held when this command was given.
- i) c qstr1 qstr2 Change - In this and all subsequent change subcommands, qstr1 and qstr2 are quoted strings (PL/I character string constants). This subcommand requests that the first occurrence of qstr1 in any line being retained should be replaced by qstr2. The

response to this subcommand and all change subcommands described below is the same. If any line is altered, the resulting line will be displayed if a change results in the new line being longer than 80 characters, only the first 80 characters will be retained; in this case a message will be displayed along with the new line retained. If the only response to a change subcommand is "E?" that implies that no lines were altered.

- j) c qstr1 qstr2 ALL Change - All occurrences of qstr1 found in the lines being retained should be replaced by qstr2.
- k) c ln#1 qstr1 qstr2 Change - The first occurrence of qstr1 found in the line with line number ln#1 should be replaced with qstr2.
- l) c ln#1 qstr1 qstr2 ALL Change - ALL occurrences of qstr1 found in the line with line number ln#1 should be replaced with qstr2.
- m) c ln#1 ln#2 qstr1 qstr2 Change - The first occurrence of qstr1 found in the range of lines from the line with line number ln#1 through the last line with line number less than or equal to ln#2 should be replaced with qstr2.
- n) c ln#1 ln#2 qstr1 qstr2 ALL Change - All occurrences of qstr1 found in the range of lines from the line with line number ln#1 through the last line with line number less than or equal to ln#2 should be replaced with qstr2.
- o) End - This subcommand requests that the searching process be terminated without performing a search. CSEARCH will respond with a "?" and wait for the next CSEARCH command.
- p) S Search - This subcommand signifies that the query has been completed and that the search can now be performed. When the search has been completed, the number of citations satisfying the search will be displayed and then CSEARCH will respond with a "?" and wait for the next CSEARCH command.

CSEARCH

READY

CSEARCH A

CONVERSATIONAL FAMULUS - INITIALIZATION FOR SEARCH

FAMULUS /ID/DOE BIBLIOGRAPHY

277 CITATIONS

FIELD LABELS ARE: SUBJ TITL AUTH PUBL NOTE NMBR

? SF(SUBJ)

? S

00001? GAS&PROCESSING

00002?

E? S

1 CITATION SATISFIED THE SEARCH REQUEST

? PH

CIT# 0149

SUBJ GAS PROCESSING

TITL POTENTIAL METHODS FOR METHANE EXTRACTION FROM
GEOPRESSURED BRINE AT HIGH TEMPERATURE AND PRESSURE

AUTH QUONG, R. ET AL...

PUBL LAWRENCE BERKELEY LABORATORIES, UNIV OF CALIFORNIA, 1980

NOTE #SPE-9469, 9P: TABLES, FIGURES

NMBR 634, QUO VF

END

Example of CSEARCH

APPENDIX C

User's Guide by The Information Center for
Geopressured Geothermal: Information
Storage and Analysis for the Data Set:
'EPWRIG.GEOWAT'

TECHNICAL SUPPORT FOR GEOPRESSURED GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

INFORMATION SYSTEM COMPONENT

Information Center for Geopressured Geothermal

User's Guide by The Information Center for
Geopressured Geothermal: Information
Storage and Analysis for the
Data Set: 'EPWRIG.GEOWAT'

November 1981
Revised August 1982

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Louisiana Geological Survey
Louisiana State University
Baton Rouge, Louisiana 70803

Table of Contents

1. Introduction
2. File Organization
3. Information Storage
4. Access to GEOWAT Members for Running
SAS Program

1. Introduction

In support of the Environmental Monitoring Component of the DOE/LSU project entitled, "Technical Support of Geopressured Geothermal Well Activities in Louisiana", the Information System Component created the data file, 'EPWRIG.GEOWAT': EPWRIG is the user ID for the Information Center for Geopressured Geothermal (ICGG) data base; GEOWAT is the data file that stores and analyzes the sample observations of the water quality sampling stations and climatological data from the DOE/Louisiana test well sites. Data for this file was collected from the following sites and locations on a monthly basis:

- o the Parc Perdue test site is located approximately 15 miles south of Lafayette; environmental monitoring was conducted at the Dow Chemical site. Data from seven locations were collected and reported on a monthly basis by Petroleum Laboratories, Inc. of Lafayette.
- o Sweet Lake is located 14 miles southwest of Lake Charles, Louisiana; monitoring studies were conducted at the Magma Gulf/Technadrill site. Data from six locations were collected and analyzed by Kemron Environmental Services of Port Neches, Texas.
- o Gladys McCall test well is located in the Rockefeller Refuge prospect in the coastal Marshlands of southwestern Louisiana. Data from five locations were collected and analyzed by Kemron Environmental Services.

Climatological data reported in this file is for all sites but not all locations; data is extracted and compiled from the Louisiana Climatological Monthly reports (1980-1982) by the environmental monitoring staff and

submitted to ICGG for data entry. This data as well as the water quality data is managed by the Statistical Analysis System (SAS). SAS is a complete computer system that runs on IBM 360/370/ 30xx/43xx and compatible machines in batch and interactively under OS, OS/VS, VM/CMS, DOS/VSE, and TSO. ICGG incorporated SAS into the design of the data base as an all-purpose data analysis system and programming tool for information storage and retrieval, data modification, file handling, statistical analysis, graphics and forecasting.

2. File Organization

GEOWAT is comprised of several members that contains data from the Louisiana test well sites; each location and its associated data constitute one member (Table 1. Members of GEOWAT). Data is collected and stored on a monthly basis; thirty-six (36) variables are reported for each location or member. A record in GEOWAT is comprised of one month's data collected at each site location and includes the listed variables in Table 2. Records are manipulated with SAS programs to produce plots, graphs and various statistical analysis to interpret environmental effects from collected well data. GEOWAT was designed to analyze and produce the statistical properties of the water quality and climatological data; ICGG data sequence is represented in SAS input format as illustrated in the following section, "Information Storage".

Other members of GEOWAT are SAS programs created to statistically manipulate the data and perform such functions as listing variables, descriptive statistics and correlation analysis. These functions are stored in the member file, 'EPWRIG.GEOWAT (SAS1)'; a second SAS member creates plot when the member 'EPWRIG.GEOWAT (SAS2)' is executed. Additional SAS members can be created as needed to perform other SAS programs, these members aren't fixed and can be

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

<u>MEMBER</u>	<u>SITE</u>	<u>LOCATION</u>
BPP	Parc Perdu	Bayou Parc Perdu
DOW130	Parc Perdu	DOW'S 130 Feet 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.

<u>VARIABLE</u>	<u>MEANING</u>
MONTH (M)	Month
DAY (D)	Day
YEAR (YR)	Year
LOCNO	Location Number
SITENAME (NAME)	Site Name
WELLNO	Well Number
LATITUDE	Latitude
LONGTUDE	Longitude
SMPLTYPE	Sample Type
FLDIRECT (FD)	Flow Direction
STAFGAUG (TIDE)	Staff Guage (inch)
PRECIPT (RA)	Precipitant (cm)
WTEMP (TA)	Weather Temperature (°C)
DEPTH (DT)	Depth (cm)
DSCHARGR	Discharge Rate (gal/min)
SDCHARGD	Discharge Duration (min)
TEMPTURE (TW)	Sample Temperature (°C)
PH	PH Value
CONDUCT (SC)	Specific Conductance (umhos AT 25 °C)
TURBITY (TBTY)	Turbidity (N.T.U.)
ORCARBON (C)	Total Organic carbon (mg/l)
HARDNESS (CAC03)	Total Hardness (mg/l)
DISOXY (02)	Dissolved Oxygen (mg/l)

SODIUM (NA)	Sodium (mg/l)
POTASIUM (K)	Potassium (mg/l)
AMMONIA (NH4)	Ammonium (mg/l)
MAGNESUM (MG)	Magnesium (mg/l)
SULFATE (SO4)	Sulfate (mg/l)
CADIUM (CD)	Cadium (mg/l)
MANGANSE (MN)	Manganese (mg/l)
CALCIUM (CA)	Calcium (mg/l)
CHLORIDE (CL)	Chloride (mg/l)
LEAD (PB)	Lead (mg/l)
ARSENIC (AS)	Arsenic (mg/l)
MERCURY (HG)	Mercury (mg/l)
CHROMIUM (CR)	Chromium (mg/l)
BARIUM (BA)	Barium (mg/l)
BORON (B)	Boron (mg/l)

designed to meet any user's needs.

3. Information Storage

Water quality and climatological data is stored in the ICGG data set 'EPWRIG.GEOWAT'. Each member consists of the data collected at one site location for one month, the SAS input format is as follows:

```
month 1-2 day 3-4 year 5-6 locno 7-8 sitename $ 9-22
wellno 23-24 latitude 25-30 longitude 31-36 smpltpe $ 37
fldirect $ 38-40 stafgaug depth dschargd dschard tempture
ph conduct turbity orcarbon hardness disoxy sodium
potasium ammonia magnesum sulfate cadium manganse
calcium chloride barium lead arsenic boron mercury
chromium wtemp precipit
```

This is the data sequence for input which must be followed exactly; Table 2 shows the variable definitions for the data above. Each variable with column-restrictions must be in the same position as the format specifies. For example: format month 1-2 DAY 3-4 YEAR 5-6 for the date 5/21/81, coding which starts from column 1 can be entered as '5 2181' or ' 52181'. For variables without column-restrictions, follow the sequence and use blank(s) to separate variables which will allow the user flexibility. The following guidelines should be observed when entering new data:

1. zero before decimal point is omitted to save space.
2. Use '.' to code missing value
3. Use the number zero (0) to represent the variable
too small to detect, i.e. <.05, <.005

Raw data for GEOWAT is submitted to ICGG in different standards of measurement, all data should be converted to the metric system (i.e., well

[illegible]

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The following is an example of input data utilizing the SAS format:

```

MEMBER BPP                                DSN=EPWRIG.GEOWAT
-----
124801PPARC PERDU . SE 0 18 . . 9 6.24 83 280 12.6 25.4 8.6
6.62 5.25 1.36 1.69 4 0 .16 7.27 6 .08 0 .0037 0 0 0 11 1.83
220801PPARC PERDU . SNR 4 25 . . 16 6.6 142 236 17.8 45.5
7.3 12.9 6.2 .56 4.25 8 0 .27 11 15 .14 0 .0046 0 0 0 21 .61
321801PPARC PERDU . SSE -3 10 . . 17 6.75 227 233 26 77.6 4.5
23.6 7.76 .86 6.25 6 0 1.73 19.5 27 .22 0 .0089 0 0 0 16 1.7
421801PPARC PERDU . SE -1.5 10 . . 19 6.4 112 2650 54.5 60.8
2.6 10.9 3.87 1.06 4.68 0 0 1.79 15 14 .53 0 .0033 0 0 0 21 1.17
521801PPARC PERDU . SE 2 18 . . 24 6.36 80 792.5 24.6 30.3
5.6 5.2 4.13 1.43 2.6 0 0 .48 7.5 5.4 .28 0 .0024 .1 0 0 24 9.55
623801PPARC PERDU . SE -3 10 . . 27 7.05 147 500 11.8 44.84
5.2 11 2.75 .43 4.1 7.3 0 .4 11.2 11.75 .31 0 .0018 .3 0 0 33 6.4
722801PPARC PERDU . SE 10 33 . . 28 7 207 186 9.8 73.61 3
15.45 4.19 1.68 6.68 4 0 1.788 17.9 13 .18 0 .0048 .15 0 0 33 .7
821801PPARC PERDU . SE -.5 28 . . 28 7.16 230 19 4.4 102.6
1.6 14.6 2.38 .82 9.02 0 0 1.84 24.9 7 .19 0 .019 .05 0 0 30 1.63
922801PPARC PERDU . SW 1 36 . . 29 6.5 133 40 8.4 40.8 2.4
8.2 7.22 1.33 3.23 0 0 .71 10.5 11.5 .38 0 .0055 .09 0 0 31 3.96
1022801PPARC PERDU . SE 0 25 . . 16 6.18 148 24 19.6 52.6
2.4 6.7 1.1 1.39 4.48 2 0 .8 13.1 7.6 .19 0 .0045 .1 0 0 18 12.85
1120801PPARC PERDU . SE -4 10 . . 9 7.7 237.6 38 12.4 80.2
8.6 31.5 10.5 1.49 7.7 3 0 .31 19.2 30 .16 0 .0012 .05 0 0 8 1.45
1217801PPARC PERDU . SE -3 30 . . 10 6.65 124 94 12.3 43.3
7.6 10.5 6.9 1.63 3.13 0 0 .39 11.9 12.4 .17 0 .001 .02 0 0 11 0
126811PPARC PERDU . SW 0 20 . . 16 7.1 198 88 9.8 55.7 8.2
20.5 8.01 5.01 4.7 12 0 .48 14.2 21.55 .13 0 .001 .01 0 0 18 0
220811PPARC PERDU . SE 0 18 . . 18 8.38 490 2100 30.2 138.2
5.2 138 35 4.66 21 5 0 .88 20.1 88 .29 0 .011 .6 0 0 26 .2
319811PPARC PERDU . SE 0 10 . . 13 7.4 546 1875 96 99.9 6 32
9.8 23 6.1 30 0 1.3 29 67.8 3.5 0 .026 .25 .001 0 13 0
423811PPARC PERDU . SE 0 76 . . 24 7.2 328.4 81 14.3 108.5
4.5 32 5.8 2.72 9.8 0 0 1.8 26 19 .55 0 .008 .15 0 0 23 0
521811PPARC PERDU . SE 0 61 . . 19 7.51 283 18 16.4 95.6
8.8 28.1 4.6 1.57 8.6 4 0 .83 23.5 19 .18 0 .006 .025 0 0 19 .18
623811PPARC PERDU . SE 0 46 . . 30 7.02 166 150 18.8 64 5.1
11.3 5.15 5.7 5.3 3 0 1.25 16 14.5 .35 0 .003 .1 0 0 29 .58
721811PPARC PERDU . SE 0 25 . . 29 7.02 138 56 5.7 32.7 4.1
12.2 2.6 3.1 3.9 2 0 .8 6.1 10.2 .13 0 .08 .14 0 0 31 0
818811PPARC PERDU . S 0 36 . . 31 7.22 233 70 12.3 59.3
6.1 20.3 7.15 3.03 4.9 7 0 .94 15 17.5 .16 0 .004 .1 0 0 32 1.32
922811PPARC PERDU . S 0 30 . . 24 6.92 199 76 14.3 49.7
.93 10.5 8.4 5.55 4.2 12 0 1.09 12.2 11.5 .17 0 .005 .03 0 0 23 0
1026811PPARC PERDU . S 0 61 . . 18 6.9 392 84 15.3 69.5 4
53.2 9.5 2.6 6.3 8 0 .62 17 25.4 .22 0 .0012 .03 0 0 16 1.5
1123811PPARC PERDU . S 0 38 . . 16 7.05 232 33 9.2 69.9 6.1
27 8.1 .7 6.3 13.5 0 .7 17.5 31.25 .04 0 .001 .03 0 0 17 .23
1216811PPARC PERDU . SSE 0 76 . . 11 6.95 128 100 15 28.9 8.6
7.4 9.31 1.46 2.58 8 0 .16 7.21 15 0 0 .0012 .03 0 0 9 7.21
120821PPARC PERDU . SSSEU 38 . . 23 8.2 166 164 14.4 47.5 9.5
14 8.5 2.04 4 10.5 0 .6 12 16.5 .05 0 .0012 .03 0 0 23 0
222821PPARC PERDU . S 0 38 . . 16 7.1 413 100 25.7 61.7 6.2
77.1 6 8.83 4.8 80 0 1.08 16 32.5 .18 0 .0033 .02 0 0 17 0
324821PPARC PERDU . SSSEU 66 . . 22 6.52 135 195 26.5 22.66
6.2 14.1 5.66 2.01 2.41 10 0 .76 4.55 22 .05 0 .004 .02 0 0 18 2.97
428821PPARC PERDU . S 0 51 . . 21 5.8 162 580 28.6 41.6 5.8
11.7 13.5 3.17 5.1 7.5 0 1.17 7.4 24.5 .05 0 .0014 .015 0 0 23 .71
525821PPARC PERDU . S S 0 41 . . 24 6.75 214 5.6 9.8 68.98
6.9 19.1 4.7 .91 5.9 6 0 .82 17.9 23.9 .05 0 .0013 .0012 0 0 .

```

4. Access to GEOWAT Member(s) for Running SAS Programs

Frequently used SAS programs are stored in 'EPWRIG.GEOWAT (SAS#)' member files. The following is an example of a SAS program to perform:

1. Correlation Analysis
2. Plot Chemicals vs Months over a three (3) year period.

```
1      DATA;
2      INFILE MYDATA;
3      INPUT M 1-2 D 3-5 YE 6 LOCNO $ 7-8 NAME $9-22 WELLNO 23-24
4      LATITUDE 25-30 LONGITUDE 31-36 SHELTYPE $ 37 PD $ 38-40
5      TIDE DT DSCHARGE DSCHARGE DT FH SC PETY C CACO3 O2 NA K MH
6      HG SO4 CD MN CA CL BA PB AS B EG CA TA RA;
7      GETTICS MCLATS SKIP=5;
8      TITLE PARCERDUE, LEBLANC DITCH NEAR CHURCH -- SURFACE, 1981, UNIT:MG/L;

NOTE: INFILE MYDATA(LEBLANCC) IS:
      DSN=EPWRIG.GEOWAT(LEBLANCC)
      UNIT=DISK, VCI=SER=USE=01, DISP=SHR,
      LCL=(BLKSIZE=3600, LRECL=80, RECFM=FB)

NOTE: SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
      REACHED THE END OF A LINE.
NOTE: 58 LINES WERE READ FROM INFILE MYDATA(LEBLANCC).
NOTE: DATA SET WORK.DAT1 HAS 29 OBSERVATIONS AND 38 VARIABLES. 158 OBS/TAK.
NOTE: THE DATA STATEMENT USED 0.19 SECONDS AND 76K.

9      PROC CORR; VAR CACO3 NA K HG SO4 CA CL;
10
NOTE: THE PROCEDURE CORR USED 0.18 SECONDS AND 112K AND PRINTED PAGE 1.

10     PROC PLOT; PLOT(CACO3 NA K HG SO4 CA CL)* M=YE;
NOTE: THE PROCEDURE PLOT USED 0.30 SECONDS AND 158K AND PRINTED PAGES 2 TO 8.
NOTE: SAS USED 156K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      BOX 8000
      CARY, N.C. 27511-8000
```

Each time a SAS program runs, a data set should be allocated to a file (assign an arbitrary name to the file). For example, GEOWAT (SAS1) as your SAS program and 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 SAS program INFILE statement.
File name 'mydata' must match the file name in command %sas options(sysin=)

If you wish to execute 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=myspgm)
```

By using the FREE and ALLOCATE commands, a different data set can be used as input data without changing the program.

APPENDIX D

Examples of GEOWAT

- 1. Descriptive Statistics**
- 2. Correlation Analysis**
- 3. Plot of Variables**

GOWAT Example 1. Descriptive Statistics

PARC PERDUE, LEBLANC DITCH NEAR CHURCH -- SURFACE, 1981, UNIT: MG/L

VARIABLE	N	MEAN	STD DEV	SUM
CACC3	27	68.80222222	53.97154210	1857.66000000
NA	27	27.84296296	48.60739955	751.76000000
K	27	8.69333333	20.80690326	234.72000000
MG	27	4.95333333	2.67381462	133.74000000
SO4	27	5.95555555	7.38133474	160.80000000
CA	27	19.06481481	17.69335150	514.75000000
CL	27	35.40740741	69.31477907	956.00000000

VARIABLE	MINIMUM	MAXIMUM
CAC03	11.56000000	265.00000000
NA	4.10000000	240.00000000
K	1.00000000	112.20000000
MG	1.39000000	12.81000000
SO4	0	35.00000000
CA	1.75000000	85.00000000
CL	4.70000000	351.00000000

GGEOWAT Example 2. Correlation Analysis

CORRELATION COEFFICIENTS / PROB R UNDER HO:RHO=0 / N = 27

	CAC03	NA	K	MG	S04	CA	CL
CAC03	1.00000 0.0000	0.87165 0.0001	0.24347 0.2210	0.92206 0.0001	0.16223 0.4188	0.99114 0.0001	0.85013 0.0001
NA	0.87165 0.0001	1.00000 0.0000	0.34984 0.0736	0.74830 0.0001	0.35753 0.0671	0.89234 0.0001	0.95526 0.0001
K	0.24347 0.2210	0.34984 0.0736	1.00000 0.0000	0.18848 0.3464	0.20596 0.3027	0.25113 0.2064	0.13878 0.4900
MG	0.92206 0.0001	0.74830 0.0001	0.18848 0.3464	1.00000 0.0000	0.00590 0.9767	0.90307 0.0001	0.72312 0.0001
S04	0.16223 0.4188	0.35753 0.0671	0.20596 0.3027	0.00590 0.9767	1.00000 0.0000	0.19101 0.3399	0.23701 0.2339
CA	0.99114 0.0001	0.89234 0.0001	0.25113 0.2064	0.90307 0.0001	0.19101 0.3399	1.00000 0.0000	0.86914 0.0001
CL	0.85013 0.0001	0.95526 0.0001	0.13878 0.4900	0.72312 0.0001	0.23701 0.2339	0.86914 0.0001	1.00000 0.0000

GGEOWAT Example 3. Plot of Variables
 PARC PERDUE, LEBLANC DITCH NEAR CHURCH -- SURFACE WATER UNIT: MG/L
 PLOT OF CAC03*MONTH SYMBOLS ARE VALUES OF YEARS

NOTE: 2 OBS HAD MISSING VALUES

LEGEND:

0 - 1980
 1 - 1981
 2 - 1982

APPENDIX E

Information Center for Geopressed Geothermal

Cataloging Procedures

APPENDIX E

Information Center for Geopressured Geothermal

Energy Research Library

Cataloging Procedures

- I. Accession Record Entry
- II. Classification
 - A. Classify books by subject
 - B. Assign call numbers and cutter number
 - C. Prepare catalog cards
 - 1. shelf-list - white
 - 2. author - yellow
 - 3. title - pink
 - 4. subject - blue
- III. Lettering of Books and Marks of Ownership
 - A. Call Number
 - 1. spine of book
 - 2. lettered in pencil in the upper left hand corner of the page following the title page.
 - 3. Key page entry (#5), lettered in pencil in the lower left hand corner on page 5.
 - B. Accession Number
 - 1. lettered in ink or stamped on the page following the title page, should be parallel to and about an inch from the bottom of page, as nearly as possible in the center.
 - 2. should be placed on key page #5, in the same position as on the page following title page.
 - C. Marks of Ownership
 - 1. ID stamp (Energy Library) should be placed on the page following title page under the accession number.
 - 2. key page entry (#5) place same as on title page.
 - 3. stamp the edges of the body of book.
- IV. Book Cards, Pockets and Due Date
 - A. Book Cards
 - 1. call number of book is placed at the left on the first line.
 - 2. accession number on the right, first line.
 - 3. volume number should be used as part of the call number.
 - 4. (Optional) Cost of book should be noted above the accession number.
 - 5. author's last name in CAPS.
 - 6. brief or abbreviated title of book.

B. Book Pockets

1. call number on the upper left tab.
2. accession number on the upper right tab.
3. mark of ownership (Energy Library Stamp) should be placed across the bottom of the pocket.
4. pocket is pasted on the inside back cover of book, as nearly in the center as possible.

C. Due Date Slips

1. slips are pasted on the last page in the book, usually the fly leaf, opposite the book pocket, placed as nearly in the center as possible.
2. in case there is reading material on the last page of the book, the due-date slip should be pasted across the top margin of the page so that the reader can still read the printed lines beneath the date-due slip.

ENVIRONMENTAL MONITORING

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

INTRODUCTION

All phases of the environmental monitoring program, except air quality monitoring, were continued between November 1981 and October 1982. Air quality monitoring was completely eliminated from the program when, in May 1982, the last air quality station was removed from its location at Sweet Lake. Water quality monitoring was scaled down at Parcperdue and Sweet Lake.

For all phases of the environmental monitoring program, the most important goal is a thorough understanding of background data, those environmental impacts resulting from natural occurrences or from cultural activities other than geopressured-geothermal energy development. Water quality can be affected by saltwater intrusion, drilling activities, and waste disposal; subsidence may be a result of natural sediment compaction or ground-water withdrawal; and seismic activity may result from natural fault-slippage or may be a reflection of oil field exploration techniques or weather patterns.

Some interpretations are possible during the analyses of raw data; as more data are included in the data base, interpretations will be more complete. The final result will be a determination of environmental impacts resulting from geopressured-geothermal energy development.

WATER QUALITY MONITORING

Introduction

Monthly water quality monitoring continued at the three design well test sites, Parcperdue, Sweet Lake, and Rockefeller Refuge, for the period 1 November 1981 to 30 April 1982. In May 1982, monitoring operations at

Parcperdue and Sweet Lake were scaled down to a quarter-year sampling frequency. Sampling continued on a monthly basis at Rockefeller Refuge.

A large volume of water quality data has accumulated since the inception of the environmental monitoring program. In the natural waters at Sweet Lake and Parcperdue, 22 parameters are being observed; at Rockefeller Refuge, 23 parameters are being observed (Table 1). To date, a total of 7793 monthly water quality observations for all three design well sites has been made. The addition of precipitation and weather temperature data for each region to the data base results in a total of 7921 observations (Table 2). This expansive amount of data justified the use of computer files for data storage and analyses. A statistical package is being developed which, when applied, will aid in determining the amount and sources of variation within and between samples at each test site. Preliminary statistics will be introduced in later sections of this report. A review of physical and known chemical characteristics at each site is first necessary.

Parcperdue

The Parcperdue test site is located in the North Parcperdue oil and gas field, approximately 15 miles (24 km) south of Lafayette, Louisiana. Land use is primarily agricultural; pastureland and irrigated rice fields dominate the landscape. The site is approximately 20 ft (6 m) above mean sea level (MSL) in an area of very low relief between the Vermilion River to the west and Bayou Parcperdue to the east. Surface water flow through the site is southward toward Leblanc ditch, which is hydraulically connected to the Vermilion River and Bayou Parcperdue. In its natural state, surface water should be fresh, with seasonally fluctuating amounts of elements derived from organic and inorganic agricultural compounds. The following three surface-water sampling stations were located radially south of the test well and are

TABLE 1. List of parameters (and their abbreviations)
sampled at the prospects.

<u>Parameter (Abbreviation)</u>	<u>Parcperdue</u>	<u>Sweet Lake</u>	<u>Rockefeller Refuge</u>
Rain			
Turbidity (Tbty)			
Depth (Dt)			
Air Temperature (TA)			
Water Temperature (TW)			
Sodium (Na)			
Potassium (K)			
Magnesium (Mg)			
Calcium (Ca)			
Manganese (Mn)			
Chloride (Cl)			
Specific Conductance (Sc)			
Dissolved Oxygen (O ₂)			
pH			
Organic Carbon (C)			
Hardness (CaCO ₃)			
Ammonia (NH ₄)			
Sulfate (SO ₄)			
Barium (Ba)			
Cadmium (Cd)			
Lead (Pb)			
Arsenic (As)			
Boron (B)			
Mercury (Hg)			
Chromium (Cr)			

TABLE 2. Duration and number of monthly water quality observations
at Parcperdue, Sweet Lake, and Rockefeller Refuge.

PROSPECT	STARTING DATE	ENDING DATE	NUMBER OF OBSERVATIONS
PARCPERDUE			
--Surface water stations			
2 stations	24 Jan. 1980	25 May 1982	
22 parameters			
30 monthly observations			1320
1 station	24 Jan. 1980	21 June 1982	
22 parameters			
31 monthly observations			682
--Ground water stations	24 Jan. 1980	21 June 1982	
2 stations			
22 parameters			
30 monthly observations			1320
--Climatological data	24 Jan. 1980	28 Apr. 1982	
2 parameters			
28 monthly observations			56
SWEET LAKE			
--Surface water stations	6 May 1980	27 Apr. 1982	
3 stations			
22 parameters			
24 monthly observations			1584
--Ground water stations	24 Oct. 1980	27 Apr. 1982	
3 stations			
22 parameters			
19 monthly observations			1254
--Climatological data	6 May 1980	27 Apr. 1982	
2 parameters			
24 monthly observations			48
ROCKEFELLER REFUGE			
--Surface water stations			
2 stations	8 May 1981	4 Aug. 1982	
23 parameters			
16 monthly observations			736
1 station	4 Aug. 1981	4 Aug. 1982	
23 parameters			
13 monthly observations			299
--Ground water stations			
2 stations			
23 parameters			
13 monthly observations			598
--Climatological data			
2 parameters			
12 monthly observations			24

Total 7921

named after geographic features: "Bayou Parcperdue," "Leblanc ditch near church," and "Leblanc ditch near river." They are shown on the map (Fig. 1) as stations S1, S2, and S3, respectively.

The general subsurface geology in the area consists of a sand which extends from the surface to an average depth of -500 ft (-152 m) MSL. A 200-ft (61-m) thick shale (or clay) separates the upper sand from a deeper sand that extends down to contact another shale at about -850 ft (-259 m) MSL. The sand in the upper part of the stratigraphic section is probably the result of Pleistocene Mississippi River alluviation, as the landscape here is strewn with relict meanders from this ancient system. Point-source recharge to shallow ground water is therefore likely. Water chemistry of the upper sand should be similar to that of the natural surface waters, whereas water chemistry of the deeper sands will probably be more saline due to saltwater intrusion from downdip. Ground waters were first sampled from two domestic wells which were 50 ft (15 m) and 100 ft (30 m) deep; these wells are located approximately 500 ft (152 m) west of the test well. Other wells were constructed and brought on-line to sampling as drilling and testing of the geothermal well progressed. These wells are 180 ft (55 m), 90 ft (27 m), and 130 ft (40 m) deep (numbers 1, 2, and 3, respectively, on Fig. 1).

The producing reservoir in the Parcperdue geopressured-geothermal prospect is at depth between -13,349 and -13,406 ft (-4069 to -4086 m) MSL. After gas separation, the resultant brine is injected through a disposal well to a depth of -4520 to -4660 ft (-1378 to -1420 m) MSL. In addition, surface pits have been constructed to hold the waste fluids should problems occur in the disposal well. Changes in the physical and chemical characteristics of the natural waters could occur during any stage in the exploration process. Natural water contamination is most likely to occur during drilling as muds and chemicals are added to the unprotected hole and during disposal in

FIGURE 1. Area map of Parcerdue geopressured-geothermal test site showing locations of parameter observation stations.

surface pits should soil seals prove ineffective. Contamination is not likely to occur during production, provided all necessary precautions are taken to insure that no connections occur between the production well bore and the surrounding hydropressured aquifers. Subsurface disposal, on the other hand, is being monitored more closely. Ground-water quality monitoring may provide some evidence about local shallow geology and the lateral extent of natural subsurface clay seals in the area.

Should brine contamination occur in the natural waters at Parcperdue, it would be detectable due to increased concentrations of brine constituents in the natural waters. Chemical analyses of the brine during May 1982 and the following three months yielded an average chemical composition of 98,751 ppm TDS (App., Table I-1). Major constituents, which included sodium (33,770 ppm), calcium (1850 ppm), and chloride (55,660 ppm), accounted for over 92% of the total. Concentrations of most brine constituents were very high when compared to the average concentrations of these elements in the natural ground waters at Parcperdue (Table 3). The concentrations of sodium, potassium, chloride, sulfate, and boron were 80 times greater than their average concentrations in shallow ground waters; similar comparisons were evident between the brine and the surface waters at Parcperdue. In addition to the elements mentioned above, calcium and hardness concentrations in the brine were over 90 times higher than their average concentrations in the surface waters at Parcperdue.

Sweet Lake

The Sweet Lake geopressured-geothermal prospect is located in a structural basin on the north flank of the Hackberry/Big Lake/Sweet Lake salt ridge 14 miles (23 km) southwest of Lake Charles, Louisiana. As at Parcperdue, the land, consisting of rice or soybean fields and pastureland, is used

TABLE 3. Comparison of chemistry between the geopressed-geothermal brine and surface waters, Parcperdue.

PARAMETER	BRINE AVERAGE	THIS STUDY--1982		U.S. GEOLOGICAL SURVEY--1968-1975	
		Surface	200 ft	200-450 ft	600-920 ft
TDS (ppm)	98,751			256	375
Na (ppm)	33,770	24	20.78	18	88
K (ppm)	178	8.10	1.95	1	2
Mg (ppm)	260	5	5.82	12	12
Ca (ppm)	1,850	16	17.91	52	34
Mn (ppm)	1.8	0.97	0.21	0.3	0.1
Cl (ppm)	55,660	28	8.70	35	71
Sc (umhos)	121,575	213	206	512	698
pH	6.3	7.00	6.60	7.7	7.6
CaCO ₃ (ppm)	5,960	64	68.72	250	259
HCO ₃ (ppm)	1,536			293	303
NH ₄ (ppm)	26.5	2.45	0.57		
SO ₄ (ppm)	511	6.11	0.12		
Pb (ppm)	0.9	0.00	0.00	1.5	2.0
B (ppm)	61.1	0.07	0.08		

primarily for agriculture. The prospect lies on the southern edge of the Pleistocene Prairie Terrace, which borders the coastal wetlands. As a result, elevation and relief are low, with a hydrologic gradient to the south through man-made canals and levees used for irrigation and drainage. One such canal drains the area through a truncation in the road south of the test site. Sampling station "Bridge" is located here (labeled as 4 on Fig. 2). This canal is hydraulically connected to Square Lake, which is situated in the coastal marshlands and serves as an irrigation return reservoir. Square Lake is, in turn, connected to Sweet Lake, a natural marshland lake. Two additional surface-water sampling stations, L2 and L3, were located near the entrances to Square Lake and Sweet Lake, respectively, and are named as such. The chemistry of the natural surface waters here will probably be more complex than that at Parcperdue. Seasonal fluctuations may reflect tidal ranges originating in the coastal marshlands to the south as well as variations in rainfall and runoff from the north. Therefore, the natural surface waters will be brackish. Elements derived from agricultural compounds should also enhance seasonal variations.

The upper 700 ft (213 m) of the subsurface stratigraphic column is predominantly shale or clay, with a thin, 100-ft (30-m) veneer of sand and a few subsurface sandy lenses. A much thicker sand is located between -700 and -860 ft (-213 to -262 m) MSL. Below -860 ft is another shale or clay; its average thickness is about 125 ft (38 m). The ground-water chemistry in the veneer of sand should be very similar to that in the natural surface waters because of the sand's probable genesis from Holocene alluviation. The deeper sand will probably be affected by saltwater intrusion and thus will be more saline than shallower waters. Although continental recharge to this sand is likely, it probably occurs far to the north and will not be as effective as saltwater intrusion from the south. Three ground-water observation wells

FIGURE 2. Area map of Sweet Lake geopressured-geothermal test site showing locations of parameter observation stations.

were drilled into the first thick sand (Fig. 2). Well no. 1 was located 100 ft (30 m) north of the disposal well and is screened in the top of the sand at -280 ft (-85 m) MSL. Well no. 2 was also completed in the top of the sand, but is located 150 ft (46 m) north of the production well. The deepest well, no. 3, was completed in the bottom of the sand at -435 ft (-133 m) MSL. It is located 200 ft (61 m) north of the production well.

The Sweet Lake well produces from a depth of -15,387 to -15,414 ft (-4690 to -4698 m) MSL. The resultant brine, once depleted of usable gas, is injected into a disposal well to a depth of -7015 to -7320 ft (-2138 to -2231 m) MSL. As at Parcperdue, although some contamination may occur during drilling, none should occur during production or disposal provided there is no communication between the well bores and the hydro pressured aquifers. The disposal horizon should be sufficiently deep to guarantee local confinement.

Production and brine sampling commenced at the Sweet Lake prospect in mid-June 1981. The dominant constituents in the brine samples were sodium and chloride, with concentrations of 42,000 and 93,340 ppm, respectively (App., Table II-1). Other major constituents included calcium (11,200 ppm), potassium (1690 ppm), and magnesium (630 ppm). These five constituents accounted for over 94% of the total dissolved solids in the brine and a high specific conductance. The brine sample was also fairly high in ammonia (112 ppm), cadmium (0.33 ppm), and boron (69 ppm) relative to the average concentrations of these elements in shallow ground waters. Data from surface waters indicated that, with the exception of boron, average concentrations of the major elements were much lower, as much as 1600 times lower, than concentrations of these elements in the geopressured-geothermal brine (Table 4).

Rockefeller Refuge

The Rockefeller Refuge prospect is located in the East Crab Lake oil and gas field approximately 7 miles (11 km) southeast of Grand Chenier,

TABLE 4. Comparison of chemistry between the geopressured-geothermal brine and surface waters, Sweet Lake.

PARAMETER	BRINE AVERAGE	THIS STUDY--1982		U.S. GEOLOGICAL SURVEY--1948-1979	
		Surface	280-435 ft	280-450 ft	950 ft
TDS (ppm)	156,900			722	2,400
Na (ppm)	42,000	275	107	222	865
K (ppm)	1,690	17.400	2.100	5.40	7
Mg (ppm)	630	90	19	13	35
Ca (ppm)	11,200	25	31	29	3.40
Cl (ppm)	92,340	465	47	214	1,270
Sc (umhos)	162,000	1,604	564	1,180	4,270
pH	5.6 @ 50°C	7.300	7.900	8.10	7.600
HCO ₃ (ppm)	317			314	301
NH ₄ (ppm)	112	0.070	0.070		
Cd (ppm)	0.33	0.002	0.001		
B (ppm)	69	1.400	0.490	0.18	0.08

Louisiana. Cattle grazing is secondary to extractive land use; levees and canals excavated for oil and gas development have modified the surface hydrology of the area. The region is also characterized by relict beach ridges (cheniers) usually no higher than about 10 ft (3 m) MSL and low-lying coastal marsh. This area is characterized by restricted tidal flow; situated in the marsh, the test site is bounded on the north by Grand Chenier Ridge and impounded on the east, west, and south by levees through which there is only one opening. Surface water sampling station "Lake" (identified as S1 on Fig. 3) is an area of open water located inside the levee system. This water body is a result of marsh degradation within the levee. The opening in the southeastern corner of the impoundment drains into a small marshland lake which, in turn, is hydraulically connected to the Gulf of Mexico via a leveed channel known as Hog Bayou. This hydraulic connection to the Gulf assures an adequate influx of seawater to the area surrounding the test site. The natural surface waters at Rockefeller Refuge should therefore have a chemistry similar to seawater. Sampling station "Bridge" is located outside of the levee system near the southeastern outlet. "Hog Bayou" (S3 on Fig. 3) is located approximately 1 mile (1.6 km) southwest of "Bridge" (S2 on Fig. 3) in the Hog Bayou channel.

The uppermost 100 ft (31 m) of the subsurface stratigraphic column consists of clay. Below this clay is a sand which averages approximately 200 ft (61 m) thick and extends down to a maximum depth of about -300 ft (91 m) MSL. Well no. 1 was screened in this sand at a depth of -310 ft (-95 m) MSL and is located 2000 ft (607 m) north-northwest of the production well (Fig. 3). The second observation well, no. 2, produces ground water from a second underlying sand at a depth of -660 ft (-201 m) MSL and is located 200 ft (61 m) north-northwest of the production well. A thick 300-ft (91-m) clay underlies the sand and extends down to a regionally consistent

FIGURE 3. Area map of Rockefeller Refuge geopressured-geothermal test site showing locations of parameter observation stations.

depth of about -605 ft (-184 m) MSL. This sand has an average thickness of 400 ft (122 m) and is underlain by another clay unit. Ground-water chemistry, in general, should be more saline than that found at Sweet Lake and Parcperdue because of the area's proximity to the Gulf of Mexico. However, ground water may be considerably fresher than the surface waters at Rockefeller Refuge. Ground-water aquifers may be recharged far to the north under continental conditions and do not seem to be hydraulically connected to nearby surface waters. Saltwater intrusion, however, is likely and could be a source of seasonal variation.

The producing horizon at Rockefeller Refuge is between 15,597 and -15,626 ft (-4754 to -4763 m). Subsurface injection of the depleted brine will occur between -3050 and -3500 ft (-930 to -1067 m). Preliminary shallow subsurface investigations indicated that thick clays separate the hydropressed aquifers. In general, these clays should also be fairly continuous over a large area. Therefore, local contamination after disposal is unlikely; contamination during other stages of the process, however, could occur.

Because production from the Rockefeller Refuge geopressured-geothermal reservoir has not yet begun, a true comparison between brine chemistry and natural shallow-water chemistry cannot be made. Concentrations of those elements expected in the geothermal brine are generally high in shallow-water environments at Rockefeller Refuge (Table 5). Water quality data from this study indicate generally decreasing amounts of these elements with depth from the surface to -660 ft (-201 m) MSL. The reverse is true for historical wells drilled and tested by the U.S. Geological Survey. These wells are located to the north of the prospect and presumably tap a shallower aquifer or set of aquifers.

TABLE 5. Comparison of surface and ground-water chemistries, Rockefeller Refuge.

PARAMETER	THIS STUDY--1982			U.S. GEOLOGICAL SURVEY		
	Surface	310 ft	660 ft	1975 <400 ft	1955 460 ft	1974-75 >500 ft
TDS (ppm)				628	1,115	3,950
Na (ppm)	5,547	932	760	225	362	1,400
K (ppm)	165	12.160	4.287	3.5	4.05	8.0
Mg (ppm)	702	85	31	9.1	18	45
Ca (ppm)	199	106	45	18	46	90
Cl (ppm)	9,985	1,620	1,280	165	482	1,510
Sc (umhos)	24,974	4,857	4,070	1,070	2,055	4,785
pH	8.118	7.730	7.812	7.5	7.4	7.6
HCO ₃ (ppm)				394	388	288
NH ₄ (ppm)	0.198	1.435	1.010			
SO ₄ (ppm)	1,241	83.200	9.860			
Cd (ppm)	0.003	0.002	0.001			
B (ppm)	1.049	0.321	0.195		0.080	

Preliminary Statistics

Major elements in the geopressured-geothermal brine may provide signatures for possible contamination of shallow waters resulting from the production of geothermal fluids. Concentrations of these elements in the natural waters must be consistently lower than the base-line average after natural seasonal fluctuations and other events are taken into account.

A good test of the variation within and between water sampling stations is the coefficient of variation provided by the following formula:

$$s/\bar{y}$$

where $\bar{y}$ = the mean for the concentration of an element
 during the sampling period
and s = the standard deviation from the mean.

A high coefficient of variation in relative terms indicates that seasonal variation is high. A station with a low natural variation would be best suited for marker element identification. The monthly analyses presented in this report began some time before drilling and continued through drilling and/or resource testing at each site. The statistical data will include natural variations and any variations that may be caused by unnatural and catastrophic events. For representative elements, monthly values which are two or more standard deviations from the mean will be considered anomalous and will be tested against other background data for a relationship between water quality variations and geopressured-geothermal well activities.

Parcperdue: Temporal variations between the parameters sodium, potassium, chloride, calcium, and hardness are greatest at "Leblanc ditch near church" than at any other station, presumably because the station is subjected to both runoff and saltwater intrusion (Table 6). Sodium, potassium, and chloride are less variable in "Leblanc ditch near river," possibly

TABLE 6. Coefficients of variation ($s/\bar{y}$) for selected parameters in surface and ground waters, Parcperdue.

	LEBLANC DITCH NEAR CHURCH			LEBLANC DITCH NEAR RIVER			BAYOU PARCPERDUE		
	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$
Na	28	49	1.8	20	14	0.7	23	26	1.1
K	9	21	2.3	8	4	0.5	7	6	0.9
Cl	35	69	2.0	28	25	0.9	21	17	0.8
Ca	19	18	0.9	15	10	0.7	15	6	0.4
CACO ₃	69	54	0.8	61	40	0.7	61	28	0.5
SO ₄	6	7	1.2	4	6	1.5	9	15	1.7
B	0.1	0.1	1.0	0.1	0.1	1.0	0.1	0.1	1.0

	50-ft WELL			100-ft WELL			130-ft WELL			180-ft WELL		
	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$
Na	23	1.7	.07	21	1.4	.07	22	3.1	.14	17	3.1	.18
K	1.9	.19	0.1	2.2	.36	.16	2.4	2.0	.83	1.4	0.2	.14
Cl	8.6	4.4	0.5	5.9	2.6	0.4	11	4.6	0.4	9.2	16	1.7
SO ₄	0	0	-	.14	0.5	3.6	0	0	-	.11	.46	4.2
B	.08	.14	1.8	.06	.08	1.3	.08	.04	0.5	.11	.06	0.6

because of the proximity of this station to a consistent water input source, Vermilion River. The lowest variation for calcium was observed in Bayou Parcperdue. Boron variation is consistent across the area.

Differences between ground-water chemistries at Parcperdue may have been caused by differences in the frequency and timing of well sampling. At times it was necessary to substitute one well for another when a well became plugged or a pump malfunctioned. In addition, sampling, which commenced in two existing wells--50 ft (15 m) and 100 ft (30 m) deep, respectively--at the beginning of the program, was switched halfway through the program to two deeper wells--130 ft (40 m) and 180 ft (55 m) deep, respectively--drilled specifically for the geothermal project. Deeper ground waters were considered to be more characteristic of natural ground waters at Parcperdue. Despite this problem, a few observations can be made using the statistical data. Variations for sodium, potassium, chloride, and boron are similar between the 50-ft well and the 100-ft well (Table 6) probably because these wells are producing from the same horizon and have coinciding sample dates. In a similar fashion, both the 130- and the 180-ft (55 m) wells have higher variations in sodium content and lower variations in boron content than the shallower wells. The higher variation of potassium concentration in the 130-ft well may be due to its proximity to the geothermal well bore.

In general, concentrations of sodium, potassium, and chloride are more variable in Parcperdue surface waters than ground waters (Table 6) probably because of the persistence of these elements in the subsurface environment. Sulfate, on the other hand, is more variable in ground waters because of the seasonal effects of saltwater intrusion.

The most significant water chemistry anomalies occurred at Parcperdue on 20 November 1980 in Leblanc ditch and on 20 February 1981 in Bayou Parcperdue (App., Table I-2). The values for sodium, calcium, chloride, hardness,

potassium, and boron in Leblanc ditch on 20 November 1980 are not related to geothermal well activities since drilling had not yet begun on the site. The anomalies are probably related to the Jefferson Island salt dome collapse, which occurred at about 9:00 A.M. on 20 November 1980. Lake Peigneur, which rests atop the dome located 7 miles (11 km) southeast of the geothermal site, drained into the dome till noon, then began to backfill with a surge of seawater from the Gulf of Mexico. This seawater may have found its way into ditches and canals as far north as the Parcperdue site.

At the time of the other anomaly observed on 20 February 1981, drilling of the geothermal well had attained a depth of about 10,000 ft (3048 m). It is doubtful, however, that well activities at the site caused these anomalies. The high values reported for sodium, potassium, magnesium, chloride, calcium carbonate, and boron could be due to other drilling activities located adjacent to Bayou Parcperdue. Most anomalies in ground-water data occurred prior to well activities and are attributable to seasonal fluctuations (App., Table I-3). Furthermore, the anomalies are temporally erratic and inconsistent between ground-water stations. A high potassium value was recorded in the 130-ft (40-m) well on 21 May 1981 shortly after completion of drilling at the Parcperdue geopressured-geothermal well located only 100 ft (30 m) to the southeast. This anomalous value for potassium may be due to entrainment of drilling fluids into ground-water flow.

Sweet Lake: Variations in the concentrations of certain marker elements are statistically similar in the surface waters at Square Lake and Sweet Lake (Table 7). Variations in the major marker elements sodium, potassium, chloride, and calcium are conspicuously lower at these two sites than at "Bridge" to the north. Likewise, variations in magnesium and ammonia are noticeably higher at Square Lake and Sweet Lake than at "Bridge." Sweet Lake and Square Lake, which are marshland lakes, are more susceptible to a consistent influx

TABLE 7. Coefficients of variation ($s/\bar{y}$) for selected parameters in surface and ground waters, Sweet Lake.

	BRIDGE			SQUARE LAKE			SWEET LAKE		
	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$
Na	107	134	1.3	337	313	0.9	380	337	0.9
K	14	26	1.9	19	26	1.4	20	26	1.3
Cl	146	213	1.5	618	589	1.0	632	604	1.0
Ca	31	35	1.1	22	16	0.7	21	14	0.7
Mg	13	19	1.5	111	320	2.9	146	369	2.5
NH ₄	.13	.19	1.5	.06	.17	2.8	.02	.05	2.5
Cd	.001	.002	2.0	.003	.004	1.3	.002	.004	2.0

	280-ft WELL 1			280-ft WELL 2			435-ft WELL		
	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$
Na	104	34	.33	108	43	.40	109	41	.38
K	1.9	2.2	1.2	2.1	2.3	1.1	2.2	2.2	1.0
Cl	42	13	.31	45	17	.38	54	23	.43
Ca	30	16	.53	31	18	.58	33	18	.55
Mg	17	26	1.5	20	27	1.4	20	25	1.2
NH ₄	.06	.12	2.0	.07	.14	2.0	.08	.14	1.8
Cd	.001	.002	2.0	.001	.002	2.0	.002	.005	2.5
B	.40	.42	1.0	.52	.38	.73	.54	.47	.87

of saline waters from the south and hence less variable in major seawater components. Magnesium and ammonia, on the other hand, are continental components, probably derived from alluvial soils and decaying organic matter, respectively; hence, there is a higher variation of these elements in marshland lakes.

Variations in the components sodium, potassium, chloride, calcium, and boron between the observation wells at Sweet Lake are not as expected. The coefficients of variation for these elements in the ground-water observation stations "280-ft well 2" and "435-ft well" are statistically similar (Table 7). Unlike the four aforementioned components, concentrations of magnesium, ammonia, and cadmium are statistically similar in the two shallower wells. Magnesium and ammonia are more variable and cadmium is less variable in the shallow wells than in the deeper well. The 280-ft (85-m) well and the 435-ft (133-m) well are directly in the path of ground-water flow around the production well bore. Contamination from the geothermal well may cause the unexpected variation. Another possible cause of chemical variation in ground waters at Sweet Lake is that the site borders two highly contrasting environments, prairie and marshland. As with surface waters, magnesium and ammonia are probably derived from a continental source. Saltwater tongues and wedges migrating from the south could cause variations in the other major elements. In general, at Sweet Lake, all elements in surface waters have a greater variation than those in the ground waters (Table 7); this situation is probably due to the greater effect of saltwater intrusion and runoff on surface waters.

The erratic nature of most anomalies at Sweet Lake (App., Table II-2) indicates that they are probably natural. The high values reported for sodium, magnesium, chloride, calcium carbonate, and sulfate in surface and ground waters on 12 November 1980 occurred in the early stages of drilling at

the geothermal well and may be indirectly related to well drilling. The high sulfate content is indicative of saltwater intrusion. The anomalies observed in ground waters on 19 May 1981 for potassium and magnesium occurred during the final stages of production well drilling (App., Table II-3) and may also be indirectly related to drilling activities. Drilling of a deep well may cause a temporary lowering of the potentiometric surface, reflected in the depth of the water surface in the observation wells on 19 May 1981 (App., Table II-2). The resulting cone of depression could cause an increase in the rate of saltwater intrusion from the south.

Rockefeller Refuge: For the surface water stations at Rockefeller Refuge, the coefficients of variation are lower for sodium and potassium and higher for chloride at "Lake" than for the same elements at "Bridge" and "Hog Bayou" (Table 8). Calcium, magnesium, cadmium, and boron are similar at "Lake" and "Hog Bayou" and are highest at "Bridge." Ammonia is more variable at both "Lake" and "Bridge" than at "Hog Bayou." Variations in surface waters at Rockefeller Refuge are probably due to hydrologic differences between stations. The lake is inside the Gladys McCall impoundment, and circulation here is restricted to one opening in the levee system situated in the southeastern corner of the impoundment. The bridge is located at this opening. The hydrologic system then opens into a marshland lake and diverts from the lake into a minor component tidal channel to the southeast and the major component to the southwest, Hog Bayou, which is connected to the Gulf of Mexico. Water chemistry variations between the three surface water stations are probably controlled by this mechanism of restricted tidal flow. The impoundment receives and collects precipitation, runoff, and tidal exchange. The bridge receives total flow into and from the impoundment during waxing and waning tides. Hog Bayou receives this same flow in addition to flow from the tidal channel.

TABLE 8. Coefficients of variation ($s/\bar{y}$) for selected parameters in surface and ground waters, Rockefeller Refuge.

	LAKE			BRIDGE			HOG BAYOU		
	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$
Na	5429	1386	.26	5786	1969	.34	5423	1584	.29
K	156	58	.37	169	67	.40	170	64	.38
Cl	10259	3396	.33	10147	2824	.28	9550	2343	.25
Ca	197	62	.31	213	78	.37	188	59	.31
Mg	698	198	.28	736	289	.39	671	198	.30
NH ₄	.177	.271	1.5	.206	.292	1.4	.212	.223	1.1
Cd	.004	.008	2.0	.003	.009	3.0	.003	.006	2.0
B	1.08	.723	.67	1.17	.863	.74	.895	.563	.63

	310-ft WELL			660-ft WELL		
	$\bar{y}$	s	$s/\bar{y}$	$\bar{y}$	s	$s/\bar{y}$
Na	932	461	.49	760	31	.04
K	12	8	.67	4	1	.25
Cl	1620	825	.51	1280	287	.22
Ca	106	57	.54	46	4	.09
Mg	85	54	.64	31	6	.19
NH ₄	1.4	.73	.52	1.01	.49	.49
Cd	.002	.004	2.0	.001	.004	4.0
B	.321	.301	.94	.195	.133	.68

The ground-water observation wells at Rockefeller Refuge tap two different subsurface aquifers, hence the consistent differences in variation for the elements sodium, potassium, chloride, calcium, magnesium, ammonia, and boron (Table 8). These elements are less variable in the deeper well. The variation for cadmium is higher in the deeper well, indicating an additional source of variation in the deeper aquifer.

At Rockefeller Refuge, variations for sodium, potassium, chloride, cadmium, magnesium, and ammonia are lowest in the deep ground-water well (Table 8). In addition, low mean values indicate that the aquifer may be restricted. Higher variations in the shallow well relative to surface waters may be due to the connection of this aquifer to surface recharge and infiltration by a saltwater wedge.

At Rockefeller Refuge, consistent anomalies occurred in the values reported for sodium, magnesium, cadmium, chloride, and boron in the surface waters on 8 May 1981 and for sodium, potassium, magnesium, cadmium, and chloride in shallow ground waters on 11 June 1981 (App., Table III-1). Because drilling at the site had not yet commenced, these anomalies are probably natural occurrences (App., Table III-2). Other anomalies occurred after termination of drilling activities and will also be considered natural. Overall, few anomalies were observed in the ground waters at Rockefeller Refuge during the sampling period.

Summary

The major brine-forming elements in the Parcperdue geopressured-geothermal reservoir that may serve as marker elements for surface waters contamination are sodium, potassium, chloride, calcium, sulfate, and boron. In general, the least overall variation for these elements in natural waters was observed in the ground waters at Parcperdue. Major anomalies were observed

in Parcperdue surface waters on 20 November 1980. High values reported for seawater elements are probably the result of saltwater intrusion following the Jefferson Island salt dome collapse. A high potassium variation in the water obtained from one well is due to an anomaly observed on 21 May 1981 and may be due to drilling fluid contamination.

In general, the chemistry of the brine at Sweet Lake, although similar to that at Parcperdue, has greater amounts of magnesium, ammonia, and boron relative to the concentrations of these elements in surface waters. Variations for these elements in surface waters at Sweet Lake are all attributable to natural events, namely seasonal saltwater intrusion and runoff. Water quality data from the two observation wells in the path of ground-water flow around the production well bore are statistically similar, indicating that water quality in these wells may be affected by geothermal well activities. An indirect effect may be indicated by the coincidence of lower water levels in the observation wells with concentration anomalies. Drilling of the geopressured-geothermal well may have caused a temporary lowering of the potentiometric surface, thus allowing for local saltwater intrusion.

To date, no testing or brine sampling has taken place at the Rockefeller Refuge prospect. In general, variations in the major elements for natural waters are lowest in the deepest ground-water observation well and are highest in the shallow ground-water well. The most evident anomalies occurred prior to drilling activities at the geothermal well site and are probably due to seasonal surface recharge and saltwater intrusion.

Variations in natural water chemistries at the geopressured-geothermal design well sites may be caused by seasonal changes in patterns of precipitation, runoff, and saltwater intrusion, which are considered natural occurrences. Other variations may be caused by drilling and production at the test well or by other activities in the area at the sites of oil and gas

wells not related to the geothermal program. Catastrophic events such as the Jefferson Island salt dome collapse are rare and seldom show up in monitoring programs of this scope.

As the statistical package for analysing the water quality data is further refined, more will be understood about natural variations in surface waters around the geopressured-geothermal prospects. A comparison of variations within and between all parameters and stations at each site should help to separate the direct and indirect effects of geothermal well activities from natural events.

SUBSIDENCE MONITORING

The primary emphases of the subsidence monitoring program are to understand the history of ground movements around each of the geopressured-geothermal test sites and to separate the natural and cultural causes of ground movement from potential effects resulting from geopressured-geothermal energy development.

Preliminary work (Wrighton and others, 1981, p. 47-105; Groat and others, 1982, p. 248-250; Trahan, 1982, p. 231-236) quantified relative historical movements in the vicinity of each test site. These movements can, however, be misleading due to the limited area of coverage and lack of multiple years of survey data for comparison. An interconnection and adjustment of the survey networks to a stable area would be necessary to define ground movements more absolutely. Repeated surveys of each area are forthcoming.

The first-order network in southern Louisiana was resurveyed from November 1981 through March 1982 through a cooperative effort between the National Geodetic Survey and the Louisiana Geological Survey. This data, once available, should allow for more accurate prediction of ground movements around the geopressured-geothermal test sites.

Subsidence is likely to occur as a result of shale compaction caused by depressurization of deep subsurface aquifers. This subsidence will be reflected on the surface as structural damage, increased flooding, land loss, and local transgression of the shoreline. The latter two effects are most relevant at Sweet Lake and Rockefeller Refuge where land losses are occurring at substantial rates (Gorman, 1982, p. 499). Field studies at Rockefeller Refuge have shown that the shoreline is migrating inland at a rate of over 40 ft/yr (12 m/yr). This land loss is attributable to some combination of erosion, eustatic sea level rise, and subsidence. The subsidence monitoring

program will provide the data to more fully understand phenomena such as these and will further allow a determination of the additional effects of geopressured-geothermal energy development.

References

- Gorman, L. T., 1982, Marsh alteration in Louisiana--Natural and man-induced: Abstracts with programs, Geol. Soc. America, vol. 14, no. 7, p. 499.
- Groat, C. G., V. R. Van Sickle, D. Trahan, and L. T. Gorman, 1982, Environmental monitoring, in Technical support for geopressured-geothermal well activities in Louisiana--Annual report for the period November 1, 1980 - October 31, 1981: La. Geol. Survey, La. State Univ., Rept. to U.S. Dept. Energy, Contract no. DE-AC08-81NV10174, p. 248-250.
- Trahan, D. B., 1982, Monitoring local subsidence in areas of potential geopressured fluid withdrawal, southwestern Louisiana: Trans., Gulf Coast Assoc. Geol. Soc., vol. 32, p. 231-236.
- Wrighton, F. M., D. Bebout, D. R. Carver, C. G. Groat, and A. E. Johnson, Jr., 1981, Technical support for geopressured-geothermal well activities in Louisiana--Final report for the period September 27, 1978 - December 31, 1980: La. State Univ., Energy Programs Office, Advanced Studies and Research, Rept. to U.S. Dept. Energy, Div. Energy Technology, Contract no. DE-AS05-78ET27160, p. 47-105.

ECOSYSTEM MONITORING

Introduction

A large portion of land-surface area within the two coastal geopressed-geothermal prospect areas (Sweet Lake and Rockefeller Refuge) is composed of sensitive marsh and aquatic ecosystems. Previously published reports describing potential impacts of geopressed-geothermal resource development indicate that land-surface subsidence is a major environmental concern in coastal areas where minor changes in elevation could result in the conversion of productive marsh into open water. In order to document the natural ecosystems surrounding the coastal design wells, base-line surveys of vegetation and aquatic habitats were performed prior to well testing. Because the potential for subsidence impact is much lower in upland locations such as the Parcperdue prospect located on the Pleistocene terrace, no further ecological studies or field acquisition was conducted at the Parcperdue site.

An analysis of historical aerial photography indicates that land loss and subsidence are occurring in the vicinity of the Sweet Lake and Rockefeller Refuge well sites. Standard planimetric techniques were used to quantify land-loss rates. Major land features, such as roads, canals, open water, and impounded marsh, were delineated using U.S. Geological Survey topographic maps with corresponding black-and-white Tobin Aerial Survey photographs for 1935 and 1955 and NASA color-infrared photos for 1978.

Sweet Lake

The Sweet Lake study area is located in southeastern Calcasieu Parish and north-central Cameron Parish along the Pleistocene Prairie and Holocene wetland contact (Fig. 4). The study area is bounded to the north by Highway

FIGURE 4. Location map of Sweet Lake and Rockefeller Refuge study areas.

384; to the east by Highway 27; and to the south and west by the Gulf Intra-coastal Waterway.

Two major ecosystems are found in the study areas: freshwater marsh and prairie. Sagittaria lancifolia (bulltongue) and Pontederia cordata (pickerelweed) are the major species found in the freshwater marsh. Short grasses and weedy herbs typify the Pleistocene prairie ecosystem. Prairie vegetation has been further modified by the agricultural development of rice and soybean crops.

Two soil transects (Figs. 5 and 6), which were conducted in the Sweet Lake marsh, were described according to sediment texture and organic matter content. The soil terms are based on an inorganic-organic classification devised by Kearns (1981). Both cross sections (Figs. 5 and 6) show thick accumulations of organic-rich silts and clays underlain by Pleistocene clays and sandy clays. Dip cross section A-A' indicates two distinct organic-rich layers: one layer of muck containing 35 to 55% organic matter located approximately 24 in. (60 cm) deep and a second layer of peaty muck composed of 56 to 75% organic matter located approximately 79 in. (200 cm) deep. The relatively high organic content and clay composition in the shallow subsurface cause soil compaction and dewatering of the clays throughout the region.

The trends in soil composition shown in strike section B-B' (Fig. 6) are similar to those in the dip cross section. Two organic-rich layers bounded by clays are at equivalent depths as those in A-A', except that the first muck layer is discontinuous across the study area due to shallow faulting.

Structures are absent due to root mottling and previous burrowing. There are sporadic silty-clay to clay laminations throughout the cores, reflecting intermittent flood conditions. This freshwater marsh sequence is underlain by Pleistocene sediments, sandy clays, and dense clays containing

VERTICAL EXAGGERATION = 1000

LEGEND

- PLEISTOCENE**
(SANDY CLAY AND SILTY CLAY)
- ORGANICS <35%**
(ORGANIC CLAY, MUCKY CLAY, CLAYEY MUCK)
- ORGANICS >35%**
(MUCK, PEATY MUCK, PEAT)

FIGURE 5. Dip cross section A-A' in the Sweet Lake study area.

FIGURE 6. Strike cross section B-B' in the Sweet Lake study area.

oxidized nodules. These sediments dip to the south on the average of 3 to 4 ft/mi (5.6 to 7.6 m/km) in the study area.

Approximately 25%, or 5229 acres (2116 ha), of marshland in the Sweet Lake study area was lost during 1935 to 1978 (Figs. 7-9). During this same period, canal building increased 65%, from 19 mi (31 km) in 1935 and 55 mi (89 km) in 1978 (Table 9).

Man's activities have contributed to much of the land reduction in the Sweet Lake area. Agricultural development in the upland terrace and the construction of canals on the marsh surface have contributed to local land loss. The Gulf Intracoastal Waterway, built in the 1950's, has altered the natural surface water hydrology of the area. The marsh has been subdivided by rig access canals and levees that trap surface drainage and impound the marshland. Local landowners pump water into the adjacent marshes via canals. Square Lake, a man-made drainage pond, receives most of the pumped water. In addition, breaks within the levee on the west side of Square Lake account for the land loss between Willow and Square Lakes.

Natural land subsidence may also be contributing to local land loss. Releveling surveys, which are in progress as part of the geopressured-geothermal test well program, will provide the data needed to document elevation trends, if any, within this prospect.

Rockefeller Refuge

The study area (Fig. 4) is located in the southwestern part of the Chenier Plain south of Grand Chenier Ridge, between Price Lake Road on the east and Club Canal on the west. Physiographic units of the study area can be divided into seven distinct groups: coastal mudflats, shell beach, saline marsh, brackish marsh, impounded brackish marsh, dewatered marsh-pasture, and chenier ridge. Each class has a distinct group of plant community, as listed in Table 10.

FIGURE 7. Map of land and water features in the Sweet Lake study area, 1935.

FIGURE 8. Map of land and water features in the Sweet Lake study area, 1955.

FIGURE 9. Map of land and water features in the Sweet Lake study area, 1978.

TABLE 9. Land-loss data for Sweet Lake prospect area.

	<u>1935</u>	<u>1955</u>	<u>1978</u>	<u>Net Change 1935-1978</u>
Total Area (acres)	21,805	21,485	19,863	9% loss
Inland Open Water (acres)	2176	2983	5463	60% gain
Marshland (acres)	19,629	18,502	14,400	27% loss
Canals (mi)	19	25	55	65% gain

TABLE 10. Major vegetative types in Rockefeller Refuge prospect.

SHELL BEACH

<u>Scientific Name</u>	<u>Common Name</u>
<u>Batis maritima</u>	Saltwort
<u>Salicornia sp.</u>	Glasswort

SALINE MARSH

<u>Spartina alterniflora</u>	Smooth grass
<u>Distichlis spicata</u>	Saltgrass
<u>Salicornia sp.</u>	Glasswort

BRACKISH MARSH

<u>Spartina patens</u>	Wire grass
<u>Phragmites communis</u>	Roseau cane
<u>Scirpus validus</u>	Soft stem bulrush
<u>Scirpus olneyi</u>	Three-corner grass

IMPOUNDED BRACKISH MARSH

<u>Spartina patens</u>	Wire grass
<u>Phragmites communis</u>	Roseau cane
<u>Borrichia frutescens</u>	Sea ox eye
<u>Iva frutescens</u>	Marsh elder

DEWATERED MARSH-PASTURE

<u>Spartina patens</u>	Wire grass
<u>Distichlis spicata</u>	Saltgrass
<u>Rupus sp.</u>	Blackberry

CHENIER RIDGE

<u>Populus deltoides</u>	Cottonwood
<u>Quercus virginiana</u>	Live oak
<u>Pragmites communis</u>	Roseau cane
<u>Verbena sp.</u>	Verbena
<u>Ambrosia sp.</u>	Ragweed

Brackish to saline marsh, supported by organic-rich soils, predominates in the study area. A typical soil sequence (Fig. 10) has a surficial layer of humus followed by a thick sequence of mucky clays underlain by organic gray clay. Clay laminations are common in the upper 20 in. (50 cm); otherwise, sedimentary structures are absent in the cores. Intermittent shell layers found throughout the Rockefeller Refuge prospect indicate the presence of buried beach ridges. These ridges are parallel to Grand Chenier Ridge and the present shoreline, as identified from boreholes and aerial photographs.

Land loss in the Rockefeller Refuge study area (Figs. 11-13) is significant: 4894 acres (1981 ha), or 28%, of marshland was lost during 1935 to 1978 (Table 11). The immediate coastline below the well site is receding at rapid and varied rates (Fig. 14). During 1935 to 1954, beach erosion occurred at a mean rate of 30 ft/yr (9 m/yr) and accelerated to a mean rate of 47.5 ft/yr (14.5 m/yr) for the period from 1955 to 1978.

Since the early 1950's, a tremendous amount of marshland has reverted to open water due to expanding oil and gas development in the immediate area. Roads and canals have increased 100% and 86%, respectively, between 1935 and 1978; in turn, open water has increased 86% over the 43-year study period. The canal network and corresponding spoil banks surrounding the Rockefeller Refuge prospect have impounded 1300 acres (526 ha) of brackish marsh. The accumulation of standing water in this impoundment area has converted marsh vegetation into barren mudflats and open water spaces.

The second significant area of land loss occurs along the shoreline and saline marsh zone. Ongoing processes, such as overwash deposition, sea level rise, storm activities, and subsidence, are possible contributors to regional shoreline retreat and coastal erosion. These processes have developed the present shore zone within the study area, which is composed of coarse shell material.

TABLE 11. Land-loss data for Rockefeller Refuge.

	<u>1935</u>	<u>1955</u>	<u>1978</u>	<u>Net Change 1935-1978</u>
Total Area (acres)	17,957	17,026	16,155	10% loss
Inland Open Water (acres)	491	3217	3583	86% gain
Marshland (acres)	17,466	13,809	12,572	28% loss
Roads (mi)	0	8	25	100% gain
Canals (mi)	7	31	48	85% gain

FIGURE 10. Composite soil profile in the Rockefeller Refuge study area.

FIGURE 11. Map of land and water features in the Rockefeller Refuge study area, 1935.

FIGURE 12. Map of land and water features in the Rockefeller Refuge study area, 1955.

FIGURE 13. Map of land and water features in the Rockefeller Refuge study area, 1978.

FIGURE 14. Shoreline changes along Rockefeller Refuge prospect, 1935-1978.

Tropical storms and hurricanes inundating the Chenier Plain have caused short periods of landward sediment migration and flooding. From 1935 to 1978, 19 storm events were recorded (Figs. 15 and 16). The frequency of these storms has prevented the backshore facies of the Rockefeller Refuge beach from developing a berm; consequently, the local beach profile is relatively flat and unprotected.

Within the beach zone, abandoned well sites, rig access roads, and canals are specific sites where land loss and erosion have accelerated at a rate greater than the mean rate of 47.5 ft/yr (14.5 m/yr). A remnant pond on the eastern side of Rockefeller Refuge beach and the Beach Prong outlet located in the western limits of Rockefeller Refuge have also been eroding at a rate of approximately 50 ft/yr (15.3 m/yr). Further inland along the banks of Beach Prong and Hog Bayou, erosion and enlargement of the bayou have caused the denudation of nearby marshland.

A study of the Beach Prong-Hog Bayou system by Nichols (1955) shows that the present land-loss and saltwater intrusion problems along Rockefeller Refuge beach have been prevalent since the 1950's.

Summary

Land loss in the Sweet Lake and Rockefeller Refuge study areas is typical of the Chenier Plain. Both man-induced and natural processes are interacting and accelerating coastal wetland loss. Man's activities, such as canal dredging and agricultural development, have reduced marshland by 4106 acres (1662 ha) in the vicinity of Sweet Lake. Furthermore, the interruption of fluvial-derived sediment on the marsh surface has halted vertical accretion of the marsh. Regional processes, such as erosion, saltwater encroachment, lack of sediment deposition, and subsidence, are factors contributing to natural land loss in the Rockefeller Refuge prospect. Local oil and gas

FIGURE 15. Tropical cyclones affecting the Chenier Plain, 1935-1954.

MODIFIED AFTER NEUMANN AND OTHERS, 1978

FIGURE 16. Tropical cyclones affecting the Chenier Plain, 1955-1982.

MODIFIED AFTER NEUMANN AND OTHERS, 1978

development, including construction of access canals, spoil banks and impoundments, caused significant inland land loss in both areas. This study and other investigations in coastal Louisiana have shown that erosion rates have been increasing since the early 1900's.

References

- Kearns, F. L., 1981, Personal commun.: La. Geol. Survey, Baton Rouge, La.
- Neumann, C. J., G. W. Cry, E. L. Caso, and B. R. Jarvinen, 1981, Tropical cyclones of the North Atlantic Ocean, 1871-1980 (rev.): National Climatic Center, Asheville, N.C.
- Nichols, L. G., 1955, A study of Beach Prong of Hog Bayou: Rept. to La. Wildlife and Fisheries Commission, Fur and Refuge Division, New Orleans, La.

MICROSEISMIC MONITORING

Introduction

The Louisiana Geological Survey (LGS) and Louisiana State University (LSU) conducted base-line seismic studies at the DOE Parcperdue, Sweet Lake, and Rockefeller Refuge prospects to investigate microseismicity associated with geopressured-geothermal fluid production. These monitoring programs were designed, first, to establish the nature of the local seismic activity prior to production and, second, to determine if well activities induce changes in the rate of local fault movement. Published accounts of seismic monitoring at similar sites indicate that flow testing and reinjection can induce natural, local microseismic events (Sorrells, 1980; Mauk, Sorrells, and Kimball, 1981; Van Sickle and Groat, 1981; Mauk, 1982).

This section describes the installation and operation of the three seismic networks established at Parcperdue, Sweet Lake, and Rockefeller Refuge and presents the results obtained through October 1982.

Parcperdue

The Parcperdue microseismic array consists of five continuous recording seismograph stations in the North Parcperdue gas field in Vermilion Parish, Louisiana. The locations of these stations, local cultural features, and estimated locations of growth faults at a depth of 16,000 ft (4877 m) are shown in Figure 17. The aperture of the array is 4 km. Latitudes, longitudes, and elevations of the sensors are listed in Table 12 below. Each station consists of a Geotech S-500 seismometer which is locked in a borehole at depths between 70 and 80 ft (21 to 24 m). The signal from the seismometer is magnified using an amplifier and then is FM multiplexed to a voice-band carrier frequency for transmission to a common data collection point in a

FIGURE 17. Locations of seismograph stations, test wells, and growth faults at a depth of about 16,000 ft, Parcperdue.

shelter at Youngsville, Louisiana. Data is transmitted via telephone telemetry circuits. At Youngsville, the signals from the five stations are amplitude-conditioned and multiplexed together for transmission via ATT long lines to the Teledyne Geotech laboratory (subcontracted by LSU) at Garland, Texas.

TABLE 12. Parcperdue seismic array.

<u>Site</u>	<u>North Latitude</u>	<u>West Longitude</u>	<u>Elevation (ft)</u>	<u>Magnification (x 1000 @ 5 Hz)</u>	<u>VCO Hz</u>
LSU1	30°04'23.7"	91°58'55.5"	-74	180	1020
LSU2	30°04'42.6"	92°01'53.4"	-80	198	1360
LSU3	30°02'57.0"	92°00'25.5"	-80	169	2040
LSU4	30°02'06.0"	92°02'46.5"	-72	155	2380
LSU5	30°04'02.4"	92°03'15.3"	-79	154	1700

In Garland, the five station signals are demultiplexed from their respective carriers using Teledyne Geotech 46.12 discriminators. The signals and precise time code recorded in Universal Coordinated Time (UTC) are then recorded on magnetic tape and on 16-mm film. The unit-gain velocity response of the system is illustrated in Figure 18. The magnification at a frequency of 5 Hz of the individual stations is given in Table 12. Variations in effective magnification reflect the variability of the ambient noise at the different sites.

A routine analysis involves a review of the 16-mm film for extraction of data for processing.

Data Analysis Procedures

Data generated by the monitoring system are analyzed using standard microseismic techniques to yield basic information about the origin times,

FIGURE 18. Velocity response, Parcperdue.

locations, and magnitudes of observed events. The seismograms are reviewed carefully to detect any microseismic events that may occur. When an event is detected, the analyst measures the amplitude, period, and arrival times of the P (compressional), S (shear), and L_R (surface) wave of the event. The desired accuracy of the arrival time estimate is ± 0.01 second for P waves and ± 0.05 second for S waves. If this degree of accuracy cannot be achieved with the film records, the analyst may request a filtered version of the signal recorded on magnetic tape. Filter options include variable high-pass, low-pass, and band-pass operators. The amplitude, period, and arrival time data are stored for subsequent input into a computer code (MEHYPO) which estimates the origin times, source coordinates, and local magnitudes of the observed events. This code utilizes arrival time data, sensor location data, and a plane-layered seismic velocity model of local subsurface structures to estimate origin times and source coordinates for the observed events. The estimation algorithm is similar to that described by Lee and Lahr (1972). The algorithm computes the origin time and source coordinates which minimize the mean square difference between observed and predicted arrival times at the various sensor locations. The code also provides various location uncertainty estimates, which are based upon the assumption that the arrival time errors are normally distributed and that the seismic velocity structure is known without error. The sensor frequency response data, the P-wave amplitude, and period data are used to compute the local magnitudes of the observed events.

The P-wave velocity structure is based on the Schlumberger sonic log from the Dow L. R. Sweezy No. 1 well. Mean velocities for lithologic units were derived by averaging velocities determined every 10 ft (3 m) for thick units and every 2 ft (0.6 m) for thin units. The dual induction and caliper logs were used as measures of reliability for the sonic log. Wide departures

of the deep and intermediate induction logs were taken as indications of significant formation penetration by drilling muds. The sonic log for these zones is probably not an accurate indication of the true velocity. Three sand units with very low velocities at depths less than 4000 ft (1219 m) had significant curve departures on the dual induction logs. Drilling reports for 13 January through 15 January 1982 indicate loss of mud to, and subsequent influx of sand from, these horizons, an indication of high porosity and permeability and low shear strength. Thus, although the true velocities for these units may not be as low as that indicated by the sonic log, they are significantly different from those of the surrounding strata.

The P-wave velocity model used for hypocenter determination at the Parcperdue array is given in Table 13. This flat-earth model is used for local events only. The corresponding S-wave velocity structure was determined using the following formulation:

$$V_S = V_P \left(1 + \frac{1}{1-2\sigma} \right)^{1/2}$$

where V_S = shear wave velocity,
 V_P = compressional wave velocity, and
 σ = Poisson's ratio (0.25).

Epicenters are computed only for events observed at three or more stations because of possible ambiguities of solutions based on data from fewer stations.

Some of the signals of interest consist primarily of surface waves. The velocities of the fundamental and the first and second higher mode Rayleigh (surface) waves for this region are illustrated in Figure 19. Because the average surface wave observed has a frequency less than 2 Hz, it was possible to determine a general (not accurate) location of the sources of these signals using a fixed average acoustic velocity.

TABLE 13. Velocity model for Sweet Lake
microseismic monitoring network.

Layer Parameters	Thickness (km)	P-Wave Velocity (km/sec)	S-Wave Velocity (km/sec)
1	0.1310	1.0000	0.3015
2	0.3270	1.3910	0.4194
3	0.0800	2.2300	0.6724
4	0.1180	2.3880	0.7049
5	0.0550	2.0320	0.6127
6	0.0120	0.9060	0.2732
7	0.1300	2.3020	0.9398
8	0.0090	2.5400	1.0370
9	0.0370	1.3890	0.8417
10	0.2600	2.5000	1.0206
11	0.0140	1.6600	0.6777
12	0.6930	3.2000	1.3064
13	0.2120	3.5000	1.4289
14	0.3310	3.7160	1.5171
15	0.4320	3.9930	1.6301
16	0.3810	4.1940	1.7122
17	0.4680	4.3630	1.7812
18	0.2860	3.7700	1.5391
19	0.0220	4.0910	1.6701
20	0.0570	3.3920	1.3848
21	0.3000	3.5000	1.8708
22	0.3000	3.8000	2.0312
23	0.3000	4.1000	2.1915
24	0.3000	4.4000	2.3519
25	1.0000	4.7000	2.5123
26	5.0000	4.9000	2.6192
27	200.0000	5.1000	2.7261
28	1000.0000	5.3000	2.8330

FIGURE 19. Rayleigh wave phase and group velocities for the Texas and Louisiana coast.

Local seismic magnitudes were based upon maximum surface wave amplitude and were calculated as the following:

$$M_L = \log_{10} (A/2) - 1.15 + 0.8 \log_{10} (X)^2$$

where M_L = the local magnitude,

A = the peak-to-peak surface wave amplitude in nanometers (10^{-9} m),

$X = [(\text{epicentral distance in km})^2 + (\text{hypocentral depth in km})^2]^{1/2}$,

and $X \geq 1.0$

The constant -1.15 in the magnitude equation assumes a surface wave to P-wave amplitude ratio of 10. Thus, a magnitude 0 event at a 1-km distance would generate surface waves with a peak-to-peak amplitude of 28.3 nanometers (nm) and P-waves with an amplitude of about 2.8 nm.

Magnitudes may be calculated alternatively using duration as

$$M_D = -2.22 + 2.28 \log (D)$$

where D = duration in seconds from onset of P to return of coda to ambient noise level.

This equation is based on the magnitude duration equation used by the Tennessee Earthquake Center for the Gulf Coastal Plain which correlates with the Richter magnitude scale.

Given the magnification of the Parcperdue stations and the typical average background noise level, the minimum magnitude event which can be detected and located using three or more stations is 1.0. This magnitude is the realistic detection threshold of the array. Events with smaller magnitudes occasionally may be detected and located under unusual circumstances.

Monitoring Results

Only one naturally occurring seismic event with sufficient amplitude for detection of local subsurface sources was recorded during November 1981 to

September 1982. However, a variety of background signals demonstrated the capability of the monitoring system and data analysis procedures. These signals include 1) seismic signals far beyond the reservoir area, such as salt mine blasting, chemical plant explosions, and regional and teleseismic events; 2) explosions, such as seismic exploration shots and calibration shots; 3) acoustic signals from well drilling, well production, and sonic boom sources; and 4) noise from cultural activity in the area. Table 14 lists all of the important events recorded from November 1981 to September 1982; these events are divided into three groups: earthquakes, special events, and large-amplitude impulsive Rayleigh events.

Only two naturally occurring earthquakes with discernible P-waves were recorded at the Parcedue seismic array during 1 November 1981 to 1 September 1982. These events were both recorded during February 1982, and only one of these was located within 6 miles (10 km) of the array center. This event occurred at 14:46:16.65 UCT on 26 February 1982 and had a duration magnitude (M_D) of approximately 1.5. A hypocentral solution depth of 5085 ft (1550 m) was computed using several different solution techniques. The resulting epicenter is illustrated on Figure 20 as an asterisk with ellipse axes indicating a 90% level of confidence. A 16-mm Develocorder film seismogram of this earthquake is illustrated in Figure 21.

The analysis of the 26 February 1982 earthquake was assisted by the production of tape reproductions, which were time-expanded and bandpass-filtered (Fig. 22). The corner frequencies for filtering were selected to be 20 and 200 Hz, respectively, with an 18 dB (decibel)/octave roll-off.

The primary P- and S-wave arrival times used in the location procedure are indicated on Figure 22 by arrows. In addition to the primary wave arrivals, there are complex P- and S-wave coda trains which are rich in

TABLE 14. Parcperdue event log from 1 November 1981 to 1 September 1982.

I. EARTHQUAKES

9 February 1982	17:44:42.48 UCT	No epicenter determined
26 February 1982	14:46:16.65 UCT	Depth=1.55 km, Magnitude=1.5

II. SPECIAL EVENTS

16 December 1981	23:19:03.20 UCT	Law Engineering Test Shot #1
17 December 1981	12:12:03.15 UCT	Law Engineering Test Shot #2

III. LARGE-AMPLITUDE IMPULSIVE RAYLEIGH EVENTS

14 December 1981	09:23:33	Best solution at 300 m/sec
10 June 1982	08:14:02	No epicentral solution found
17 June 1982	01:04:30	No epicentral solution found
17 June 1982	01:07:44	No epicentral solution found
17 June 1982	01:12:19	No epicentral solution found
25 June 1982	21:04:53	No epicentral solution found
17 July 1982	21:44:25	No epicentral solution found
23 July 1982	11:45:36	No epicentral solution found
31 July 1982	23:11:20	No epicentral solution found
3 August 1982	16:23:19	No epicentral solution found
5 August 1982	16:56:41	No epicentral solution found
5 August 1982	21:04:20	No epicentral solution found
6 August 1982	23:33:34	Best solution at 300 m/sec
7 August 1982	00:25:51	No epicentral solution found
8 August 1982	11:39:27	Best solution at 340 m/sec
14 August 1982	20:39:41	No epicentral solution found
16 August 1982	19:16:10	No epicentral solution found
17 August 1982	00:19:40	No epicentral solution found
17 August 1982	00:21:50	No epicentral solution found

FIGURE 20. Epicenter of 26 February 1982 earthquake, 14:46:16.65 VCT. ($M_D = 1.5$; depth = 1.55 km.)

FIGURE 21. Seismogram of 26 February 1982 earthquake, 14:46:16:65.
($M_D = 1.5$; depth = 1.55 km.)

FIGURE 22. Bandpass-filtered (20-200 Hz, 18 dB/octave roll-off) signals for 26 February 1982 earthquake. Polarities may be reversed in playback.

refracted and reflected energy packets. Stations LSU1 and LSU3 have significant high-frequency arrivals early in the P-wave trains. These arrivals are distinctly absent from LSU2, LSU4, and LSU5. Several high-amplitude reflected P phases prominent on the records for LSU1, LSU2, and LSU3 are either absent or not obvious on LSU4 and LSU5. These variations of complexity of P- and S- wave codas were also noted for the Law Engineering explosions of 16 and 17 December 1981, which will be discussed next. Additional digitization and analyses of these events could contribute significantly to our understanding of the Parcperdue structure and seismic characteristics.

On 16 and 17 December 1981, two sets of explosives were detonated by Law Engineering approximately 4.3 miles (7 km) from the nearest seismometer at the Parcperdue array. The explosives consisted of 50-lb (23-kg) shots in a 200-ft (61-m) borehole. The location of the borehole is lat $29^{\circ}59'15.0''$ N., long $91^{\circ}59'38.9''$ W. on the northwest edge of Lake Peigneur (Fig. 23). Both shots yielded phase arrivals which are very clear (Figs. 24 and 25). Because the locations and origin times for both explosions are known, these events were used as calibration shots to determine several characteristics about array location capabilities and regional phase propagation effects.

A series of location experiments conducted with each shot are summarized in Table 15. By fixing the location and origin time of the event and comparing the computed travel times of the P-phase to each station with the observed travel time, we determined the absolute travel time residual. The residual contains the common clock error and the individual time errors for each station. Since both shots are at the same location, the travel time residuals to each station for each shot should be identical if the clock error is the same. The stations have been arranged in order of increasing epicentral distance rather than in their normal numerical progression

FIGURE 24. Seismogram of 16 December 1981 explosion, 23:19:02.2 VCT.
(Clock correction = 1.2 sec.)

FIGURE 25. Seismogram of 17 December 1981 explosion, 12:12:03.15 VCT.
(Clock correction = +1.49 sec.)

TABLE 15. Geophysical blasting time residuals for the Sweet Lake microseismic monitoring network.

	P-WAVE TIME RESIDUALS (FIXED LOCATION AND ORIGIN TIME)					ABSOLUTE EPICENTRAL ERROR			90% CONFIDENCE ERROR ELLIPSE		
	LSU3 (7.10 km) (sec)	LSU4 (7.72 km) (sec)	LSU1 (9.54 km) (sec)	LSU5 (10.93 km) (sec)	LSU2 (10.94 km) (sec)	Time Error (sec)	Lat Error (km)	Long Error (km)	Semi axis (km)	Lengths (km)	azimuth (° from N.)
Shot 1a (Uncorrected)	1.08	1.20	1.44	1.45	1.50	1.43	-0.212	-0.310	39.2	± 5.7	159
Shot 1b (Corrected for 1.44 sec)	-0.36	-0.23	0.00	0.05	0.00	0.00	-0.337	-0.369	37.3	± 5.5	159
Shot 1c (Corrected for station residuals)	0.00	0.00	0.00	0.00	0.00	0.00	0.199	0.049	0.8	± 0.1	158
Shot 2a (Uncorrected)	-1.66	-1.54	-1.31	-1.25	-1.30	-1.28	-0.212	-0.310	39.2	± 5.7	159
Shot 2b (Corrected for -1.31 sec)	-0.35	-0.23	0.00	0.06	0.01	0.05	-0.275	-0.340	38.2	± 5.6	159
Shot 2c (Corrected for station residual)	0.00	0.00	0.00	0.00	0.00	0.05	-0.03	-0.02	0.3	± 0.1	158

(Table 15). Comparing rows 1a and 2a of Table 15 clearly indicates that there is a different recording clock error for each of the shots which are separated by approximately 13 hours. In addition, if the hypocenter algorithm is permitted to converge to a solution given the two sets of arrival times, both data sets converge to the same location, which is 696 ft (212 m) south and 1017 ft (310 m) west of the actual explosion location. The error in origin time is nearly identical to the travel time error associated with station LSU1, which is roughly the mean distance to the center of the array. The 90% confidence ellipses are also given for these solutions and indicate a low level of confidence in the computed locations. The known absolute error, however, is really very small, particularly when the location is fully an array diameter outside the network. The locations of the first trial solutions are illustrated in Figure 23 as 1a and 2a.

Because the absolute origin time error and the travel time error to the center of the array are equivalent, it can be assumed that this error is predominantly a common clock error. For shot 1, therefore, 1.44 seconds were subtracted from the arrival times at each station, and for shot 2, 1.31 seconds were added. Although the exact clock correction is unknown, this, in effect, should result in a travel time residual set for each explosion which is station-equivalent. The hypocenter algorithm was run on these corrected data sets, and the results are given in Table 15 in rows 1b and 2b. Note that this procedure resulted in sets of travel time residuals for the two explosions which are now equivalent. Furthermore, the principal effect on the iterative solution is to remove the origin time error without significantly affecting the absolute epicentral error or the dimensions of the confidence ellipses. The locations of these corrected solutions are illustrated in Figure 23 as 1b and 2b. It is not surprising that this correction had the effect it did because origin time error and array clock

error are station-common effects and will not affect location. Similarly, it is not surprising that the error ellipse has not changed dimensions since common travel time errors contribute nothing to relative station travel time differences. It is interesting to note the enormous dimensions of the 90% confidence ellipse when the actual differential residuals are very small and the computed location is very close to the absolute location.

The final location procedure was to eliminate individual station corrections and to reiterate the hypocenter solution. Generally, station corrections are necessary when the velocity model deviates in some manner from the real earth. Three possibilities include lateral heterogeneities in velocity (geologically, this may relate to fault blocks), deviation of the actual vertical velocity distribution from the model used, and non-horizontal layering or dipping interfaces. Of these three, we believe that a combination of fault-blocked dipping interfaces is the reason for the observed residuals. The span of travel time residuals across the dimensions of the array is too large to be accommodated easily by a simple dipping interface. The similarity of the residuals at stations LSU3 and LSU4 and large difference from the other three stations indicate that a major discontinuity in velocity structure separates LSU3 and LSU4 from the rest of the array. The decrease in negative residual from LSU3 to LSU4 suggests the likelihood of a south-southeast dipping interface rather than the flat earth model used in the MEHYPO algorithm. The dimensions of the remaining residuals are too small to suggest meaningful analyses or interpretation.

Inserting the station corrections in the hypocenter solutions for the two explosions yields rows 1c and 2c (Table 15). The computed hypocenters are illustrated on Figure 23 as 1c and 2c. Note that only when these station corrections are added to the solutions do the computed locations converge to the actual location of the explosions, and, more importantly, the dimensions

of the error ellipses dramatically decrease. The importance of this experiment cannot be overemphasized. It unquestionably indicates that the computed locations of events within two diameters of the array for which five P-wave observations are possible are reasonably accurate even when the error ellipse is large. When the error ellipse is small, the computed epicenter can be considered the actual epicenter with a very high degree of confidence.

A second interesting observation can be made from these explosions by examining the P-wave coda from a high-speed playback of the first five seconds of data (Fig. 26). The complexity of the P-wave signature is a function of several parameters, including many possible reflections and refractions. It has been shown convincingly by Aki and Chouet (1975) that the complexity and duration of the coda are directly related to the number and orientation of possible backscattering sources in the region. From the examination of the expanded P-wave coda for the LSU array stations generated by the second Law Engineering explosion, it is apparent there are three distinctively characteristic coda records. Stations LSU3 and LSU4 have relatively identical coda details; both have complex signals with durations exceeding 4.5 seconds. Stations LSU2 and LSU5 have less complex coda trains, and, regardless of the overlying noise source in LSU2, the signal associated with the explosion is nearly identical with that of LSU5. The duration of these coda trains is less than four seconds. LSU1, the least complex of all, had a coda duration of less than two seconds. We believe the variations in complexity of these signals are significant and, furthermore, are rational in a backscattering theory context. The observed coda complexity does not show any consistent relationship with distance and probably not with azimuth (Note: The aperture is not large enough to make a definitive statement about azimuth). The coda complexity is not a function of attenuation or wave front spreading.

FIGURE 26. Expanded P-wave coda for 17 December 1981 explosion. (Polarities may be reversed in playback.)

By comparing the observed P-wave codas (Fig. 26) given the station distribution with respect to growth faults (Fig. 23), it is possible to infer a logical explanation for the observed coda behavior. It is well known that fault surfaces constitute first-order diffraction sources, particularly for high-frequency waves. Thus, it can be assumed that the growth faults will be probable geological sources for backscattering sources. Stations LSU3 and LSU4 are on the south and downdip side of the known local growth faults. If it is assumed that the growth faults dip at approximately 45° to 65° , then stations LSU2 and LSU5 lie north of many, but not all, of the known growth faults at 16,000 ft (4877 m). It seems likely that these growth faults are acting as primary reflectors, and fewer of them are capable of reflecting waves to LSU2 and LSU5 than to LSU3 and LSU4. Finally, LSU1 appears to have relatively less complexity in its P-wave coda because it has even fewer backscattering sources available than any of the other stations. This is an important observation because it has never before been observed that the coda can be affected so dramatically by local discontinuities. Additional similar studies using local and near-regional exploration shots for both development of station travel time residuals and analysis of P-wave coda complexity could be very revealing.

The category of large-amplitude impulsive Rayleigh events consists of all impulsive events for which no P- or S-waves are discernible. Only one or more Rayleigh phases are present, generally the Airy phase, and the arrivals are impulsive. Only three of these events have been located successfully using velocities of approximately 300 m/sec. The first event listed in group III of Table 14 is believed to originate from an operating gas well located near the epicenter. The other events in this group which have been located have epicenters that do not correspond to any type of known activity or source. Normal methods of locating Rayleigh events have not been successful

with the remaining events and yield very unpredictable results. The temporal correspondence of these events with well production and disposal strongly suggests that these are the signatures of events related to the pumping. Figures 27 and 28 illustrate two examples of the impulsive Rayleigh events at Parcperdue. These two events were recorded during flow tests 7 and 8, respectively, and show the extreme randomness of the orders of arrivals at the various Parcperdue stations. It is unknown whether these events are related to withdrawal or injection of the brines, since accurate locations have not been obtained.

Sweet Lake

Woodward-Clyde Consultants conducted a preliminary study of background seismicity with one portable Sprengnether MEQ-800 instrument beginning in late March 1980. During the first quarter (ending 31 August 1980), the siting, design, and installation for the eight permanent seismic stations were completed. The permanent seismic network went on-line in July 1980, with two stations recording data at the central recording facility in the consultants' Baton Rouge, Louisiana, office. The remaining six permanent stations became operational by 28 August 1980.

The Sweet Lake microseismic monitoring network consists of eight permanent field stations (Fig. 2). Location coordinates are given in Table 16. Other pertinent station data, are also installation, and recording dates of seismic activity listed in Table 17. Data collected at each field station are multiplexed and transmitted over telephone lines to the central recording facility in Baton Rouge, Louisiana.

At the central recording facility, all data are continuously recorded on magnetic tape. Parallel with the magnetic tape recording system, selected station data are recorded on three drum recorders. Drum records are scanned

FIGURE 27. Impulsive Rayleigh arrival, 17 June 1982, 01:07:44 VCT.

21:05:00 UCT (UNCORRECTED)

10 SEC

FIGURE 28. Impulsive Rayleigh arrival, 25 June 1982, 21:04:54 VCT.

TABLE 16. Sweet Lake microseismic monitoring
network station coordinates.

	<u>Latitude</u>	<u>Longitude</u>
CPT	30°N02'37"	93°W12'47"
CPF	30°N00'04"	93°W08'02"
CLB	30°N01'16"	93°W08'43"
SFY	30°N00'50"	93°W10'56"
HWN	30°N01'05"	93°W05'19"
WLR	30°N03'34"	93°W07'41"
JCF	30°N02'16"	93°W07'01"
HWS	29°N59'33"	93°W05'17"

TABLE 17. Station data from the Sweet Lake microseismic monitoring network.

<u>Station Code</u>	<u>Station Name</u>	<u>Seismometer Depth (ft)</u>	<u>Date Seismometer Installed</u>	<u>Date On- Line to B. R. Office</u>	<u>Date First Recorded on Mag. Tape</u>	<u>Date of First Recording on Mag. Tape</u>
CLB	Core Lab	65	26 July 1980	30 July 1980	3 Aug. 1980	29 Aug. 1980
CPF	Charlie Precht's Farm	90	26 July 1980		31 July 1980	
JCF	James Cox's Farm	75	28 July 1980		3 Aug. 1980	
CPT	Charlie Precht's Trl. Hwy. 385	70	25 July 1980		28 Aug. 1980	
HWS	Hwy. 27 South	75	28 July 1980		28 Aug. 1980	
HWN	Hwy. 27 North	90	28 July 1980		31 July 1980	
SPY	Sammy Faulk's Yard	70	28 July 1980		4 Aug. 1980	
WLR	Ward Line Rd.	75	29 July 1980		4 Aug. 1980	

daily to detect possible seismic activity. Upon detection of a possible natural seismic event, all station data are played back from the magnetic tape into hard copy format through an oscillograph. Station data are further reviewed and analyzed in hard copy format such that hypocenter locations and other characteristic information may be obtained. At present, data reduction is accomplished using a modified version of the earthquake location program FASTHYPO.

Data Analysis Procedures

All VR-60 visual drum records are reviewed daily. Events of interest are played back from the magnetic tape recorder into the oscillograph, which prints all station data and the time code onto UV light-sensitive paper. The arrival times for the event are measured for each station along with other data such as the amplitude of the largest body wave and its respective period, the duration of the event at each station, and first motion direction, compressional or dilatational wave. The observed arrival times at each station are entered as data into a microcomputer used to locate the epicenter, depth to focus, and origin time of the event. The computer program FASTHYPO uses the arrival time data along with the station locations and an assumed ten-layer velocity model to arrive at a "best-fit" location. The best location is listed in the catalog of events in Appendix IV-1 along with the error estimates and is plotted on maps of the area to show its relation to the network location and known or inferred faults in the area.

The velocity model employed for computer location of naturally occurring events and blasts at the Sweet Lake DOE/Amoco Fee No. 1 test well is based in part on the sonic log of the Sweet Lake well (Table 18). Examination of the Sweet Lake well log suggests that the actual velocity conditions include an area of decreasing velocity near the geopressed zone. For the purposes of

TABLE 18. Velocity model for Sweet Lake seismic monitoring network.

<u>Velocity (km/sec)</u>	<u>Depth Interval (km)</u>
1.530	0.00 - 0.08
1.710	0.08 - 0.15
1.800	0.15 - 0.27
2.050	0.27 - 0.60
2.257	0.60 - 1.20
2.620	1.20 - 2.28
2.891	2.28 - 4.99
3.182	4.99 - 6.00
3.409	6.00 - 7.00
3.636	7.00 +

P-Wave: S-wave velocity ratio equals 1.66:1.00.

ALTERNATIVE "SLOW WAVE"*
VELOCITY MODEL FOR
THE SLSMN

<u>Wave Velocity (km/sec)</u>	<u>Depth Interval (km)</u>
0.342	0.00+

*Slow waves are assumed to be long-period Rayleigh (L_R) waves, but could be S-waves, since depth to focus can sometimes be determined.

computer location, the actual velocities have been averaged so that the velocity model contains nine layers of increasing velocity, with depth overlying a half-space of higher velocity.

The ratio of P-wave to S-wave velocity is also used in the FASTHYPO algorithm. For the Gulf Coast region, the ratio of P-wave to S-wave velocity decreases exponentially with increasing depth down to approximately 1.3 mi (2.1 km), then decreases linearly with depth. The change in the P to S velocity ratio reflects the change in Poisson's ratio with depth. At the depth of the geopressured zone 14,500 to 17,000 ft (4.42 to 5.18 km), the P to S velocity ratio varies from approximately 1.67 to 1.63. For the purposes of event location with the FASTHYPO program, the velocity ratio has been set at 1.66.

Earthquakes are assigned magnitudes that estimate the sizes of the events relative to some zone-magnitude hypothetical event. Direct application of the Richter scale of magnitude to earthquakes occurring at local and regional distances from the Sweet Lake network is inappropriate because of differences in site geology and in the type of detection equipment used. Several other types of magnitude scales exist, including ones based on duration of the recorded signal. Magnitudes reported for events occurring at a geothermal test well in Texas (Mauk, 1982) are based on signal duration:

$$(1) \quad M_D = 2.28 \log^{10}(T) - 2.22$$

where T = the time in seconds from P-wave first motion until the signal is no longer recognizable above average noise level.

Magnitudes calculated with this scale should not be confused with magnitudes of the Richter scale; i.e., a magnitude of 1.0 on the above scale may not correspond with a Richter magnitude of 1.0. In the comparison of the sizes of events occurring at local distances within the Sweet Lake monitoring array, the duration magnitude formula is used, as shown in equation (1)

above; however, listed magnitudes for the Sweet Lake network should not be thermal prospects.

Monitoring Results

During the period 1 November 1981 to 31 July 1982, 418 events were recorded by the Sweet Lake monitoring array. An event catalogue is presented in Appendix IV-I; Table 19 is the key to the event catalog. Of the 418 recorded events, 87 could not be located; 210 were possible natural events outside the boundaries of the network; 4 were probably blasts; and 48 were of unknown origin outside the network. The remaining 69 events are possible natural events which occurred inside the network. The character of these events has been variable. A few of the events appear to have identifiable high-frequency body waves (P- and S-waves), while others were recorded only as low-frequency waves (probably S-waves or surface waves). Some events have been tentatively identified as earthquakes because they occurred at otherwise quiet times of day (i.e., they are not part of normal geophysical exploration blast series which occur almost every afternoon). Most events had no clear body-wave arrivals and had to be located using a velocity model more appropriate to surface waves. For these events, the velocity model used was a half-space with velocity equal to 0.342 km/sec. The significant variation in trace signature for a single event at different stations probably is indicative of complex attenuation in the area. In some cases, variable attenuation made wave-arrival matching between stations difficult to establish for the smaller events. Computed locations and depths of all events listed in the event catalog should be assumed to be approximate until a more accurate velocity model can be made.

Analyses of the events which occurred during August, September, and October 1982 have not been completed; some general observations, however, are possible (App. IV-2).

TABLE 19. Key to event log information, Sweet Lake microseismic monitoring network.

Origin Time (UTC)	Expressed in Universal Time Coordinated (UTC), beginning with the Julian Day, then the hour, minute, second, and hundredths seconds of the calculated origin time of the event.
Latitude (N)	The north latitude of the epicenter, expressed in degrees, minutes, and seconds.
Longitude (W)	The west longitude of the epicenter, expressed in degrees, minutes, and seconds.
Depth (km)	The calculated depth to the hypocenter, expressed in km.
+/- (km)	Estimated error in depth calculation.
M _L	Richter Local Magnitude. Only listed for naturally-occurring events.
M _D	Duration Magnitude. Only listed for naturally-occurring events.
Error Ellipse (XxY)	Ellipse of one standard deviation about the calculated epicenter, expressed in km. The first value is the length of the X-axis and the second value is the length of the Y-axis.
X-Axis Azimuth	Degrees clockwise from north of the orientation of the X-axis of the error ellipse.
Comments	Added information about the particular listed event, as follows:
	E Naturally occurring earthquake
	E? Possible natural earthquake
	B Geophysical blasting (Oil Exploration)
	S Possible offshore slump event
	C Depth constrained to given value
	I Event occurred inside the network
	O Event occurred outside the network
	F Event occurred too far away for a good location estimate
	U Unknown source
	P Poor solution
(Numbers)	First - Wave velocity that best locates the event, in km/sec.
	Second - Number of stations used in the location of the event.

All microseismic events recorded during the period 1 November 1981 to 1 July 1982 are plotted in Figure 29. The 176 events which were located within the boundaries shown in Figure 29 (69 inside the network and 107 outside) do not, in general, correlate with the known or inferred subsurface growth faults.

A total of 263 located or suspected local microearthquakes occurred during the nine-month period of operation (November 1981 through July 1982); 69 events were located inside the network, 107 events were located outside the network but close enough to plot on Figure 29, and 87 additional events were observed, but were too small or otherwise unsuitable for location. The magnitude of the largest of these is estimated at +1.13 (outside the network on 30 June 1982) on the duration magnitude scale discussed in the text. The largest event to occur inside the network had a duration magnitude of +1.04 (2 February 1982). A longer period of monitoring is necessary to better estimate the annual rate of seismicity.

No direct correlation exists between the event epicenters and the location of growth faults in the area. The presently listed epicenters are approximate and will be revised when a better velocity model can be derived.

Since no local events were detected prior to fluid withdrawal at the Sweet Lake DOE/Amoco Fee No. 1 test well, it is possible that the observed seismicity is, in some way, related to testing at the well site. In the next year of microseismic monitoring, records of well fluid withdrawal and pressure fluctuations obtained from Magma Gulf will be used to correlate this well data with the seismic event catalogue.

Rockefeller Refuge

The Rockefeller Refuge microseismic monitoring network consists of eight permanent field stations (Fig. 3) which are maintained by the University's

FIGURE 29. Recorded seismic events at Sweet Lake for the period November 1981 through July 1982.

subcontractor, Woodward-Clyde Consultants. Location coordinates are given in Table 20 along with other pertinent station data. Each field station consists of a seismometer and a standard amplifier/VCO unit and power supply. The sensors, Mark Products L28LB 4.5 Hertz seismometers, were installed in boreholes ranging from 35 to 50 ft (11 to 15 m) below the ground's surface. Data collected at each field station are telemetered by high-frequency radio transmission to an equipment shed at the well site. From the equipment shed, the data is multiplexed and transmitted over telephone lines to a central recording facility in the Woodward-Clyde Consultants office in Baton Rouge, Louisiana.

At the central recording facility, all data are continuously recorded on magnetic tape. Parallel with the magnetic tape recording system, selected station data are recorded on three dual-pen drum recorders. Drum records are scanned daily to detect possible seismic activity. Upon detection of a possible natural seismic event, all station data are played back from the magnetic tape into hard copy format through an oscillograph. Station data are further reviewed and analyzed in hard copy format so that hypocenter locations and other characteristic information may be obtained. Universal Time Coordinates (UTC) is the basis for analysis and reporting of seismic data. Data reduction is accomplished using a modified version of the earthquake location program FASTHYPO (Herrmann, 1979).

Data Analysis Procedures

All VR-60 visual drum records are reviewed daily. Significant events are played back from the magnetic tape recorder into the oscillograph, which prints all station data plus the time code onto UV light-sensitive paper. The arrival times for the event are measured for each station along with other data, such as the amplitude of the largest body wave or surface wave

TABLE 20. Rockfeller Refuge seismic monitoring network.

<u>Station Code</u>	<u>Station Name</u>	<u>North Latitude</u>	<u>West Longitude</u>	<u>Seismometer Depth (ft)</u>	<u>Seismometer Installation Date</u>	<u>Date On-Line to B. R. Office</u>	<u>Date First Recorded on Mag. Tape</u>
BCH 680 Hz	Beach	29°40'38"	92°53'19"	35	24 June 1981	9 July 1981	20 July 1981
LEV 1020 Hz	Levee	29°42'43"	92°52'54"	50	25 June 1981	9 July 1981	20 July 1981
SHR 1360 Hz	Sohio Rd.	29°42'25"	92°50'31"	50	25 June 1981	9 July 1981	20 July 1981
PLR 1700 Hz	Price Lake Rd.	29°41'14"	92°50'00"	50	25 June 1981	9 July 1981	22 Aug. 1981
ALP 2040 Hz	Alligator Ponds	29°43'13"	92°48'32"	50	26 June 1981	9 July 1981	20 July 1981
GCS 2380 Hz	Grand Chenier School Property	29°44'05.3"	92°53'54"	50	25 Jan. 1982	24 May 1982	24 May 1982
WRD 2720 Hz	Well Road	29°43'51.42"	92°52'19.43"	50	26 Jan. 1982	22 May 1982	22 May 1982
HQS 3060 Hz	Equipment Shed	29°44'31"	92°52'27"	35	23 June 1981	9 July 1981	20 July 1981

and its respective period, the duration of the event at each station, and first motion direction, e.g., compressional wave. The observed arrival times at each station are entered as data into a microcomputer used to locate the epicenter, depth to focus, and origin time of the event. The computer program FASTHYPO uses the arrival time data along with the station locations and an assumed ten-layer velocity model to arrive at a "best-fit" location (the location having the smallest root mean square residual in seconds) by repeatedly improving the location in a series of up to twenty steps. The best location is listed in a monthly catalog of events in Appendix V-I, along with the error estimates, and is plotted on a map of the area (Fig. 30), which depicts the relation of seismic events to network location and known or inferred faults in the area.

All earthquake locations are based on the use of a velocity model. It is assumed that the earth is composed of flat-lying layers of differing velocity overlying a half-space. The degree to which the velocity model approximates the actual velocity profile of the region can affect the accuracy of seismic event location. Although the events will be precisely located with respect to the assumed velocity model, the accuracy of the computed locations may be low if the velocity model does not reflect the actual conditions of the area.

The velocity model employed for computer location of naturally occurring events and blasts at the Rockefeller Refuge microseismic network was also used at the Sweet Lake DOE/Amoco Fee No. 1 test well. This velocity model is based in part on the sonic log of the Sweet Lake well and is presented as Table 21. The computer program FASTHYPO will accept up to nine flat-lying layers over a half-space, although low-velocity layers (a layer with lower velocity than the layer above it) must be excluded. Examination of the Sweet Lake well log suggests that the actual velocity conditions include an area of

FIGURE 30. Recorded seismic events at Rockefeller Refuge for the period November 1981 through October 1982.

TABLE 21. Velocity model for Rockefeller Refuge seismic monitoring network.

<u>P-Wave Velocity (km/sec)</u>	<u>Depth Interval (km)</u>
1.530	0.00 - 0.08
1.710	0.08 - 0.15
1.800	0.15 - 0.27
2.050	0.27 - 0.60
2.257	0.60 - 1.20
2.620	1.20 - 2.28
2.891	2.28 - 4.99
3.182	4.99 - 6.00
3.409	6.00 - 7.00
3.636	7.00 +

P-Wave: S-wave velocity ratio equals 1.66:1.00.

ALTERNATIVE "SLOW WAVE"* VELOCITY MODEL

<u>Wave Velocity (km/sec)</u>	<u>Depth Interval (km)</u>
0.342	0.00+

*Slow waves are assumed to be long-period Rayleigh (L_R) waves, but could be S-waves, since depth to focus can sometimes be determined.

decreasing velocity near the geopressured zone. For the purposes of computer location, the actual velocities have been averaged so that the velocity model contains nine layers of increasing velocity with depth overlying a half-space of higher velocity.

Earthquakes are assigned magnitudes that estimate the sizes of the events relative to a zero-magnitude hypothetical event. The most widely known magnitude scale is the Richter scale. Originally it was intended only for larger scale earthquakes in other areas. Direct application of the Richter scale to earthquakes occurring at local and regional distances from the Rockefeller test well is inappropriate because of differences in site geology between Louisiana and California as well as the differences in type of detection equipment used. Several other types of magnitude scales exist, including ones based on duration of the recorded signal. Magnitudes reported for events occurring at a geothermal test well in Texas (Mauk, 1982) are based on signal duration:

$$(1) M_D = 2.28 \log_{10}(T) - 2.22$$

where T = the time in seconds from P-wave first motion until the signal is no longer recognizable above average noise level.

Magnitudes calculated with this scale, i.e., a magnitude of 1.0 on the above scale, correspond closely with a Richter magnitude of 1.0. In the comparisons of the sizes of events occurring at local distances within the Rockefeller microseismic monitoring network, the duration magnitude formula is used, as shown in equation (1) above; however, listed magnitudes for the Rockefeller network should not be compared with magnitudes of events occurring at other seismic networks.

Monitoring Results

Various types of background noise, such as cultural noise (e.g., traffic, pumps, geophysical blasting, and well activities) and other noise

related to bad weather, ocean waves, barometric changes, etc., complicate the detection of naturally occurring events (Figs. 31 and 32). Cultural noise, with the exception of blasting, usually affects only one or two seismometers at a time and can be easily distinguished from natural events. Blasting usually occurs in the afternoon and consists of many events spaced at 2- to 3-minute intervals. Other noncultural noise can be extremely variable in amplitude and can affect most or all of the seismometer stations in the network. The detection capability of the network changes in direct proportion to the amplitude of the background noise level of the area. To be detected, a local event must be of greater amplitude than the background noise level (Figs. 33 and 34). In general, background noise in the vicinity of the test well is concentrated in the 1- to 5-Hz frequency range. At present, the amplifiers have been set to filter out most of this low-frequency noise.

Since November 1981, 34 events (App. V-1) have been recorded by the Rockefeller Refuge network. Of the 37 events, 19 were too small to locate, 9 were possible natural events located outside the boundaries of the network, 2 may have been blasts, and 3 were probably noise associated with well activity; the remaining 4 events were possible natural events which occurred inside the network. The character of these events has been variable. A few of the events appear to have identifiable high-frequency body waves (P- and S-waves), whereas others were recorded only as low-frequency waves, probably S-waves or surface waves. Some events have been tentatively identified as earthquakes (Figs. 33 and 34) because they occurred at otherwise quiet times of day (i.e., they are not part of normal geophysical exploration blast series which occur almost every afternoon). Some events had no clear body-wave arrivals and had to be located using a velocity model more appropriate to surface waves. For these events, the velocity model used was a half-space

FIGURE 31. Seismic signature of local blasting within the Rockefeller Refuge Microseismic Monitoring Network.

FIGURE 32. Seismic signature of local well noise within the Rockefeller
Refuge Microseismic Monitoring Network.

FIGURE 33. Seismic signature of possible microearthquake within the Rockefeller Refuge Microseismic Monitoring Network.

FIGURE 34. Seismic signature of possible microearthquake within the Rockefeller Refuge Microseismic Monitoring Network.

with velocity equal to 0.342 km/sec. The significant variation in trace signature for a single event at different stations probably is indicative of complex attenuation in the area. In some cases, variable attenuation made wave-arrival matching between stations difficult to establish, especially for the smaller events. Computed locations and depths of all events listed in the event catalog should be assumed to be approximate until a more accurate velocity model can be made.

The seismic events which were located within the geopressured prospect do not, in general, correlate with the known or inferred subsurface growth faults. At this time, it is difficult to say whether any significance should be placed on this lack of correlation; the small number of natural events which were recorded and located with the velocity model of unknown accuracy prevented a statistical correlation between locations of seismic events and mapped faults. After a sufficient number of local events occur and the velocity model is improved, it may be possible to establish a better relationship between the events and the inferred faults.

Present seismicity in the vicinity of the Gladys McCall well site is low. A total of 38 located or suspected microearthquakes occurred during the first 16 months of operation (July 1981 through October 1982) at the permanent seismic network. The magnitude of the largest of these is estimated at 0.62 on the duration magnitude scale (equivalent to the Richter scale), as discussed in the text. If the observed seismicity rate is typical for the area prior to fluid withdrawal at the test well, the annual rate of natural background seismicity would be approximately 28 to 29 detectable (but not necessarily locatable) events per year of magnitude 0.62 or less.

In summary, no direct correlation exists between the event epicenters and the location of growth faults in the area. The listed epicenters in the event log are approximate and will be revised when a better velocity model is derived.

References

- Aki, K. S. and L. B. Chouet, 1975, Origin and coda wave: Source, attenuation and scattering effect: Jour. Geophysical Research, vol. 80, p. 3322-3342.
- Gregory, A. R., 1977, Aspects of rock physics from laboratory and log data that are important to seismic interpretation, in C. E. Payton, ed., Seismic stratigraphy--Applications to hydrocarbon exploration: Am. Assoc. Petr. Geol., Memoir 26, Tulsa, Okla.
- Herrman, R. B., 1979, FASTHYPO--A Fortran program for simple hypocenter determination: Earthquake Notes, vol. 50, no. 2.
- Lee, W. H. K., and J. C. Lahr, 1975, HYP071 (rev.): A computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes: U.S. Geol. Survey open-file rept. 75-311.
- Mauk, F. J., 1982, Microseismic monitoring of Bayou Parcperdue, Louisiana: The Dow L. R. Sweezy No. 1 geopressured/geothermal energy test well program, 1981 annual progress report: Teledyne Geotech Rept. No. TR82-1.
- Mauk, F. J., G. G. Sorrells, and B. C. Kimball, 1981, Microseismicity associated with development of Gulf Coast geopressured-geothermal energy wells: Two studies, Pleasant Bayou No. 2 and Dow L. R. Sweezy No. 1, in D. G. Bebout and A. L. Bachman, eds., Geopressured-geothermal energy, U.S. Gulf Coast: Proceedings of the fifth conference: La. State Univ., La. Geol. Survey, Baton Rouge, La., p. 105-109.
- Sorrells, G. G., 1980, Microseismicity at the Brazoria County geopressured reservoir, September 1978 - December 1979, in Surendra K. Saxena, ed., Geotechnical and environmental aspects of geopressure energy: Engineering Foundation, N. Y., N. Y.

Van Sickle, V. R., and C. G. Groat, 1981, Subsidence and induced faulting: Key environmental issues in geopressured-geothermal resource development, in D. G. Bebout and A. L. Bachman, eds., geopressured-geothermal energy, U.S. Gulf Coast: Proceedings of the fifth conference: La. State Univ., La. Geol. Survey, Baton Rouge, La., p. 325-327.

CONCLUSION

Analyses of the 1981-1982 data indicate that there are no direct, verifiable effects of geopressured-geothermal well activities on the parameters being monitored. Some of the water quality and microseismic anomalies are correlatable with drilling and testing activities, but cannot yet be pinpointed as an actual cause. These data are being analyzed in more detail. Subsidence and ecosystem data are still not sufficiently complete to allow for any speculations concerning geopressured-geothermal development effects. For all the parameters, however, significant progress has been made toward a complete understanding of background conditions.

APPENDIX I

**Parcperdue
Water Quality Monitoring**

APPENDIX I-1
 Parcperdue Geopressed-Geothermal Prospect
 Brine Chemistry (ppm)

Constituent	May 1982	June 1982	July 1982	Aug. 1982	Average
TDS	100900	97480	98200	98425	98751
Temp (°C)	83.2	95.4	95.5	96.3	92.6
Na	34200	33200	32980	34700	33770
K*	554	330	320	178	346
Mg	272	264	246	259	260
Ca	1850				1850
Mn	3.22	1.4	1.3	1.4	1.8
Cl	56600	55310	55260	55470	55660
SC (umhos)	116800	122800	123300	123400	121575
pH (equil.)	6.29	6.37	6.31	6.40	6.34
CO ₂ (mol%)	2.73	2.44	2.51	2.43	2.53
CaCO ₃	6650	5950	5690	5550	5960
HCO ₃	1495	1550	1560	1540	1536
NH ₄	8.8			44.2	26.5
SO ₄	545	482	526	492	511
Cd	0.26	<0.1	<0.1	<0.1	<0.14
Pb	3.62	0.2	0.12	0.05	0.99
B			60.2	62	61.1
Cr		0.37	<0.1	<0.1	<0.19

* Reagent found contaminated with potassium in August. Values for May, June, and July too high. August value correct.

APPENDIX I-2

Monthly Water Quality Observations, Parcperdue

Appendix Table I-2a. Parcperdue, Leblanc Ditch near Church--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	1	24	80	1.83	217.0	10.2	11	10.0	4.87	4.61	1.39	5.18	0.12	5.00	68.0
2	2	20	80	0.61	144.0	5.1	21	17.0	13.00	1.90	4.00	10.50	0.40	20.00	142.0
3	3	21	80	1.71	222.0	2.5	16	17.0	25.00	5.24	4.95	18.40	1.36	89.00	229.0
4	4	21	80	1.17	3200.0	7.6	21	19.0	12.90	3.80	5.57	16.00	2.89	8.00	168.0
5	5	21	80	9.33	758.0	12.7	24	24.0	4.50	3.70	2.66	6.50	0.66	4.70	71.0
6	6	23	80	6.41	1000.0	10.1	33	32.5	5.78	2.75	2.13	5.00	0.48	5.60	54.0
7	7	22	80	1.78	57.0	5.1	33	29.0	15.61	2.45	8.01	21.50	1.08	5.00	228.0
8	8	21	80	1.63	19.0	2.5	30	27.0	28.70	2.60	7.65	24.00	1.23	32.50	201.0
9	9	22	80	3.97	11.5	2.5	31	27.0	5.70	4.45	3.70	11.20	5.58	7.00	210.0
10	10	22	80	12.86	25.0	10.2	18	16.0	6.80	1.00	3.55	9.00	0.27	8.60	112.0
11	11	20	80	1.45	14.0	0.0	8	9.0	240.00	9.50	12.81	85.00	0.08	351.00	765.6
12	12	17	80	0.00	50.0	2.5	11	9.0	5.20	5.20	3.01	7.60	0.45	7.30	79.0
13	1	26	81	0.00	46.0	5.1	18	15.0	11.50	7.55	3.70	10.80	0.42	16.40	132.0
14	2	20	81	0.21	78.0	7.6	26	18.0	6.40	6.00	3.18	8.00	0.94	10.50	80.0
15	3	19	81	0.00	58.0	0.0	13	11.0	9.80	1.40	6.10	23.00	1.41	10.80	160.0
16	4	23	81	0.00	.	0.0	23	.	.	.	.	.	.	.	.
17	5	21	81	0.18	15.0	7.6	19	19.0	85.50	4.30	10.10	46.30	0.19	127.20	401.0
18	6	23	81	0.59	200.0	5.1	29	28.0	7.90	5.62	5.10	13.00	1.80	13.60	144.0
19	7	21	81	0.00	.	0.0	31	.	.	.	.	.	.	.	.
20	8	18	81	1.33	45.9	2.5	32	29.0	7.70	3.92	6.60	22.00	4.90	7.00	193.0
21	9	22	81	0.00	73.0	7.6	23	21.0	9.00	8.00	6.00	26.00	1.09	12.20	238.0
22	10	26	81	1.50	50.0	0.0	16	18.0	103.50	112.20	7.40	38.70	0.14	67.80	896.0
23	11	23	81	0.23	22.0	7.6	17	19.0	40.00	7.30	5.00	41.20	0.44	50.00	195.0
24	12	16	81	7.22	102.0	15.2	9	11.0	4.10	7.32	2.12	4.02	0.08	15.45	77.0
25	1	20	82	0.00	120.0	10.2	23	22.0	8.60	8.00	3.00	8.00	0.72	15.30	117.0
26	2	22	82	0.00	120.0	12.7	17	22.0	37.90	5.00	3.10	8.00	0.81	16.00	223.0
27	3	24	82	2.98	220.0	33.0	18	22.0	12.70	4.71	1.51	1.75	0.54	7.95	100.0
28	4	28	82	0.72	210.0	20.0	23	19.0	18.40	5.00	4.60	14.00	0.51	23.50	213.0
29	5	25	82	.	1.4	12.7	.	22.0	20.70	1.20	6.80	30.10	5.88	18.60	265.0

Appendix Table I-2a, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	1	24	80	7.90	6.54	15.6	18.90	2.30	5.0	0.050	0	0	0.00350	0.000	0	0
2	2	20	80	7.80	6.98	21.0	43.40	0.70	9.0	0.120	0	0	0.00420	0.000	0	0
3	3	21	80	9.40	7.35	25.0	68.80	1.17	4.0	0.120	0	0	0.01390	0.000	0	0
4	4	21	80	4.10	6.35	68.7	68.10	1.93	0.0	0.780	0	0	0.00430	0.000	0	0
5	5	21	80	4.70	6.40	22.9	28.40	1.70	0.0	0.310	0	0	0.00023	0.100	0	0
6	6	23	80	4.20	6.55	19.7	22.63	0.59	6.8	0.620	0	0	0.00230	0.300	0	0
7	7	22	80	7.40	7.48	6.8	88.62	1.15	0.0	0.160	0	0	0.01300	0.090	0	0
8	8	21	80	5.80	7.52	9.7	62.20	1.26	0.0	0.080	0	0	0.02350	0.080	0	0
9	9	22	80	6.50	6.91	12.6	53.40	1.26	0.0	0.300	0	0	0.00350	0.200	0	0
10	10	22	80	3.60	5.85	20.6	37.60	1.42	6.0	0.130	0	0	0.07500	0.100	0	0
11	11	20	80	8.10	7.25	7.2	265.00	0.91	14.0	0.260	0	0	0.00900	0.280	0	0
12	12	17	80	5.80	5.75	17.6	32.20	1.26	0.0	0.080	0	0	0.00100	0.020	0	0
13	1	26	81	6.80	6.80	12.6	43.00	2.15	2.0	0.080	0	0	0.08100	0.010	0	0
14	2	20	81	4.30	6.91	16.8	34.80	1.19	0.0	0.160	0	0	0.00400	0.100	0	0
15	3	19	81	7.00	6.50	20.3	85.10	2.23	5.5	0.160	0	0	0.00500	0.020	0	0
16	4	23	81	.	.	.	.	.	.	.	.	.	.	.	.	.
17	5	21	81	8.40	7.58	10.8	158.40	2.23	4.5	0.120	0	0	0.01000	0.280	0	0
18	6	23	81	6.20	6.56	26.3	56.70	9.60	0.0	0.180	0	0	0.00600	0.080	0	0
19	7	21	81	.	.	.	.	.	.	.	.	.	.	.	.	.
20	8	18	81	3.20	6.95	23.0	91.00	3.69	3.0	0.110	0	0	0.00700	0.080	0	0
21	9	22	81	3.80	7.31	14.5	91.60	4.25	7.0	0.190	0	0	0.00070	0.030	0	0
22	10	26	81	8.20	6.90	19.2	127.30	3.20	13.0	0.160	0	0	0.01000	0.030	0	0
23	11	23	81	8.00	7.20	14.0	124.30	0.83	12.5	0.030	0	0	0.00850	0.050	0	0
24	12	16	81	8.00	6.85	16.8	18.90	2.01	6.0	0.000	0	0	0.00200	0.050	0	0
25	1	20	82	5.35	7.20	14.9	33.60	1.86	6.5	0.090	0	0	0.00200	0.050	0	0
26	2	22	82	4.00	6.90	23.8	34.20	7.92	35.0	0.250	0	0	0.00220	0.030	0	0
27	3	24	82	5.80	6.68	26.0	11.56	1.91	13.0	0.080	0	0	0.00300	0.040	0	0
28	4	28	82	6.10	6.61	17.0	54.80	0.93	0.0	0.075	0	0	0.00460	0.045	0	0
29	5	25	82	3.25	6.59	13.6	103.15	1.18	8.0	0.072	0	0	0.00500	0.040	0	0

Appendix Table I-2b. Parcperdue, Leblanc Ditch near River--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	1	24	80	1.83	211.0	15.2	11	10	6.25	6.37	1.67	7.39	0.14	7.00	72.0
2	2	20	80	0.61	120.0	5.1	21	19	17.00	9.65	4.65	12.60	0.17	30.00	192.0
3	3	21	80	1.71	104.0	2.6	16	15	50.80	18.60	10.30	28.10	0.40	68.00	440.0
4	4	21	80	1.17	1370.0	10.2	21	18	16.90	5.29	6.17	18.00	0.91	29.00	180.0
5	5	21	80	9.56	710.0	175.3	24	25	6.00	5.23	2.54	7.10	0.36	9.50	81.0
6	6	23	80	6.41	868.0	25.4	33	30	6.35	3.01	3.95	8.60	0.28	5.25	101.0
7	7	22	80	1.78	36.0	10.2	33	29	19.35	2.07	9.03	30.50	0.34	7.50	284.0
8	8	21	80	1.63	25.0	12.7	30	29	13.80	4.12	5.08	13.70	0.41	18.00	166.0
9	9	22	80	3.97	29.0	20.3	31	28	8.00	7.40	3.30	9.90	0.11	12.70	122.0
10	10	22	80	12.86	8.0	12.7	18	16	9.50	1.30	4.72	11.60	0.16	14.10	159.0
11	11	20	80	1.45	24.1	17.8	8	8	74.00	20.50	15.00	44.00	5.05	133.00	629.8
12	12	17	80	0.00	51.0	10.2	11	8	8.00	6.40	2.82	7.90	0.16	13.00	110.0
13	1	26	81	0.00	33.0	7.6	18	14	16.10	14.20	4.14	14.40	0.40	27.80	180.0
14	2	20	81	0.21	66.0	15.2	26	17	15.00	9.50	3.30	8.80	0.17	22.60	128.0
15	3	19	81	0.00	18.0	0.0	13	11	28.50	10.80	12.60	38.00	8.60	34.80	358.0
16	4	23	81	0.00	18.0	12.7	23	24	26.80	7.30	9.00	21.00	0.70	35.50	287.6
17	5	21	81	0.18	25.0	30.5	19	18	28.20	7.30	5.70	15.10	0.21	39.00	212.0
18	6	23	81	0.59	34.0	7.6	29	28	17.50	5.30	4.60	13.00	0.16	22.50	179.0
19	7	21	81	0.00	.	.	31	.	.	.	.	.	.	.	.
20	8	18	81	1.33	10.0	7.6	32	30	19.80	8.00	6.90	19.00	0.82	13.50	220.0
21	9	22	81	0.00	6.2	12.7	23	22	17.70	9.20	4.10	10.50	0.38	23.10	239.0
22	10	26	81	1.50	10.0	7.6	17	18	29.60	10.40	7.10	22.00	0.06	45.00	405.0
23	11	23	81	0.23	.	.	.	.	.	.	.	.	.	.	.
24	12	16	81	7.22	53.5	22.9	9	11	16.10	11.70	3.26	6.72	0.20	22.50	173.0
25	1	20	82	0.00	262.0	22.9	23	20	15.00	11.00	3.90	8.00	0.08	19.50	140.0
26	2	22	82	0.00	90.0	22.9	17	14	11.90	6.50	3.20	6.00	0.11	14.25	134.0
27	3	24	82	2.98	90.0	0.0	18	21	10.30	5.90	2.70	2.89	0.40	15.00	110.0
28	4	28	82	0.72	160.0	22.9	23	21	13.90	10.10	3.20	5.90	0.30	24.50	173.0
29	5	25	82	.	30.6	17.8	.	25	27.80	4.60	5.50	15.50	0.37	42.40	240.0

Appendix Table I-2b, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	1	24	80	9.90	6.50	13.6	25.60	1.60	5.0	0.080	0	0	0.0043	0.000	0	0
2	2	20	80	9.60	7.54	17.8	50.90	0.63	10.0	0.170	0	0	0.0038	0.000	0	0
3	3	21	80	8.80	7.30	37.0	113.30	1.03	5.0	0.190	0	0	0.0056	0.000	0	0
4	4	21	80	5.20	6.90	35.6	72.00	0.74	6.0	0.860	0	0	0.0031	0.000	0	0
5	5	21	80	3.80	6.14	24.9	28.80	1.70	5.0	0.270	0	0	0.0019	0.100	0	0
6	6	23	80	5.90	7.22	16.1	29.16	0.42	2.0	0.440	0	0	0.0022	0.200	0	0
7	7	22	80	7.10	7.90	4.9	113.95	1.29	0.0	0.200	0	0	0.0056	0.050	0	0
8	8	21	80	5.40	7.76	5.2	55.90	1.24	0.0	0.120	0	0	0.0105	0.050	0	0
9	9	22	80	6.60	7.20	5.2	38.50	0.39	0.0	0.120	0	0	0.0046	0.070	0	0
10	10	22	80	4.20	6.60	20.6	48.70	1.39	0.0	0.160	0	0	0.0072	0.250	0	0
11	11	20	80	8.70	7.80	24.6	180.80	4.11	0.0	0.400	0	0	0.0000	0.180	0	0
12	12	17	80	8.60	6.72	11.1	31.60	1.11	0.0	0.120	0	0	0.0020	0.020	0	0
13	1	26	81	3.00	8.00	16.4	53.70	3.17	0.0	0.210	0	0	0.0010	0.050	0	0
14	2	20	81	9.60	7.21	15.7	35.90	1.39	5.0	0.190	0	0	0.0030	0.100	0	0
15	3	19	81	6.60	6.70	14.4	162.40	2.88	2.0	0.600	0	0	0.0010	0.060	0	0
16	4	23	81	6.50	7.40	19.1	90.70	4.36	0.0	0.170	0	0	0.0030	0.050	0	0
17	5	21	81	7.90	7.25	13.7	61.50	1.71	12.2	0.190	0	0	0.0010	0.025	0	0
18	6	23	81	7.20	7.14	13.2	51.70	3.10	0.0	0.190	0	0	0.0050	0.100	0	0
19	7	21	81	.	.	.	.	.	.	.	.	.	.	.	.	.
20	8	18	81	5.60	7.35	8.4	77.30	3.69	2.0	0.240	0	0	0.0050	0.120	0	0
21	9	22	81	1.65	7.30	14.3	43.80	2.25	7.0	0.290	0	0	0.0070	0.080	0	0
22	10	26	81	6.00	6.71	12.3	84.20	0.70	7.0	0.280	0	0	0.0020	0.006	0	0
23	11	23	81	.	.	.	.	.	.	.	.	.	.	.	.	.
24	12	16	81	9.60	7.25	29.4	30.60	1.92	10.0	0.240	0	0	0.0000	0.006	0	0
25	1	20	82	6.40	7.20	23.4	36.20	1.80	6.0	0.250	0	0	0.0001	0.006	0	0
26	2	22	82	8.20	7.30	21.6	28.40	6.11	4.0	0.200	0	0	0.0041	0.006	0	0
27	3	24	82	6.80	6.63	31.4	19.05	2.70	2.0	0.030	0	0	0.0040	0.007	0	0
28	4	28	82	6.90	6.73	16.9	28.50	2.44	4.5	0.020	0	0	0.0040	0.007	0	0
29	5	25	82	7.20	6.51	10.0	61.34	0.58	6.5	0.015	0	0	0.0035	0.007	0	0

Appendix Table I-2c. Parcperdue, Bayou Parcperdue--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	1	24	80	1.83	280.0	18	11	9	6.62	5.25	1.69	7.27	0.16	6.00	83.0
2	2	20	80	0.61	206.0	25	21	16	12.90	6.20	4.25	11.00	0.27	15.00	142.0
3	3	21	80	1.71	233.0	10	16	17	23.60	7.76	6.25	19.50	1.73	27.00	227.0
4	4	21	80	1.17	2650.0	10	21	19	10.90	3.87	4.88	15.00	1.79	14.00	112.0
5	5	21	80	9.56	792.5	18	24	24	5.20	4.13	2.60	7.50	0.48	5.40	80.0
6	6	23	80	6.41	500.0	10	33	27	11.00	2.75	4.10	11.20	0.40	11.75	147.0
7	7	22	80	1.78	186.0	33	33	28	15.45	4.19	6.68	17.90	0.78	13.00	207.0
8	8	21	80	1.63	19.0	28	30	28	14.60	2.38	9.02	24.90	1.84	7.00	230.0
9	9	22	80	3.97	40.0	36	31	29	8.20	7.22	3.23	10.50	0.71	11.50	133.0
10	10	22	80	12.86	24.0	25	18	16	6.70	1.10	4.48	13.10	0.80	7.60	148.0
11	11	20	80	1.45	38.0	10	8	9	31.50	10.50	7.70	19.20	0.31	30.00	237.6
12	12	17	80	0.00	94.0	30	11	10	10.50	6.90	3.13	11.90	0.39	12.40	124.0
13	1	26	81	0.00	88.0	20	18	16	20.50	8.01	4.70	14.20	0.48	21.55	198.0
14	2	20	81	0.21	2100.0	18	26	18	138.00	35.00	21.00	20.10	0.88	88.00	490.0
15	3	19	81	0.00	1875.0	10	13	13	32.00	9.80	6.10	29.00	1.30	67.80	546.0
16	4	23	81	0.00	81.0	76	23	24	32.00	5.80	9.80	26.00	1.80	19.00	328.4
17	5	21	81	0.18	18.0	61	19	19	28.10	4.60	8.60	23.50	0.83	19.00	283.0
18	6	23	81	0.59	150.0	46	29	30	11.30	5.15	5.30	16.00	1.25	14.50	166.0
19	7	21	81	0.00	56.0	25	31	29	12.20	2.60	3.90	6.10	0.80	10.20	138.0
20	8	18	81	1.33	70.0	36	32	31	20.30	7.15	4.90	15.00	0.94	17.50	233.0
21	9	22	81	0.00	76.0	30	23	24	10.50	8.40	4.20	12.20	1.09	11.50	199.0
22	10	26	81	1.50	84.0	61	16	18	53.20	9.50	6.30	17.00	0.62	25.40	392.0
23	11	23	81	0.23	33.0	38	17	16	27.00	8.10	6.30	17.50	0.70	31.25	232.0
24	12	16	81	7.22	100.0	76	9	11	7.40	9.31	2.58	7.21	0.16	15.00	128.0
25	1	20	82	0.00	164.0	38	23	23	14.00	8.50	4.00	12.00	0.60	16.50	166.0
26	2	22	82	0.00	100.0	38	17	16	77.10	6.00	4.80	16.00	1.08	32.50	413.0
27	3	24	82	2.98	195.0	66	18	22	14.10	5.66	2.41	4.55	0.76	22.00	135.0
28	4	28	82	0.72	580.0	51	23	21	11.70	13.50	5.10	7.40	1.17	24.50	162.0
29	5	25	82	.	5.6	41	.	24	19.10	4.70	5.90	17.90	0.82	23.90	214.0
30	6	21	82	.	78.0	0	.	26	7.00	6.20	3.50	6.50	0.30	15.90	151.9

Appendix Table I-2c, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	1	24	80	8.60	6.24	12.6	25.40	1.36	4.0	0.080	0	0	0.0037	0.0000	0.000	0
2	2	20	80	7.30	6.60	17.8	45.50	0.56	8.0	0.140	0	0	0.0046	0.0000	0.000	0
3	3	21	80	4.50	6.75	26.0	77.60	0.86	6.0	0.220	0	0	0.0089	0.0000	0.000	0
4	4	21	80	2.60	6.40	54.5	60.80	1.06	0.0	0.530	0	0	0.0033	0.0000	0.000	0
5	5	21	80	5.60	6.36	24.6	30.30	1.43	0.0	0.280	0	0	0.0024	0.1000	0.000	0
6	6	23	80	5.20	7.05	11.8	44.84	0.43	7.3	0.310	0	0	0.0018	0.3000	0.000	0
7	7	22	80	3.00	7.00	9.8	73.61	1.68	4.0	0.180	0	0	0.0048	0.1500	0.000	0
8	8	21	80	1.60	7.16	4.4	102.60	0.82	0.0	0.190	0	0	0.0190	0.0500	0.000	0
9	9	22	80	2.40	6.50	8.4	40.80	1.33	0.0	0.380	0	0	0.0055	0.0900	0.000	0
10	10	22	80	2.40	6.18	19.6	52.60	1.39	2.0	0.190	0	0	0.0045	0.1000	0.000	0
11	11	20	80	8.60	7.70	12.4	80.20	1.49	3.0	0.160	0	0	0.0012	0.0500	0.000	0
12	12	17	80	7.60	6.65	12.3	43.30	1.63	0.0	0.170	0	0	0.0010	0.0200	0.000	0
13	1	26	81	8.20	7.10	9.8	55.70	5.01	12.0	0.130	0	0	0.0010	0.0100	0.000	0
14	2	20	81	5.20	8.38	30.2	138.20	4.66	5.0	0.290	0	0	0.0110	0.6000	0.000	0
15	3	19	81	6.00	7.40	96.0	99.90	23.00	30.0	3.500	0	0	0.0260	0.2500	0.000	0
16	4	23	81	4.50	7.20	14.3	108.50	2.72	0.0	0.550	0	0	0.0080	0.1500	0.000	0
17	5	21	81	8.80	7.51	16.4	95.60	1.57	4.0	0.180	0	0	0.0060	0.0250	0.000	0
18	6	23	81	5.10	7.02	18.8	64.00	5.70	3.0	0.350	0	0	0.0030	0.1000	0.000	0
19	7	21	81	4.10	7.02	5.7	32.70	3.10	2.0	0.130	0	0	0.0800	0.1400	0.000	0
20	8	18	81	6.10	7.22	12.3	59.30	3.03	7.0	0.160	0	0	0.0040	0.1000	0.000	0
21	9	22	81	0.93	6.92	14.3	49.70	5.55	12.0	0.170	0	0	0.0050	0.0300	0.000	0
22	10	26	81	4.00	6.90	15.3	69.50	2.60	8.0	0.220	0	0	0.0012	0.0300	0.000	0
23	11	23	81	6.10	7.05	9.2	69.90	0.70	13.5	0.040	0	0	0.0010	0.0300	0.000	0
24	12	16	81	8.60	6.95	15.0	28.90	1.46	8.0	0.000	0	0	0.0012	0.0300	0.000	0
25	1	20	82	9.50	8.20	14.4	47.50	2.04	10.5	0.050	0	0	0.0012	0.0300	0.000	0
26	2	22	82	6.20	7.10	25.7	61.70	8.83	80.0	0.180	0	0	0.0033	0.0200	0.000	0
27	3	24	82	6.20	6.52	26.5	22.66	2.01	10.0	0.050	0	0	0.0040	0.0200	0.000	0
28	4	28	82	5.80	5.80	28.6	41.60	3.17	7.5	0.050	0	0	0.0014	0.0150	0.000	0
29	5	25	82	6.90	6.75	9.8	69.98	0.91	6.0	0.050	0	0	0.0013	0.0012	0.000	0
30	6	21	82	5.90	7.02	13.6	30.64	2.64	6.0	0.035	0	0	0.0012	0.0130	0.000	0

Appendix Table I-2d. Parcperdue, 50-ft well--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	1	24	80	1.83	4.00	.	11	20.0	22.7	1.81	4.87	11.1	0.17	8.00	178
2	2	20	80	0.61	8.00	.	21	20.0	22.4	1.75	4.50	11.0	0.13	7.00	178
3	3	21	80	1.71	8.00	.	16	19.0	23.4	1.91	4.80	12.5	0.17	7.60	172
4	4	21	80	1.17	12.00	.	21	18.0	24.2	1.75	4.80	11.7	0.17	19.00	188
5	5	21	80	9.56	2.00	.	24	21.0	23.6	1.76	4.48	11.4	0.15	7.60	208
6	6	23	80	6.41	0.38	.	33	22.5	24.1	1.82	4.71	11.9	0.10	9.20	192
7	7	22	80	1.78	0.52	.	33	22.0	24.9	2.20	5.04	12.6	0.16	5.50	193
8	8	21	80	1.63	0.83	.	30	22.0	19.5	2.21	6.62	16.3	0.15	5.25	192

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	1	24	80	0.5	6.23	5.5	48.1	0.00	0	0.03	0	0	0.0008	0.00	0	0
2	2	20	80	0.4	6.09	5.1	46.2	0.45	0	0.04	0	0	0.0011	0.00	0	0
3	3	21	80	2.0	6.40	4.0	51.3	0.54	0	0.03	0	0	0.0009	0.00	0	0
4	4	21	80	0.3	6.48	0.8	49.3	0.40	0	0.02	0	0	0.0009	0.00	0	0
5	5	21	80	0.3	6.18	2.1	47.2	0.48	0	0.02	0	0	0.0008	0.10	0	0
6	6	23	80	0.5	6.22	6.6	49.1	0.15	0	0.03	0	0	0.0008	0.40	0	0
7	7	22	80	0.7	6.40	0.2	52.5	0.80	0	0.01	0	0	0.0016	0.08	0	0
8	8	21	80	0.6	5.65	0.0	68.2	0.60	0	0.02	0	0	0.0013	0.05	0	0

Appendix Table I-2e. Parcperdue, 100-ft well-ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	1	24	80	1.83	1.00	.	11	20.0	19.1	2.09	6.62	13.1	0.16	4.00	202.0
2	2	20	80	0.61	49.00	.	21	20.0	20.4	1.90	6.35	15.2	0.16	5.00	198.0
3	3	21	80	1.71	8.00	.	16	21.0	20.8	2.07	5.82	16.4	0.16	4.30	198.0
4	4	21	80	1.17	6.00	.	21	18.0	21.5	2.95	6.60	14.2	0.17	11.00	209.0
5	5	21	80	9.56	2.00	.	24	21.0	20.9	1.86	6.40	14.8	0.14	3.90	209.0
6	6	23	80	6.41	0.58	.	33	22.5	22.4	1.91	6.65	15.3	0.10	4.90	226.0
7	7	22	80	1.78	0.40	.	33	22.0	20.6	2.22	6.30	14.2	0.14	5.75	204.0
8	8	21	80	1.63	0.55	.	30	22.0	22.4	1.96	5.32	14.2	0.13	10.00	209.0
9	9	22	80	3.97	3.50	.	31	23.0	18.3	2.00	6.12	15.5	0.08	6.20	203.0
10	10	22	80	12.86	9.20	.	18	20.0	20.6	2.00	5.95	9.9	0.14	5.80	200.0
11	11	20	80	1.45	0.40	.	8	19.0	23.6	2.10	6.00	15.7	0.14	4.00	192.6
12	12	17	80	0.00	0.40	.	11	20.0	21.9	2.00	5.84	15.7	0.21	3.80	198.0
13	1	26	81	0.00	0.52	.	18	20.0	20.1	2.10	5.92	15.8	0.13	3.80	198.0
14	6	21	82	0.00	8.90	.	0	22.0	21.3	3.00	7.30	11.0	0.13	10.60	217.3

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Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	1	24	80	0.20	6.17	5.6	60.00	0.36	0	0.010	0	0	0.0008	0.000	0	0
2	2	20	80	0.20	6.28	2.5	64.40	0.53	0	0.020	0	0	0.0010	0.000	0	0
3	3	21	80	1.20	6.38	8.0	65.20	0.58	2	0.020	0	0	0.0008	0.000	0	0
4	4	21	80	1.30	6.25	1.6	62.90	0.40	0	0.020	0	0	0.0008	0.000	0	0
5	5	21	80	0.50	6.25	5.0	63.60	0.56	0	0.020	0	0	0.0009	0.100	0	0
6	6	23	80	0.30	6.55	5.2	65.37	0.15	0	0.030	0	0	0.0007	0.300	0	0
7	7	22	80	0.70	6.30	0.2	61.65	0.70	0	0.020	0	0	0.0016	0.050	0	0
8	8	21	80	1.00	5.93	1.4	57.60	0.30	0	0.010	0	0	0.0013	0.050	0	0
9	9	22	80	0.80	6.38	0.0	64.00	0.00	0	0.080	0	0	0.0004	0.100	0	0
10	10	22	80	2.20	5.75	0.0	49.50	0.25	0	0.050	0	0	0.0006	0.050	0	0
11	11	20	80	0.50	6.35	0.0	64.20	0.50	0	0.060	0	0	0.0008	0.050	0	0
12	12	17	80	0.80	6.22	0.0	63.60	0.58	0	0.120	0	0	0.0010	0.040	0	0
13	1	26	81	1.40	6.30	0.0	64.10	0.30	0	0.120	0	0	0.0005	0.010	0	0
14	6	21	82	3.93	6.62	1.7	57.51	0.25	0	0.014	0	0	0.0014	0.085	0	0

Appendix Table I-2f. Parcperdue, 130-ft well--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	2	20	81	0.21	32.00	.	26	32	18.5	1.60	5.23	11.10	0.23	6.00	146.0
2	3	19	81	0.00	8.00	.	13	18	19.5	2.00	5.60	14.50	0.21	6.20	160.0
3	4	23	81	0.00	7.80	.	23	21	16.9	1.50	5.50	16.50	0.41	4.20	216.0
4	5	21	81	0.18	6.20	.	19	18	21.1	9.10	5.90	14.70	0.19	15.20	174.0
5	6	23	81	0.59	0.80	.	29	23	21.0	1.73	6.40	16.00	0.23	7.30	172.0
6	7	21	81	0.00	8.20	.	31	23	18.6	1.70	4.50	3.50	0.30	6.00	177.0
7	8	18	81	1.33	.	.	32	.	.	.	.	.	.	.	.
8	9	22	81	0.00	.	.	23	.	.	.	.	.	.	.	.
9	10	26	81	1.50	.	.	16	.	.	.	.	.	.	.	.
10	11	23	81	0.23	.	.	17	.	.	.	.	.	.	.	.
11	12	16	81	7.22	3.20	.	9	10	24.2	1.97	4.61	11.60	0.15	14.10	234.0
12	1	20	82	0.00	4.00	.	23	20	25.0	2.00	5.00	15.00	0.11	13.50	175.0
13	2	22	82	0.00	1.50	.	17	21	27.3	2.00	5.00	10.00	0.12	12.50	178.0
14	3	24	82	2.98	2.60	.	18	21	24.0	1.89	4.32	6.75	0.14	11.00	160.0
15	4	28	82	0.72	0.60	.	23	20	23.9	1.90	3.90	10.90	0.15	12.50	187.0
16	5	25	82	.	0.42	.	.	19	24.9	1.50	4.90	12.30	0.14	15.90	213.0
17	6	21	82	.	0.36	.	.	21	21.6	2.20	4.80	7.90	0.12	18.55	194.4

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	2	20	81	8.80	6.88	0.1	49.70	0.30	0	0.050	0	0	0.0003	0.030	0	0
2	3	19	81	8.00	6.52	1.0	59.60	0.45	0	0.160	0	0	0.0001	0.020	0	0
3	4	23	81	8.20	6.72	1.2	64.60	0.62	0	0.400	0	0	0.0003	0.050	0	0
4	5	21	81	9.80	6.13	2.8	61.30	1.09	0	0.130	0	0	0.0004	0.025	0	0
5	6	23	81	8.80	6.95	6.7	66.70	2.40	0	0.370	0	0	0.0003	0.120	0	0
6	7	21	81	7.90	7.15	1.8	27.80	1.50	0	0.300	0	0	0.0008	0.100	0	0
7	8	18	81	.	.	.	.	.	.	.	.	.	.	.	.	.
8	9	22	81	.	.	.	.	.	.	.	.	.	.	.	.	.
9	10	26	81	.	.	.	.	.	.	.	.	.	.	.	.	.
10	11	23	81	.	.	.	.	.	.	.	.	.	.	.	.	.
11	12	16	81	4.00	6.52	3.6	48.20	1.46	0	0.020	0	0	0.0000	0.120	0	0
12	1	20	82	3.40	6.70	3.0	58.20	0.18	0	0.050	0	0	0.0004	0.120	0	0
13	2	22	82	4.70	6.80	0.0	45.80	0.10	0	0.110	0	0	0.0002	0.110	0	0
14	3	24	82	5.20	6.45	3.7	34.88	0.25	0	0.050	0	0	0.0002	0.100	0	0
15	4	28	82	4.40	6.35	2.0	43.50	0.18	0	0.045	0	0	0.0014	0.090	0	0
16	5	25	82	4.20	6.50	3.2	50.88	0.18	0	0.045	0	0	0.0015	0.080	0	0
17	6	21	82	3.85	6.44	1.6	39.48	0.18	0	0.050	0	0	0.0015	0.075	0	0

Appendix Table I-2g. Parcperdue, 180-ft well--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	9	22	80	3.97	2.90	838	31	.	27.9	1.61	6.26	56.2	0.11	71.20	326.0
2	10	22	80	12.86	2.00	838	18	18	16.0	1.40	6.25	30.0	0.57	11.00	296.0
3	11	20	80	1.45	2.10	838	8	20	17.3	1.50	6.62	38.2	0.47	4.80	258.5
4	12	17	80	0.00	20.00	838	11	19	16.0	1.00	6.32	40.0	0.70	3.84	278.0
5	1	26	81	0.00	3.40	838	18	18	16.5	1.39	6.82	37.0	0.40	3.76	272.0
6	2	20	81	0.21	11.00	838	26	22	15.1	1.40	6.70	37.2	0.54	4.50	210.0
7	3	19	81	0.00	6.00	.	13	19	16.3	1.60	7.20	41.0	0.38	3.80	252.0
8	4	23	81	0.00	6.80	.	23	22	15.1	1.30	7.30	32.5	0.45	3.30	275.6
9	5	21	81	0.18	5.90	.	19	16	16.5	1.80	7.70	39.9	0.40	5.20	224.0
10	6	28	81	0.59	0.90	.	29	20	16.2	1.27	7.80	42.0	0.41	8.00	242.0
11	7	21	81	0.00	3.80	.	31	21	21.3	1.30	6.60	14.9	0.40	3.80	200.0
12	8	18	81	1.33	4.00	.	32	21	17.2	1.28	8.30	41.0	0.21	4.00	205.0
13	9	22	81	0.00	4.10	.	23	20	16.2	1.30	7.40	37.8	0.33	3.80	182.0
14	10	26	81	1.50	.	.	16	.	.	.	.	.	.	.	.
15	11	23	81	0.23	.	.	17	.	.	.	.	.	.	.	.
16	12	16	81	7.22	6.60	.	9	19	17.3	1.62	6.62	15.4	0.30	5.75	280.0
17	1	20	82	0.00	26.00	.	23	22	16.6	1.50	7.90	42.0	0.28	4.50	233.0
18	2	22	82	0.00	5.85	.	17	20	15.0	1.00	6.80	28.0	0.28	4.40	198.0
19	3	24	82	2.98	4.20	.	18	22	15.2	1.35	6.80	18.8	0.28	3.80	210.0
20	4	28	82	0.72	6.30	.	23	20	13.7	1.40	6.30	3.6	0.30	5.00	264.0
21	5	25	82	.	3.90	.	.	19	18.5	1.10	8.10	38.5	0.24	21.20	314.0

Appendix Table I-2g, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	9	22	80	6.80	7.51	9.4	166.30	0.12	2	0.090	0	0	0.0005	0.250	0	0
2	10	22	80	9.20	7.20	0.0	101.70	0.48	0	0.070	0	0	0.0017	0.080	0	0
3	11	20	80	9.00	6.65	0.0	98.20	0.54	0	0.040	0	0	0.0009	0.080	0	0
4	12	17	80	9.60	6.80	0.0	127.20	0.54	0	0.060	0	0	0.0010	0.030	0	0
5	1	26	81	8.50	7.15	0.0	121.20	0.54	0	0.010	0	0	0.0005	0.050	0	0
6	2	20	81	9.20	6.84	0.1	121.40	0.45	0	0.050	0	0	0.0002	0.080	0	0
7	3	19	81	8.70	6.95	1.9	132.70	0.48	0	0.060	0	0	0.0001	0.030	0	0
8	4	23	81	9.00	7.10	4.0	112.00	0.58	0	0.050	0	0	0.0005	0.050	0	0
9	5	21	81	8.45	7.79	7.2	132.10	1.04	0	0.070	0	0	0.0004	0.050	0	0
10	6	28	81	8.60	6.93	1.8	137.70	2.20	0	0.050	0	0	0.0007	0.190	0	0
11	7	21	81	8.40	7.24	1.9	65.10	1.50	0	0.100	0	0	0.0008	0.050	0	0
12	8	18	81	9.10	7.41	0.0	136.90	2.78	0	0.040	0	0	0.0007	0.150	0	0
13	9	22	81	8.22	7.23	1.2	125.40	0.97	0	0.030	0	0	0.0006	0.170	0	0
14	10	26	81	.	.	.	.	.	.	.	.	.	.	.	.	.
15	11	23	81	.	.	.	.	.	.	.	.	.	.	.	.	.
16	12	16	81	10.20	6.80	1.4	66.30	0.52	0	0.010	0	0	0.0005	0.170	0	0
17	1	20	82	7.60	7.30	2.6	137.90	0.36	0	0.020	0	0	0.0003	0.170	0	0
18	2	22	82	9.60	7.58	0.0	98.40	0.42	0	0.000	0	0	0.0015	0.150	0	0
19	3	24	82	8.60	6.85	4.7	75.44	0.52	0	0.020	0	0	0.0006	0.150	0	0
20	4	28	82	8.80	6.80	1.0	35.50	0.30	0	0.015	0	0	0.0007	0.140	0	0
21	5	25	82	9.20	7.32	1.6	129.47	0.30	0	0.014	0	0	0.0006	0.135	0	0

APPENDIX I-3

Log of Well Activities at Parcperdue

<u>DATE</u>	<u>CONDITION</u>
Nov. 1 to 30, 1980	Water wells drilled; site made ready.
Dec. 1 to 31, 1980	Setting up rig for production well.
Jan. 6, 1981	Drilling began; drilled to 5060 ft.
Jan. 31, 1981	Cement job completed.
Feb. 7, 1981	Cemented formation below casing failed pressure test and had to be squeezed with 400 sacks cement.
Feb. 9 to 16, 1981	Drilled from 5203 to 10,017 ft.
Feb. 28, 1981	Drilling resumed to 10,446 ft.
Mar. 1, 1981	Drilled to 10,503 ft.
Mar. 2, 1981	Drilled and washed to 10,803 ft.
Mar. 3, 1981	Drilled to 11,000 ft and circulated.
Mar. 4, 1981	Drilled to 11,074 ft.
Mar. 5, 1981	Drilled to 11,264 ft and circulated.
Mar. 7, 1981	Drilled to 11,395 ft.
Mar. 9, 1981	Drilled to 11,583 ft.
Mar. 10, 1981	Drilled to 11,729 ft.
Mar. 11, 1981	Drilled to 11,820 ft.
Mar. 12, 1981	Drilled to 11,990 ft.
Mar. 13, 1981	Drilled to 12,001 ft.
Mar. 14, 1981	Drilled to 12,143 ft.
Mar. 15, 1981	Drilled to 12,187 ft.
Mar. 16, 1981	Drilled to 12,359 ft.
Mar. 17, 1981	Drilled to 12,413 ft; swabbed hole.
Mar. 18, 1981	Drilled to 12,479 ft; swabbed hole.
Mar. 19, 1981	Drilled to 12,544 ft.
Mar. 20, 1981	Drilled to 12,582 ft.
Mar. 21, 1981	Drilled to 12,650 ft.
Mar. 22, 1981	Drilled to 12,700 ft.
Mar. 24, 1981	Conditioned hole.
Apr. 26, 1981	Cemented hole.
Apr. 27, 1981	Cement did not set; required second plug.
Apr. 29, 1981	Cement firm at 13,155 ft, soft at 13,189 ft.
May 2, 1981	Drilled sidetrack 12,215 to 13,266 ft.
May 3, 1981	Drilled sidetrack 13,166 to 13,328 ft.
May 4, 1981	Reamed to 13,301 ft.
May 5, 1981	Recemented.
May 11, 1981	Drilled to 13,369 ft.
May 12, 1981	Drilled to 13,427 ft.
May 13, 1981	Drilled to 13,532 ft; washed out.
May 14, 1981	Drilled to 13,605 ft.
May 29, 1981	Fired 3 string shots.
June 27, 1981	Blew 1450 psi off annulus.
June 27, 1981	Well started flowing.
June 27, 1981	Closed hydril; caused pressure increase.
June 27, 1981	Pressure - 1550 psi.
June 27, 1981	Pressure - 2035 psi.
June 27, 1981	Pressure - 2300 psi.

DATECONDITION

June 28, 1981	Pumped 34 bbl mud; pressure - 2300 psi (stable).
June 28, 1981	Bled pressure to 1500 psi.
June 28, 1981	Bled pressure to 1000 psi.
June 28, 1981	Pumped mud to 2200 psi; shut in well.
June 29, 1981	Pressure - 2300 psi.
June 29, 1981	Shut in well; pressure increased to 3000 psi in 3 minutes.
June 29, 1981	Pumped in 14 bbl mud.
June 29, 1981	Shut down pump; pressure stable at 3300 psi.
June 29, 1981	15 bbl mud; pressure to 4000 psi. 20 bbl mud; pressure to 3600 psi. 25 bbl mud; pressure to 3800 psi.
June 29, 1981	Shut down pump; pressure to 1200 psi. 30 bbl mud; pressure to 700 psi.
June 30, 1981	102 bbl mud; pressure to 630 psi. 130 bbl mud; pressure to 600 psi.
June 30, 1981	Pressure stable at 600 psi.
July 1, 1981	Increased pressure to 750 psi.
July 2, 1981	Pumped "barite pill"; 30 bbl mud mixed with 4.5 millicuries of Iridium 192 coated on sand pellets at 1 bbl/min; 20 additional bbl at same rate; 70 bbl of 22.0 ppg barite pile with 1.5 millicuries of Ir-192 in last 5 bbl.
July 3, 1981	1.5 bbl mud; pressure to 1000 psi; bled to 500 psi.
July 3, 1981	0.5 bbl mud; pressure to 1000 psi; bled to 500 psi.
	0.5 bbl mud; pressure to 1000 psi; bled to 500 psi.
	3.5 bbl mud; pressure to 2000 psi; bled to 500 psi.
	Stabilized to 250 psi.
	Bled surface to 0 psi.
July 1 to 31, 1981	Annulus plugged with barite pill; production sand was squeezed through perforation at top and bottom of sand.
Aug. 1 to 31, 1981	Sweezy No. 1 was completed; well was gravel packed with calcium-zinc bromide solids, free completion fluid and 20/40 mesh sand in the perforations. Well perforated at 13,349 to 13,388 ft and 13,395 to 13,406 ft.
Sept. 1 to 30, 1981	Well remained static all month; completion fluid still in production tubing.
Oct. 8, 1981	Tree installed and well unplugged the following week.
Oct. 22, 1981	Well flow initiated. Nitrogen injected at 1500 ft; 325 bbl completion fluid recovered. Final flow rate was about 1000 bbl/day at 4950 psi.
Oct. 28, 1981	Well shut in; 297 bbl brine recovered at 1100 bbl/day at 5040 psi. Well ready to produce.
Feb. 1, 1982	Pipe driven for disposal well to 168 ft penetration. Well drilled to 2742 ft; hole conditioned and cased. Drilled to 5011 ft. Final closure at 5587 ft. Mud displaced with 3% KCL brine.
Feb. 25, 1982	Perforated from 4660 to 4646 ft and 4640 to 4607 ft.
Feb. 26, 1982	Perforated from 4607 to 4580 ft and 4580 to 4520 ft.
Feb. 28, 1982	Perforated from 4540 to 4520 ft.

DATECONDITION

Mar. 1, 1982 Number of open perforations calculated at 336.
Mar. 1, 1982 Sand fill to 4582 ft.
1450 bbl of brine injected into disposal well; maximum rate 2000 bbl/day. Surface pressure 290 psi and increasing 10 psi/60 bbl. Flow from production well 2954 bbl at 10,000 bbl/day. Drawdown to 4450 psi; surface pressure after shutdown 5350 psi. Maximum temperature 178°F.

Mar. 10, 1982 Fill at 4569. Injection pressure to 2435 psi bottom-hole pressure and 480 psi at surface. Fill at 4547 ft.

Mar. 18, 1982 Circulated out fill with KCL brine mud from 4538 ft to 4956 ft. Inserted gravel pack.

Apr. 1 to 30, 1982 Pressures up to 650 psi in 5-1/2 to 8-5/8 in. production tubing annulus. After bleed-off, pressure returned, indicating communication. Plugged at 10,434 ft, bled to zero; pressure still returned.

Apr. 26, 1982 Well-flow test, 689 bbl of brine, 17,000 bbl/day.

Apr. 28, 1982 20,000 bbl/day. Pressure build-up in disposal well, back pressure to 900 psi. Plugged with Otis-lubricator grease. Production well producing sand. Produced 2035 bbl of brine and 32,000 SCF gas.

May 1 to 31, 1982 Disposal well cleaned with xylene acid solvent and inhibited hydrochloric acid. Pressure down to 100 psi.

May 12 to 13, 1982 Flowed production well: 6500 bbl/day.

May 17 to 18, 1982 Flowed well: 8500 bbl/day; sand detected, well shut in; numerous leaks discovered.

May 20 to 26, 1982 Flowed well at 11,000 bbl/day; produced small amounts of sand which plugged filter pods. Stream diverted to salt water pit. May total brine production 91,000 bbl 1819 MCF gas.

June 1, 1982 Ending buildup test.

June 2 to 10, 1982 Varied flow rates to 10,000 bbl/day. Sand production.

June 11 to 23, 1982 Began long-term testing at 10,000 bbl/day. Produced large amounts of sand, dropped to acceptable level after first day.

June 23, 1982 Terminated flow test for short period (2 hours). Resumed drawdown.

June 28, 1982 Shut in well for buildup.

July 6, 1982 Continued long-term flow testing to July 26, 1982.

July 21, 1982 Disposal well back-pressure: 320 psi. Flow production well to salt water pit. Acidized disposal well.

Disposal well back-pressure dropped to 65 to 70 psi.

July 27, 1982 Malfunctioning control valve permitted gas and liquid down disposal well. Shut in production well.

July 29, 1982 Well back onstream by end of day.

July 31, 1982 Production to date 500,000 bbl; flowing well head pressure 3900 psi.

APPENDIX II
Sweet Lake
Water Quality Monitoring

APPENDIX II-1
Sweet Lake Geopressured-Geothermal Prospect
Brine Chemistry (ppm)

<u>Constituent</u>	<u>20 June 1981</u>	<u>21 June 1981</u>	<u>2 July 1981</u>	<u>Average</u>
TDS	156900	164900	166500	162767
Temp (°C)				148
Na	42000	45000	46000	44333
K	1690	1720	1740	1716
Mg	630	680	670	660
Ca	11200	11900	11000	11367
Cl	92340	100100	99350	97263
SC (umhos)	162000	177000	165000	168000
O ₂ (mol%)	<0.01	<0.01	<0.01	<0.01
pH	5.6@50°C	6.0@91°C	5.66@52°C	-----
CO ₂ (mol%)	10.81	8.36	10.59	9.92
HCO ₃	317	256	251	275
NH ₄	112	68	88	89
S=	1.2	0.12	0.45	0.59
Cd	0.33	0.38	0.38	0.36
B	69	69	62	67

APPENDIX II-2

Monthly Water Quality Observations, Sweet Lake

Appendix Table II-2a. Sweet Lake, bridge--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	5	6	80	0.72	38.0	271	26	27	62.0	2.10	5.90	35.00	0.90	49	530
2	6	3	80	0.00	24.0	192	27	29	18.4	1.70	0.84	3.20	0.32	20	424
3	7	8	80	0.03	14.0	238	30	30	61.0	1.20	5.00	14.00	0.03	94	462
4	8	12	80	1.66	10.0	219	28	30	133.0	3.01	8.83	14.50	0.05	175	720
5	9	16	80	0.00	7.0	213	32	33	115.0	56.00	6.70	21.00	0.17	26	695
6	10	15	80	0.00	30.0	250	26	23	86.0	5.84	8.14	1.60	0.26	50	606
7	11	12	80	0.00	14.0	253	22	19	203.0	9.51	93.00	19.58	0.18	210	1046
8	12	16	80	0.08	110.0	241	17	26	62.0	14.90	10.00	41.00	0.51	90	500
9	1	21	81	7.22	40.0	241	8	8	23.0	7.22	41.00	6.30	0.05	36	238
10	2	23	81	0.77	123.0	247	16	11	279.0	36.00	12.90	82.00	1.86	750	2404
11	3	30	81	0.97	50.0	238	26	21	12.0	2.20	3.36	9.60	0.09	780	98
12	4	20	81	0.00	25.0	256	26	28	649.0	9.70	4.90	29.00	0.87	475	1535
13	5	19	81	0.46	18.0	238	25	21	166.0	12.00	6.30	22.00	0.21	68	665
14	6	22	81	1.48	0.0	219	31	32	45.0	1.40	3.90	14.00	0.11	28	301
15	7	28	81	11.21	3.0	210	28	28	22.0	2.00	4.10	21.30	0.03	14	264
16	8	26	81	0.03	4.0	241	29	28	61.0	4.20	8.80	28.00	3.20	57	327
17	9	28	81	0.00	4.9	256	29	17	124.0	5.00	8.60	6.80	0.29	46	306
18	10	25	81	2.06	50.0	216	17	18	50.0	14.00	6.80	10.70	0.42	51	400
19	12	6	81	0.00	37.0	247	.	12	110.0	5.30	11.20	46.00	0.24	131	775
20	1	2	81	0.06	260.0	229	12	14	27.0	124.00	10.30	8.80	0.14	53	350
21	2	11	82	5.26	220.0	241	21	14	20.0	2.00	25.00	137.00	1.81	109	730
22	3	12	82	0.61	64.0	241	8	23	185.0	1.20	24.00	123.00	3.00	100	760
23	4	1	82	1.68	280.0	236	24	22	36.0	3.50	5.10	35.00	0.29	49	400
24	4	27	82	1.76	320.0	223	24	22	28.0	2.90	2.40	11.90	0.09	41	290

Appendix Table II-2a, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	5	6	80	4.10	7.70	12.1	127	0.12	3.2	0.30	0.000	0.00	0.008	1.10	0.0007	0
2	6	3	80	4.00	7.10	21.0	60	0.30	4.5	0.00	0.003	0.26	0.000	1.60	0.0000	0
3	7	8	80	2.60	7.20	16.0	58	0.00	5.8	0.16	0.000	0.00	0.032	0.82	0.0017	0
4	8	12	80	3.20	7.20	14.5	74	0.06	17.9	0.20	0.000	0.00	0.005	0.30	0.0123	0
5	9	16	80	3.60	7.60	37.0	82	0.22	3.7	0.20	0.000	0.00	0.006	1.40	0.0020	0
6	10	15	80	4.80	7.60	24.0	63	0.24	4.9	0.10	0.000	0.00	0.069	1.40	0.0104	0
7	11	12	80	8.80	8.00	13.0	99	0.00	9.8	2.40	0.000	0.00	0.038	0.70	0.0129	0
8	12	16	80	1.80	8.00	89.0	98	0.23	195.0	105.00	0.000	0.10	0.016	2.20	0.0039	0
9	1	21	81	8.40	7.30	28.0	48	0.12	15.0	3.90	0.000	0.00	0.022	0.64	0.0033	0
10	2	23	81	3.70	7.40	101.0	240	0.50	31.0	29.00	0.000	0.20	0.040	4.34	0.0038	0
11	3	30	81	4.20	6.78	17.0	32	0.00	16.0	0.30	0.000	0.00	0.010	0.23	0.0362	0
12	4	20	81	3.70	7.38	17.0	141	0.67	24.0	5.80	0.000	0.00	0.000	0.60	0.0054	0
13	5	19	81	5.00	7.85	18.0	90	0.33	4.2	1.40	0.005	0.00	0.001	0.43	0.0046	0
14	6	22	81	8.00	7.70	15.0	135	0.00	0.0	0.90	0.000	0.00	0.062	0.00	0.0035	0
15	7	28	81	1.90	8.00	25.0	79	0.00	6.4	0.06	0.000	0.09	0.000	0.00	0.0248	0
16	8	26	81	8.30	8.00	25.0	102	0.00	2.5	0.51	0.006	0.00	0.006	0.00	0.0080	0
17	9	28	81	4.20	7.81	14.7	91	0.00	0.0	0.30	0.009	0.12	0.010	0.37	0.0320	0
18	10	25	81	4.80	7.80	28.0	52	0.40	5.5	0.50	0.000	0.00	0.001	0.22	0.0023	0
19	12	6	81	6.00	8.00	5.0	145	0.00	5.3	0.20	0.000	0.00	0.002	0.14	0.0003	0
20	1	2	81	6.34	7.27	44.0	68	0.00	16.0	0.56	0.000	0.00	0.015	0.01	0.0000	0
21	2	11	82	7.40	7.68	16.1	160	0.00	3.0	0.00	0.000	0.00	0.003	0.05	0.0026	0
22	3	12	82	7.60	7.78	19.0	150	0.00	7.9	0.00	0.000	0.08	0.050	0.09	0.0054	0
23	4	1	82	8.20	7.67	29.0	64	0.00	2.5	0.80	0.000	0.00	0.005	0.23	0.0006	0
24	4	27	82	8.10	6.69	13.2	51	0.00	7.0	0.90	0.000	0.00	0.019	0.06	0.0025	0

Appendix Table II-2b. Sweet Lake, Sweet Lake--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	5	6	80	0.72	88.0	207	26	26	36.0	4.30	10.00	8.60	0.03	57	330
2	6	3	80	0.00	44.0	226	27	29	18.7	2.10	0.45	0.90	0.02	36	524
3	7	8	80	0.03	24.0	256	30	33	100.0	1.46	5.00	2.10	0.11	202	598
4	8	12	80	1.66	6.0	216	28	32	255.0	8.30	28.57	13.70	0.16	555	1813
5	9	16	80	0.00	6.0	204	32	32	345.0	10.68	46.00	25.00	0.03	400	3346
6	10	15	80	0.00	0.9	207	26	24	739.0	39.00	356.00	14.20	0.78	2250	6921
7	11	12	80	0.00	1.0	201	22	19	1678.0	44.00	1737.00	40.00	0.22	2260	7350
8	12	16	80	0.08	0.5	210	17	28	564.0	24.00	76.00	45.00	0.04	1179	4082
9	1	21	81	7.22	23.5	49	8	8	481.0	9.00	688.00	42.00	0.03	1015	3267
10	2	23	81	0.77	131.0	268	16	15	307.0	20.00	44.00	35.00	0.00	700	2065
11	3	30	81	0.97	100.0	168	22	21	227.0	14.00	44.00	24.90	0.23	19	1333
12	4	20	81	0.00	13.3	134	24	28	507.0	17.90	23.00	16.80	0.02	895	2789
13	5	19	81	0.46	46.0	192	31	26	515.0	28.00	55.00	35.00	0.03	1070	3796
14	6	22	81	1.48	0.0	162	31	31	399.0	12.30	30.00	19.00	0.00	860	2710
15	7	28	81	11.21	13.0	158	31	31	161.0	7.12	20.20	4.02	0.13	275	1107
16	8	26	81	0.03	11.0	143	31	31	195.0	7.40	22.00	8.00	0.10	350	846
17	9	28	81	0.00	12.0	134	31	18	284.0	10.40	25.00	17.00	0.07	445	827
18	10	25	81	2.06	32.0	146	17	18	465.0	23.00	59.00	19.60	0.03	71	1720
19	12	6	81	0.00	24.0	143	.	14	700.0	43.00	48.00	21.00	0.03	650	2750
20	1	2	82	0.06	56.0	70	12	13	321.0	129.00	77.00	9.80	0.02	745	850
21	2	11	82	5.26	650.0	143	21	10	292.0	7.30	54.00	51.00	0.09	405	1370
22	3	12	82	0.61	570.0	70	8	20	282.0	4.50	35.00	30.00	0.08	265	970
23	4	1	82	1.68	510.0	142	24	23	134.0	7.50	11.10	12.60	0.07	230	1060
24	4	27	82	1.76	530.0	168	24	18	123.0	7.00	11.70	8.80	0.06	236	1170

Appendix Table II-2b, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	5	6	80	6.70	7.20	15.6	36	0.00	0.0	0.10	0.000	0.00	0.019	0.50	0.0008	0
2	6	3	80	6.00	6.80	7.8	20	0.16	2.7	0.00	0.000	0.00	0.000	1.30	0.0000	0
3	7	8	80	6.40	6.10	10.0	28	0.00	5.8	0.20	0.000	0.06	0.004	1.23	0.0013	0
4	8	12	80	6.20	6.40	10.0	161	0.11	92.8	0.40	0.000	0.00	0.008	1.50	0.0094	0
5	9	16	80	7.80	6.50	11.0	272	0.00	165.0	0.30	0.000	0.00	0.006	2.20	0.0021	0
6	10	15	80	7.70	6.20	6.0	739	0.00	395.0	0.40	0.000	0.00	0.046	7.20	0.0059	0
7	11	12	80	8.60	7.20	5.4	770	0.00	410.0	0.30	0.000	0.00	0.024	3.80	0.0030	0
8	12	16	80	9.40	6.80	10.2	420	0.00	415.0	0.50	0.000	0.00	0.010	4.80	0.0035	0
9	1	21	81	11.50	7.10	14.6	340	0.00	168.6	0.60	0.000	0.00	0.041	4.05	0.0051	0
10	2	23	81	8.80	7.10	27.0	215	0.00	34.0	0.30	0.000	0.00	0.011	3.36	0.0041	0
11	3	30	81	8.70	7.07	32.0	184	0.00	88.0	0.50	0.006	0.00	0.009	1.25	0.0227	0
12	4	20	81	8.90	7.49	11.0	81	0.00	186.0	0.60	0.005	0.00	0.000	1.20	0.0039	0
13	5	19	81	7.20	7.05	4.0	352	0.00	133.0	0.60	0.011	0.05	0.062	3.50	0.0035	0
14	6	22	81	7.50	6.90	19.0	279	0.00	16.6	0.30	0.000	0.00	0.021	1.00	0.0066	0
15	7	28	81	6.80	7.00	14.0	25	0.00	45.6	0.06	0.011	0.00	0.017	2.03	0.0166	0
16	8	26	81	7.00	7.00	9.0	97	0.00	53.2	0.06	0.000	0.00	0.000	1.55	0.0084	0
17	9	28	81	8.50	7.70	12.3	138	0.00	30.0	0.20	0.000	0.12	0.011	0.07	0.0240	0
18	10	25	81	9.10	7.50	8.0	215	0.00	29.0	0.50	0.007	0.00	0.000	0.79	0.0022	0
19	12	6	81	7.60	7.70	12.0	244	0.00	39.0	0.20	0.000	0.00	0.005	0.51	0.0051	0
20	1	2	82	9.34	7.46	12.9	240	0.00	45.0	0.40	0.000	0.05	0.009	0.01	0.0090	0
21	2	11	82	10.20	7.44	15.4	152	0.00	36.0	0.00	0.000	0.00	0.015	0.08	0.0035	0
22	3	12	82	7.80	7.61	17.0	100	0.20	26.0	0.41	0.000	0.06	0.050	0.12	0.0029	0
23	4	1	82	8.70	7.89	17.7	98	0.00	23.0	0.70	0.000	0.07	0.017	0.15	0.0000	0
24	4	27	82	9.60	7.28	17.0	107	0.00	43.0	0.00	0.000	0.00	0.000	0.07	0.0004	0

Appendix Table II-2c. Sweet Lake, Square Lake--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	5	6	80	0.72	105.0	61	26	26	33.0	4.30	5.90	10.50	0.03	62	350
2	6	3	80	0.00	35.0	122	27	29	15.4	1.80	0.44	0.55	0.00	28	410
3	7	8	80	0.03	23.0	49	30	31	98.0	1.51	5.30	4.90	0.04	205	679
4	8	12	80	1.66	7.5	70	28	32	155.0	4.35	12.07	10.00	0.04	225	906
5	9	16	80	0.00	3.4	61	32	33	253.0	16.00	32.00	22.00	0.06	285	2336
6	10	15	80	0.00	1.0	58	26	25	323.0	26.00	91.00	5.10	0.13	1500	5075
7	11	12	80	0.00	1.0	58	22	19	1533.0	55.00	1600.00	47.00	0.22	2260	7630
8	12	16	80	0.08	65.0	64	17	27	549.0	26.00	82.00	49.00	0.11	1339	4396
9	1	21	81	7.22	88.2	195	86	8	313.0	13.40	181.00	42.00	0.13	445	1490
10	2	23	81	0.77	216.0	40	16	14	320.0	20.00	48.00	38.00	0.04	800	2326
11	3	30	81	0.97	65.0	52	22	21	240.0	12.00	30.00	20.50	0.20	530	184
12	4	20	81	0.00	9.2	52	24	28	448.0	16.00	22.00	17.60	0.02	825	2559
13	5	19	81	0.46	35.0	85	27	26	657.0	33.00	68.00	44.00	0.01	1365	4488
14	6	22	81	1.48	0.0	64	31	31	244.0	10.70	38.00	18.00	0.08	1570	1932
15	7	28	81	11.21	20.0	73	31	31	18.0	2.38	3.10	4.24	0.07	31	161
16	8	26	81	0.03	4.0	61	31	32	230.0	8.00	22.40	9.00	0.06	228	1058
17	9	28	81	0.00	17.0	64	31	22	244.0	9.20	22.00	27.00	0.08	350	834
18	10	25	81	2.06	30.0	58	17	18	430.0	17.00	54.00	18.10	0.05	69	1840
19	12	6	81	0.00	32.0	58	.	14	700.0	13.60	52.00	23.00	0.03	799	2850
20	1	2	82	0.06	57.0	152	12	14	344.0	129.00	175.00	10.20	0.59	725	800
21	2	11	82	5.26	660.0	61	21	11	320.0	7.80	56.00	50.00	0.11	389	1440
22	3	12	82	0.61	670.0	76	8	22	377.0	6.10	44.00	34.00	0.14	350	1240
23	4	1	82	1.68	380.0	70	24	20	120.0	6.80	13.00	14.40	0.05	212	940
24	4	27	82	1.76	470.0	82	24	20	130.0	7.30	6.00	8.80	0.05	250	1120

Appendix Table II-2c, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	5	6	80	8.2	7.20	16.6	37.0	0.00	7.1	0.10	0.000	0.00	0.004	0.50	0.0014	0
2	6	3	80	6.9	6.80	7.6	16.5	0.00	3.2	0.00	0.000	0.00	0.000	1.90	0.0000	0
3	7	8	80	6.8	6.70	11.0	35.0	0.00	5.4	0.00	0.000	0.00	0.004	1.15	0.0013	0
4	8	12	80	5.8	6.90	14.5	78.0	0.11	38.0	0.20	0.000	0.00	0.031	0.30	0.0045	0
5	9	16	80	4.6	6.20	13.0	177.0	0.00	87.0	0.50	0.004	0.00	0.009	2.00	0.0043	0
6	10	15	80	4.0	6.70	10.0	474.0	0.00	282.0	0.20	0.006	0.00	0.169	4.60	0.0127	0
7	11	12	80	8.0	7.30	5.9	760.0	0.00	414.0	0.40	0.000	0.00	0.039	3.30	0.0031	0
8	12	16	80	8.6	7.10	10.6	480.0	0.15	123.0	2.60	0.000	0.00	0.015	5.30	0.0027	0
9	1	21	81	8.6	7.50	32.0	230.0	0.57	0.0	20.00	0.000	0.00	0.038	3.40	0.0034	0
10	2	23	81	8.7	6.80	62.0	239.0	0.00	32.0	0.40	0.000	0.00	0.025	4.59	0.0045	0
11	3	30	81	7.9	6.81	65.0	254.0	0.00	95.0	0.60	0.000	0.00	0.013	3.18	0.0078	0
12	4	20	81	8.3	7.22	15.0	153.0	0.00	168.0	0.80	0.006	0.00	0.000	1.00	0.0049	0
13	5	19	81	7.4	6.79	12.0	463.0	0.00	190.0	0.80	0.011	0.05	0.050	4.50	0.0034	0
14	6	22	81	5.1	6.70	14.0	193.0	0.00	3.0	0.30	0.000	0.00	0.023	1.10	0.0024	0
15	7	28	81	3.8	7.00	22.0	97.0	0.00	3.9	0.04	0.008	0.05	0.016	1.31	0.0035	0
16	8	26	81	6.8	6.80	11.0	123.0	0.00	55.1	0.12	0.014	0.00	0.002	1.77	0.0117	0
17	9	28	81	9.5	9.16	18.9	128.0	0.00	25.0	0.20	0.008	0.00	0.017	0.77	0.0320	0
18	10	25	81	9.0	7.40	9.0	159.0	0.00	35.0	0.40	0.006	0.00	0.000	0.63	0.0024	0
19	12	6	81	7.2	7.80	13.0	146.0	0.00	35.0	0.20	0.000	0.00	0.000	0.22	0.0095	0
20	1	2	82	9.4	7.64	20.0	229.0	0.00	50.0	0.43	0.000	0.05	0.010	0.02	0.0030	0
21	2	11	82	9.4	7.48	22.0	156.0	0.00	38.0	0.00	0.000	0.00	0.001	0.02	0.0014	0
22	3	12	82	7.5	7.45	19.0	120.0	0.60	32.0	0.41	0.000	0.00	0.050	0.10	0.0056	0
23	4	1	82	9.0	7.73	19.5	93.0	0.00	30.0	0.00	0.000	0.00	0.000	0.00	0.2200	0
24	4	27	82	8.7	7.20	19.8	101.0	0.00	69.0	0.00	0.000	0.00	0.002	0.05	0.0042	0

Appendix Table II-2d. Sweet Lake, 280-ft well 1--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	10	24	80	0.00	3.50	.	24	18	99	1.50	8.73	39.00	0.10	60	589
2	11	12	80	0.00	0.46	.	18	21	71	2.04	102.00	15.32	0.13	50	388
3	12	19	80	0.08	0.00	.	16	22	83	1.49	8.90	37.00	0.09	91	628
4	1	21	81	7.22	2.00	1341	8	21	125	0.80	80.00	38.00	0.21	36	680
5	2	25	81	0.77	0.15	1372	17	23	80	1.46	8.96	13.90	0.14	38	575
6	3	30	81	0.97	0.75	1280	21	23	93	1.40	9.27	19.50	0.14	43	431
7	4	20	81	0.00	0.75	1341	24	24	172	2.00	3.80	13.40	0.14	37	537
8	5	19	81	0.46	5.00	2042	25	29	155	11.00	8.30	25.00	0.12	36	610
9	6	22	81	1.48	0.00	1951	29	24	78	1.40	6.80	24.00	0.08	35	502
10	7	28	81	11.21	2.00	1798	28	24	90	1.44	8.90	20.50	0.11	36	553
11	8	26	81	0.03	0.00	1646	28	24	81	1.54	7.60	22.00	0.09	39	365
12	9	28	81	0.00	4.90	1646	27	24	98	1.40	7.80	30.00	0.12	36	259
13	10	25	81	2.06	14.00	1646	14	23	70	1.75	7.85	27.40	0.04	34	400
14	12	5	81	0.06	10.00	1433	12	22	105	1.25	6.50	27.00	0.10	35	600
15	1	2	82	5.26	2.80	46	21	23	80	1.56	13.30	10.30	0.07	38	400
16	2	9	82	0.61	3.00	1341	8	21	98	0.69	14.00	68.00	0.04	37	580
17	3	12	82	0.03	5.40	1311	24	26	188	0.67	14.00	67.00	0.08	39	590
18	4	1	82	1.68	4.60	1280	24	25	105	1.40	8.00	47.00	0.13	42	710
19	4	27	82	1.76	5.70	1314	24	22	98	2.00	6.10	21.00	0.08	41	900

Appendix Table II-2d, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	10	24	80	4.20	7.58	20.0	115	0.00	3.6	0.10	0.000	0.00	0.002	1.10	0.0084	0
2	11	12	80	5.80	6.90	5.0	116	0.00	2.0	0.10	0.000	0.00	0.023	0.80	0.0142	0
3	12	19	80	4.80	7.60	3.1	103	0.00	2.7	0.30	0.000	0.00	0.006	1.00	0.0029	0
4	1	21	81	6.60	7.90	7.2	103	0.24	2.5	0.30	0.000	0.00	0.030	0.76	0.0012	0
5	2	25	81	6.00	7.60	0.0	100	0.40	2.7	0.20	0.000	0.00	0.000	1.32	0.0026	0
6	3	30	81	6.40	7.83	11.0	95	0.21	0.0	0.20	0.000	0.00	0.007	0.41	0.0046	0
7	4	20	81	5.50	7.90	0.0	44	0.00	4.9	0.20	0.000	0.00	0.000	0.30	0.0034	0
8	5	19	81	5.50	7.91	5.0	94	0.15	1.6	0.40	0.007	0.05	0.000	0.51	0.0026	0
9	6	22	81	6.20	7.90	5.0	94	0.00	0.0	0.00	0.000	0.00	0.041	0.00	0.0016	0
10	7	28	81	5.70	8.40	17.0	94	0.00	1.5	0.04	0.000	0.00	0.001	0.00	0.0095	0
11	8	26	81	5.60	8.10	12.0	85	0.00	1.0	0.04	0.007	0.05	0.000	0.00	0.0000	0
12	9	28	81	5.40	8.11	4.3	95	0.00	0.0	0.30	0.000	0.08	0.012	0.00	0.0080	0
13	10	25	81	5.40	7.70	4.0	93	0.00	0.0	0.50	0.000	0.00	0.000	0.60	0.0010	0
14	12	5	81	3.80	8.00	.	91	0.16	3.6	0.10	0.005	0.00	0.001	0.29	0.0002	0
15	1	2	82	4.96	7.96	0.0	92	0.00	5.4	0.42	0.000	0.00	0.025	0.07	0.0070	0
16	2	9	82	8.00	7.96	10.9	89	0.00	3.1	0.45	0.000	0.06	0.000	0.07	0.0010	0
17	3	12	82	6.80	7.85	6.7	95	0.00	6.2	0.00	0.000	0.00	0.010	0.08	0.0000	0
18	4	1	82	9.00	8.57	4.1	91	0.00	2.6	0.40	0.000	0.00	0.000	0.21	0.0000	0
19	4	27	82	8.10	7.98	7.6	88	0.00	0.5	0.00	0.000	0.07	0.000	0.07	0.0010	0

Appendix Table II-2e. Sweet Lake, 280-ft well 2--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	10	24	80	0.00	3.00	.	24	19	99	2.86	7.67	49.0	0.03	85	665
2	11	12	80	0.00	0.92	.	18	21	143	3.80	82.00	45.0	0.08	56	693
3	12	19	80	0.08	0.00	.	16	22	84	2.04	9.80	13.0	0.10	97	602
4	1	21	81	7.22	1.10	457	8	21	126	0.91	89.00	35.0	0.10	48	575
5	2	25	81	0.77	0.06	1372	17	23	76	1.31	9.51	15.0	0.10	38	575
6	3	30	81	0.97	0.40	1280	21	23	90	1.50	7.78	20.0	0.08	45	411
7	4	20	81	0.00	0.75	1341	24	24	166	2.10	3.50	14.3	0.09	39	512
8	5	19	81	0.46	1.00	2012	25	26	150	11.00	68.00	23.0	0.09	36	471
9	6	22	81	1.48	0.00	1951	29	26	84	1.50	6.10	24.0	0.05	36	502
10	7	28	81	11.21	3.00	1798	28	24	89	1.56	7.80	20.8	0.13	35	501
11	8	26	81	0.03	0.00	1615	28	24	90	1.34	8.60	23.0	0.11	37	385
12	9	28	81	0.00	4.00	1646	27	26	104	1.30	8.30	28.0	0.12	31	333
13	10	25	81	2.06	5.40	1646	14	23	111	1.55	9.80	28.7	0.43	34	420
14	12	5	81	0.06	9.00	1433	12	22	105	1.25	7.50	27.0	0.10	33	600
15	1	2	82	5.26	5.40	1402	21	23	84	1.52	15.30	10.1	0.05	37	500
16	2	11	82	0.61	56.00	1341	8	21	23	0.80	17.00	73.0	0.11	47	640
17	3	12	82	0.03	14.00	1311	24	25	233	0.71	16.00	69.0	0.13	52	680
18	4	1	82	1.68	12.00	1311	24	26	97	1.50	8.30	45.0	0.13	40	790
19	4	27	82	1.76	10.00	1364	24	23	97	1.90	7.00	18.9	0.09	35	800

Appendix Table II-2e, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	10	24	80	6.50	7.74	36.0	149	0.00	4.0	0.20	0.000	0.10	0.003	1.10	0.0052	0
2	11	12	80	4.10	6.90	9.0	122	0.00	4.0	0.30	0.003	0.00	0.021	0.90	0.0255	0
3	12	19	80	4.90	7.60	1.5	106	0.00	3.9	0.30	0.000	0.00	0.005	1.20	0.0032	0
4	1	21	81	6.30	7.80	7.9	106	0.29	2.6	0.60	0.003	0.00	0.038	0.85	0.0031	0
5	2	25	81	5.60	7.60	2.0	98	0.40	2.7	0.30	0.000	0.00	0.015	0.99	0.0023	0
6	3	30	81	6.00	7.64	9.0	94	0.00	0.0	0.40	0.000	0.00	0.012	0.33	0.0063	0
7	4	20	81	5.30	7.84	0.0	63	0.00	5.4	0.40	0.005	0.00	0.000	0.40	0.0054	0
8	5	19	81	5.60	7.86	7.0	97	0.00	1.2	0.60	0.008	0.06	0.000	0.70	0.0016	0
9	6	22	81	4.60	7.90	5.0	94	0.00	0.0	0.40	0.000	0.00	0.021	0.90	0.0028	0
10	7	28	81	5.60	8.40	17.0	94	0.00	1.7	0.04	0.000	0.09	0.000	0.59	0.0130	0
11	8	26	81	5.50	8.10	11.0	93	0.00	0.7	0.02	0.000	0.05	0.000	0.68	0.0073	0
12	9	28	81	5.00	8.15	4.8	94	0.00	2.0	0.20	0.000	0.00	0.014	0.24	0.0160	0
13	10	25	81	5.90	7.90	4.0	93	0.00	3.2	0.40	0.000	0.00	0.000	0.16	0.0022	0
14	12	5	81	3.60	8.00	0.0	92	0.18	3.3	0.20	0.000	0.00	0.002	0.22	0.0024	0
15	1	2	82	5.56	7.97	0.0	86	0.00	5.4	0.31	0.000	0.00	0.019	0.03	0.1860	0
16	2	11	82	7.80	7.87	0.0	91	0.00	4.7	0.69	0.000	0.00	0.002	0.06	0.0011	0
17	3	12	82	7.10	7.91	8.5	95	0.40	6.8	0.00	0.000	0.00	0.000	0.07	0.0018	0
18	4	1	82	9.00	8.45	3.0	95	0.00	1.0	0.10	0.000	0.00	0.001	0.19	0.0000	0
19	4	27	82	8.10	7.59	15.4	92	0.00	3.7	0.00	0.000	0.22	0.000	0.26	0.0027	0

Appendix Table II-2f. Sweet Lake, 435-ft well--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	10	24	80	0.00	12.00	.	24	17	87	2.36	6.67	42.0	0.03	65.0	665
2	11	12	80	0.00	4.00	.	18	21	94	2.86	79.00	51.0	0.11	85.0	776
3	12	19	80	0.08	0.20	.	16	22	89	2.27	8.60	44.0	0.04	118.0	706
4	1	21	81	7.22	1.30	1280	8	23	127	1.33	87.00	39.0	0.13	68.0	575
5	2	25	81	0.77	0.18	1341	17	22	95	2.00	9.52	14.0	0.18	67.0	653
6	3	30	81	0.97	1.10	1280	21	23	105	1.80	8.45	20.0	0.16	57.0	470
7	4	20	81	0.00	0.75	1341	24	24	172	2.20	3.80	14.1	0.17	5.3	563
8	5	19	81	0.46	2.50	1859	25	25	159	11.00	55.00	20.0	0.16	55.0	610
9	6	30	81	1.48	0.00	1829	29	23	93	3.00	7.30	23.0	0.12	53.0	470
10	7	28	81	11.21	2.00	1798	28	24	107	1.38	8.40	19.7	0.15	51.0	580
11	8	26	81	0.03	0.00	1615	28	24	104	1.48	8.20	22.0	0.13	51.0	423
12	9	28	81	0.00	2.60	1646	27	16	130	1.20	8.50	30.0	0.14	32.0	299
13	10	25	81	2.06	8.60	1646	14	23	38	1.55	9.85	32.6	0.12	50.0	480
14	12	5	81	0.06	30.00	1433	12	24	120	1.30	7.50	29.0	0.15	47.0	675
15	1	2	82	5.26	5.60	1402	21	23	96	1.51	22.00	10.0	0.05	51.0	450
16	2	11	82	0.61	12.00	1341	8	22	21	0.72	17.00	78.0	0.01	35.0	720
17	3	12	82	0.03	40.00	1311	24	27	204	0.68	16.00	65.0	0.08	36.0	600
18	4	1	82	1.68	11.00	1311	24	26	110	1.30	7.90	46.0	0.14	50.0	770
19	4	27	82	1.76	36.00	1320	24	23	115	2.00	6.90	21.0	0.10	51.0	730

Appendix Table II-2f, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	10	24	80	8.40	7.62	25.0	128	0.00	11.5	0.10	0.000	0.10	0.002	1.90	0.01060	0
2	11	12	80	8.10	6.90	5.0	143	0.00	2.5	0.00	0.000	0.00	0.022	0.90	0.01333	0
3	12	19	80	5.70	7.60	0.0	122	0.00	4.0	0.30	0.000	0.00	0.008	1.00	0.00390	0
4	1	21	81	5.20	7.70	9.0	110	0.00	4.5	0.20	0.003	0.00	0.031	1.15	0.00240	0
5	2	25	81	6.60	7.50	0.0	104	0.30	2.7	0.20	0.000	0.00	0.000	0.51	0.00200	0
6	3	30	81	1.50	7.62	8.0	97	0.21	3.7	0.20	0.000	0.00	0.012	0.38	0.00100	0
7	4	20	81	1.90	7.77	7.0	91	0.00	11.1	0.60	0.000	0.00	0.000	0.40	0.00310	0
8	5	19	81	5.30	7.94	5.0	116	0.19	5.2	0.40	0.007	0.00	0.000	0.22	0.00210	0
9	6	30	81	5.50	7.90	5.0	91	0.00	0.0	0.60	0.018	0.00	0.018	1.10	0.00400	0
10	7	28	81	6.00	8.30	17.0	95	0.00	3.1	0.06	0.000	0.00	0.000	0.52	0.01120	0
11	8	26	81	8.50	8.70	12.0	92	0.00	1.0	0.19	0.009	0.00	0.000	0.58	0.00870	0
12	9	28	81	5.80	8.12	5.1	96	0.00	3.8	0.20	0.000	0.00	0.006	0.33	0.02000	0
13	10	25	81	5.90	7.90	5.0	94	0.00	3.9	0.20	0.000	0.00	0.000	0.33	0.00090	0
14	12	5	81	4.40	8.10	0.0	94	0.24	3.3	0.20	0.000	0.00	0.005	0.20	0.00520	0
15	1	2	82	5.88	8.05	0.0	85	0.00	7.3	0.29	0.000	0.00	0.007	0.05	0.00200	0
16	2	11	82	8.20	7.88	4.3	91	0.00	3.0	0.33	0.000	0.00	0.000	0.06	0.00120	0
17	3	12	82	7.00	7.81	8.8	97	0.50	6.4	0.00	0.000	0.00	0.000	0.20	0.00530	0
18	4	1	82	8.60	8.40	2.3	93	0.00	4.5	0.60	0.000	0.00	0.000	0.17	0.00000	0
19	4	27	82	8.60	7.71	9.3	94	0.00	6.1	0.20	0.000	0.07	0.000	0.23	0.00380	0

APPENDIX II-3

Log of Well Activities at Sweet Lake

<u>DATE</u>	<u>CONDITION</u>
Aug. 18, 1980	Drive 30-in. conductor pipe.
Aug. 23, 1980	Run 20-in. casing to 835 ft.
Aug. 31, 1980	Run 13-3/8 in. casing to 4043 ft after drilling.
Sept. 19, 1980	Log and run 9-5/8 in. casing to 10,230 ft after drilling.
Sept. 23, 1980	Tense pipe-pulled 54 in.
Oct. 22, 1980	Stuck in hole; well flowing.
Oct. 30, 1980	Circulation established; PBDT 9354 ft.
Nov. 2, 1980	Wash over drill pipe.
Nov. 9, 1980	Sidetrack hole from 10,602 ft.
Dec. 26, 1980	Log and run 7-5/8 in. casing to 15,065 in.
Jan. 6, 1981	Core.
Jan. 11, 1981	Core after drilling.
Jan. 14, 1981	Core after drilling.
Jan. 16, 1981	Drilled to 15,740 ft.
Jan. 18, 1981	Run 5-1/2 in. casing.
Jan. 21, 1981	Run 7-5/8 in. tie back.
Jan. 24, 1981	Attempt to tense 7-5/8 in.; pulled free.
Jan. 25, 1981	Drilled out cement.
Jan. 29, 1981	Circulated.
Jan. 30, 1981	Cement 7-5/8 in.
Feb. 1, 1981	Attempted to tense 7-5/8 in.; movement with 60,000 psi pull.
Feb. 2, 1981	Drilled out cement.
Feb. 3, 1981	Attempted to tense 7-5/8 in.; movement with 40,000 psi pull.
Feb. 4, 1981	Cement 7-5/8 in.
Feb. 7, 1981	Tense 7-5/8 in.
Feb. 9, 1981	Drilled out cement.
Feb. 11, 1981	Cleaned hole from 12,719 to 14,536 ft.
Feb. 19, 1981	Displaced mud with 10# brine.
June 9, 1981	Perforated disposal well: 7015-7030, 7045-7065, 7085-7125, 7160-7215, 7235-7260, 7300-7320.
June 16, 1981	Perforated production well: 15,387-15,414.
June 16, 1981	Perforation; initial surge pressure 4200 psi, stabilized at 4000 psi.
June 16, 1981	Started to pressure up test wellhead.
June 17, 1981	Bottom-hole (BH) pressure at 12,250 psia.
June 17, 1981	BH pressure at 12,064 psia.
June 17, 1981	BH pressure decreasing at 0.5 psi/min to 0.3 psi/min.
June 19, 1981	BH pressure decreasing at 4.0 psi/hr.
June 19, 1981	Pressure at 15,336 ft about 12,300 psia; decreased to 12,052 psia.
June 19, 1981	Began flow test at about 2900 bbl/day.
June 19, 1981	Test well bottoms came up at 300 bbl production. No sand production.
June 19, 1981	10#/gal brine displaced with 9#/gal brine.

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June 19, 1981	Brine production increased to 4680 bbl/day; surface pressure increased to 4600 psig.
June 20, 1981	Switched brine production to disposal well.
June 20, 1981	Sent brine production back to blowdown tanks.
June 20, 1981	Switched brine production back through disposal well.
June 20, 1981	Difficulty with disposal well.
June 20, 1981	Sent all brine without filtering to disposal well; action terminated because of sharp press increase. Brine production at 4000 bbl/day.
	Switched brine production through filters to blowdown tank. Lined out production at 3000 to 4000 bbl/day and separator pressure at 500 psig.
June 20, 1981	Lined out at 3720 bbl/day.
June 20, 1981	Disposal well injectivity test at 3 bbl/min; pressure at 850 psig.
June 21, 1981	Started acid treatment of disposal well.
June 21, 1981	Injectivity test run; acid helped but pressure still too high.
June 21, 1981	Attempted to inject inhibitor into brine production line.
June 21, 1981	Switched brine production to disposal well.
June 21, 1981	Started inhibitor injection at 10 ppm concentration.
June 22, 1981	Switched brine production to blowdown tanks.
June 22, 1981	Switched back to disposal well.
June 22, 1981	Test well shut in; initial flow test completed; reservoir pressure buildup test started.
June 30, 1981	Started reservoir limit test--rate at 16,000 bbl/day, 11,974 psi.
July 4, 1981	Dropped flow rate to 14,000 bbl/day, pressure at 8093 psi.
July 7, 1981	Dropped flow rate to 12,000 bbl/day, pressure at 7997 psi.
July 17, 1981	Flow rate at 11,000 bbl/day, pressure at 7806 psi.
July 22, 1981	Flow rate at 2000 bbl/day, pressure at 691 psi.
July 31, 1981	Flow rate at 2400 bbl/day, pressure at 3463 psi.
Aug. 1, 1981	Flow rate at 2400 bbl/day, surface pressure at 3566 psi.
Aug. 6, 1981	Flow rate at 1400 bbl/day, surface pressure at 3721 psi.
Aug. 10, 1981	Flow rate at 2000 bbl/day, surface pressure at 3915 psi.
Aug. 11, 1981	Flow rate at 34,000 bbl/day.
Aug. 14, 1981	Flow rate at 13,000 bbl/day, surface pressure at 715 psi; reduced to 2000 bbl/day.
Aug. 16, 1981	Flow rate 13,000 at 18,000 bbl/day, surface pressure at 2145 psi.
Aug. 17, 1981	Flow rate at 20,000 bbl/day; well later shut in.
Aug. 26, 1981	Flow rate at 3200 bbl/day, surface pressure at 3830 psi; rate dropped to 2800 bbl/day.
Aug. 31, 1981	Rate increased to 13,500 bbl/day, pressure at 2344 psi.
Sept. 1, 1981	Flow rate at 5000 bbl/day, pressure at 2310 psi.
Sept. 9, 1981	Flow rate at 15,000 bbl/day, pressure at 1840 psi.

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Sept. 11, 1981	Flow rate at 10,000 bbl/day, pressure at 1250 psi.
Sept. 29, 1981	Flow rate at 5000 bbl/day, pressure at 1038 psi.
Oct. 1, 1981	Flow rate at 5300 bbl/day, pressure at 1882 psi.
Oct. 1, 1981	Well shut in.
Oct. 1, 1981	Flow rate at 4400 bbl/day; increased to flow rate at 5000 bbl/day, pressure 2290 psi.
Oct. 13, 1981	Well shut in.
Oct. 24, 1981	Flow rate at 5000 bbl/day, pressure at 3523 psi.
Oct. 28, 1981	Flow rate at 4800 bbl/day, pressure at 2610 psi.
Oct. 31, 1981	Flow rate at 4800 bbl/day, pressure at 2474 psi.
Nov. 1, 1981	Flow rate at 4900 bbl/day, pressure at 2477 psi.
Nov. 8, 1981	Flow rate at 5000 bbl/day, pressure at 2350 psi.
Nov. 9, 1981	Flow rate at 5000 bbl/day, pressure at 3180 psi.
Nov. 11, 1981	Flow rate at 5000 bbl/day, pressure at 2449 psi.
Dec. 2, 1981	Flow rate at 5000 bbl/day, pressure at 2180 psi.
Dec. 4, 1981	Flow rate at 5000 bbl/day, pressure at 2177 psi.
Dec. 11, 1981	Flow rate at 5000 bbl/day, pressure at 2930 psi.
Dec. 21, 1981	Flow rate at 2500 bbl/day, pressure at 2733 psi.
Dec. 24, 1981	Well shut in.
Dec. 26, 1981	Flow rate at 2200 bbl/day, pressure at 3390 psi.
Dec. 31, 1981	Flow rate at 2100 bbl/day, pressure at 3268 psi.
Jan. 1, 1982	Flow rate at 2100 bbl/day, pressure at 3263 psi.
Jan. 5, 1982	Flow rate at 5000 bbl/day, pressure at 2798 psi.
Jan. 6, 1982	Well shut in.
Jan. 7, 1982	Flow rate at 3000 bbl/day, pressure at 3380 psi.
Jan. 8, 1982	Flow rate at 4400 bbl/day, pressure at 3031 psi.
Jan. 13, 1982	Well shut in.
Jan. 14, 1982	Well shut in.
Jan. 14, 1982	Flow rate at 5000 bbl/day, pressure at 2835 psi.
Jan. 20, 1982	Well shut in.
Jan. 20, 1982	Flow rate at 5000 bbl/day, pressure at 2504 psi.
Jan. 21, 1982	Well shut in.
Jan. 21, 1982	Flow rate at 3600 bbl/day, pressure at 2708 psi.
Jan. 21, 1982	Flow rate at 5000 bbl/day, pressure at 2583 psi.
Jan. 25, 1982	Shut down.
Jan. 25, 1982	Flow rate at 5000 bbl/day, pressure at 2483 psi.
Jan. 27, 1982	Shut in.
Jan. 28, 1982	Flow rate at 5000 bbl/day, pressure at 2894 psi.
Jan. 31, 1982	Flow rate at 5200 bbl/day, pressure at 2470 psi.
Feb. 1, 1982	Flow rate at 5200 bbl/day, pressure at 2468 psi.
Feb. 1, 1982	Flow rate at 10,000 bbl/day, pressure at 2465 psi.
Feb. 1, 1982	Flow rate at 7000 bbl/day, pressure at 1923 psi.
Feb. 2, 1982	Flow rate at 8900 bbl/day, pressure at 2003 psi.
Feb. 3, 1982	Flow rate at 5000 bbl/day, pressure at 1989 psi.
Feb. 3, 1982	Flow rate at 15,000 bbl/day, pressure at 937 psi.
Feb. 4, 1982	Flow rate at 10,000 bbl/day, pressure at 944 psi.
Feb. 5, 1982	Well shut in.
Feb. 5, 1982	Flow rate at 5000 bbl/day; pressure at 1960 psi.
Feb. 9, 1982	Flow rate at 10,000 bbl/day; pressure at 2448 psi.

DATECONDITION

Feb. 9, 1982	Flow rate at 5000 bbl/day; pressure at 2520 psi.
Feb. 10, 1982	Production well shut in.
Mar. 1 to 31, 1982	Production well shut in.
Mar. 27, 1982	Disposal well cleaned; tubing parted; sand fill to 2600 ft. Washed over to 4520 ft; plug set in 7 in. tubing at 4527 ft; 11 in. cement plug placed on top at 4516 ft; 7 in. tubing cut as 4517 ft; new packer set at 2016 ft.
Apr. 5, 1982	Well reperforated; 2 runs; 4425 ft.
Apr. 6, 1982	Well reperforated; 10 runs.
Apr. 7, 1982	Well reperforated; 9 runs; 3976 ft. Injectivity test.
Apr. 29, 1982	Production well flowed 20,000 to 30,000 bbl/day.
May 17, 1982	Fishing for tools.
May 18, 1982	Began setting bridge plug; did not set; clean scale from well.
May 20, 1982	Set bridge plug. New PBTD, 15351 ft.
May 26, 1982	Fluid density log run to locate leak in 5-1/2 in. tubing.
May 27, 1982	Noise log indicated three possible leaks. Leak found at 5980 ft by radioactive tracer log.
June 1 to 30, 1982	Well shut in.

APPENDIX III

**Rockefeller Refuge
Water Quality Monitoring**

APPENDIX III-1

Monthly Water Quality Observations, Rockefeller Refuge

Appendix Table III-1a. Gladys McCall, lake--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	5	8	81	2.39	32.00	43	27	23.0	7700	140	1136	340	0.23	14400	120000
2	6	4	81	4.73	29.00	34	28	27.5	6240	88	922	242	2.50	17800	32000
3	6	30	81	1.25	26.00	64	29	29.0	4240	151	536	182	1.41	9200	17400
4	8	4	81	7.07	250.00	46	33	32.0	6000	255	728	261	0.15	11500	25000
5	9	2	81	5.95	200.00	55	31	29.0	4760	150	694	232	0.13	9250	19300
6	10	6	81	0.00	21.00	55	30	28.0	7200	251	700	243	0.39	13200	34000
7	11	3	81	1.94	20.00	58	19	20.0	5960	180	824	168	0.34	11800	5000
8	12	3	81	0.31	21.00	61	17	18.5	6960	230	756	256	0.23	13500	30000
9	1	5	82	0.00	32.00	61	21	11.0	4280	112	536	160	0.20	10000	22000
10	2	4	82	4.83	26.00	61	13	4.0	3800	88	476	132	0.22	8200	14800
11	3	8	82	0.59	120.00	34	13	21.0	4080	128	636	142	0.24	7500	17800
12	4	14	82	1.76	19.00	56	22	23.0	4200	100	536	114	0.28	4800	15100
13	5	4	82	.	32.00	52	.	28.0	3880	104	436	148	1.01	7200	15900
14	6	10	82	.	28.00	13	.	38.0	4160	108	504	133	0.37	8100	22000
15	7	15	82	.	0.63	30	.	31.0	6200	200	756	169	0.87	11500	19200
16	8	4	82	.	42.00	53	.	36.0	7200	212	990	230	0.14	6200	20300

Appendix Table III-1a, cont.

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	5	8	81	9.0	6.30	8.5	5150	0.000	2900	0.2	0.000	0.0	0.006	2.52	0.0006	0.0
2	6	4	81	6.0	7.85	17.0	6300	0.000	1700	0.4	0.000	0.0	0.003	1.78	0.0006	0.0
3	6	30	81	6.0	7.80	11.0	3100	0.170	294	0.2	0.000	0.0	0.019	1.74	0.0000	0.0
4	8	4	81	3.2	8.57	32.0	43000	0.000	1943	0.2	0.024	0.2	0.044	0.58	0.0000	0.0
5	9	2	81	9.0	8.18	27.0	33000	0.000	1500	0.1	0.000	0.1	0.000	1.34	0.0005	0.0
6	10	6	81	3.0	8.53	31.0	4200	0.000	2030	0.2	0.020	0.0	0.000	1.43	0.0034	0.0
7	11	3	81	3.0	8.66	26.0	3600	0.110	1569	0.6	0.015	0.1	0.060	1.26	0.0008	0.0
8	12	3	81	3.0	8.86	32.0	4200	0.000	1570	0.0	0.000	0.1	0.000	2.16	0.0000	0.0
9	1	5	82	3.2	8.40	63.0	3000	0.560	800	0.1	0.000	0.0	0.000	1.31	0.0012	0.0
10	2	4	82	5.4	8.32	49.0	125	0.260	580	0.3	0.000	0.0	0.004	0.17	0.0000	0.0
11	3	8	82	3.2	8.75	48.0	24800	0.000	1600	0.7	0.000	0.0	0.000	0.22	0.0000	0.0
12	4	14	82	5.4	8.13	29.0	2400	0.076	400	0.0	0.000	0.0	0.028	0.76	0.0000	0.0
13	5	4	82	3.0	7.80	39.0	2300	0.140	2000	0.1	0.000	0.0	0.000	0.90	0.0000	0.0
14	6	10	82	3.0	8.18	49.0	2400	1.000	250	0.3	0.000	0.0	0.000	0.47	0.0030	0.0
15	7	15	82	3.0	7.66	71.0	1800	0.150	590	0.2	0.000	0.0	0.016	0.39	0.0007	0.0
16	8	4	82	9.0	9.15	55.0	4000	0.370	450	0.3	0.000	0.0	0.000	0.31	0.0000	0.0

Appendix Table III-lb. Gladys McCall, bridge--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	5	8	81	2.39	152.0	25	27	27.5	9100	184	1268	370	0.46	16400	135000
2	6	4	81	4.73	172.0	43	28	27.0	8120	120	1222	314	0.22	13000	37000
3	6	30	81	1.25	164.0	37	29	31.0	5120	152	616	208	0.98	8700	17700
4	8	4	81	7.07	1020.0	15	33	34.0	5560	238	648	255	0.17	11200	24000
5	9	2	81	5.95	1040.0	21	31	29.0	4360	140	638	212	0.13	8350	19300
6	10	6	81	0.00	50.0	18	30	28.0	6600	239	620	225	0.09	11900	25700
7	11	3	81	1.94	60.0	15	19	20.0	6520	208	856	176	0.27	12900	4700
8	12	3	81	0.31	52.0	9	17	18.0	7080	240	732	256	0.48	12900	28000
9	1	5	82	0.00	60.0	15	21	11.0	3640	100	468	136	0.15	8500	19000
10	2	4	82	4.83	68.0	21	13	5.0	3800	88	476	132	0.51	7700	13100
11	3	8	82	0.59	160.0	8	13	20.0	4080	124	536	144	0.56	8200	17400
12	4	14	82	1.76	80.0	13	22	22.0	4200	104	564	162	1.10	5300	16500
13	5	4	82	.	50.0	8	.	27.0	4080	112	460	148	1.86	7800	15900
14	6	10	82	.	112.0	36	.	38.0	6360	184	716	194	0.70	11800	29000
15	7	15	82	.	1.6	43	.	33.0	4160	144	612	123	3.00	9100	16800
16	8	4	82	.	96.0	1	.	36.0	9840	328	1345	348	0.00	8600	22600

415

Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	5	8	81	4.0	6.50	5.5	5720	0.00	3190	0.1	0.000	0.0	0.043	2.98	0.0009	0.0
2	6	4	81	6.0	7.59	44.0	4900	0.21	1660	0.3	0.000	0.0	0.000	2.44	0.0009	0.0
3	6	30	81	6.0	6.80	34.0	3000	0.00	340	0.1	0.000	0.0	0.006	1.52	0.0000	0.0
4	8	4	81	4.2	8.50	44.0	42000	0.10	2079	0.4	0.034	0.2	0.042	0.57	0.0000	0.0
5	9	2	81	3.2	7.91	20.0	31000	0.16	1300	0.1	0.000	0.1	0.000	0.73	0.0004	0.0
6	10	6	81	3.2	8.54	15.0	3800	0.06	2020	0.4	0.000	0.0	0.000	1.92	0.0009	0.0
7	11	3	81	3.0	8.27	24.0	3700	0.07	1425	0.5	0.012	0.1	0.064	1.40	0.0016	0.0
8	12	3	81	3.0	8.56	46.0	4000	0.00	1900	0.0	0.000	0.1	0.000	1.94	0.0010	0.0
9	1	5	82	3.0	8.24	57.0	2400	0.57	620	0.1	0.000	0.0	0.000	1.21	0.0008	0.0
10	2	4	82	3.0	8.12	114.0	112	0.18	610	0.4	0.000	0.0	0.000	0.09	0.0000	0.0
11	3	8	82	4.2	8.71	48.0	24400	0.00	1500	0.2	0.000	0.0	0.004	0.17	0.0000	0.0
12	4	14	82	3.3	7.86	34.0	2600	0.11	440	0.0	0.000	0.0	0.026	0.80	0.0000	0.0
13	5	4	82	3.0	7.50	53.0	2400	0.17	1160	0.1	0.000	0.0	0.000	1.70	0.0000	0.0
14	6	10	82	3.2	8.18	22.0	3600	0.40	819	0.5	0.000	0.0	0.009	0.56	0.0056	0.0
15	7	15	82	3.2	7.90	92.0	1520	1.14	460	0.6	0.000	0.0	0.010	0.38	0.0010	0.0
16	8	4	82	11.8	8.65	22.0	5500	0.13	770	0.1	0.000	0.0	0.000	0.26	0.0004	0.0

Appendix Table III-1c. Gladys McCall, Hog Bayou--surface.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	8	4	81	7.07	520.0	43	33	35.5	5320	226	628	218	0.07	10900	25000
2	9	1	81	5.95	1160.0	61	31	29.0	4320	140	654	208	0.10	8500	19300
3	10	6	81	0.00	12.0	34	30	28.0	6700	249	666	237	0.09	12100	33000
4	11	3	81	1.94	56.0	34	19	20.0	6360	192	820	164	0.35	12000	5500
5	12	3	81	0.31	32.0	28	17	18.0	7040	230	748	252	0.29	13000	27000
6	1	5	82	0.00	48.0	30	21	12.0	4480	124	544	168	0.18	9000	22000
7	2	4	82	4.83	28.0	30	13	4.0	3480	84	448	138	0.34	8300	14100
8	3	8	82	0.59	100.0	30	13	20.0	4040	122	572	134	0.17	8200	15700
9	4	14	82	1.76	60.0	25	22	22.0	4560	112	584	122	0.85	4900	17900
10	5	4	82	.	48.0	23	.	27.0	4080	120	484	144	2.01	7700	17400
11	6	10	82	.	64.0	15	.	38.5	6600	184	740	216	0.38	12350	30000
12	7	15	82	.	1.5	23	.	33.0	4560	136	608	123	1.40	8900	16400
13	8	4	82	.	44.0	15	.	34.0	8960	296	1230	314	0.02	8300	22600

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Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	8	4	81	4.6	8.59	25	43000	0.220	1957	0.2	0.019	0.2	0.110	0.64	0.0000	0
2	9	1	81	2.8	8.01	14	31000	0.000	1300	0.1	0.000	0.1	0.000	0.88	0.0006	0
3	10	6	81	3.0	8.44	14	4000	0.000	1590	0.2	0.000	0.0	0.000	1.96	0.0021	0
4	11	3	81	3.0	8.31	22	3600	0.560	1653	1.0	0.011	0.1	0.000	1.11	0.0007	0
5	12	3	81	3.2	8.69	32	4100	0.350	2000	0.0	0.007	0.1	0.000	1.84	0.0000	0
6	1	5	82	3.0	8.32	60	2900	0.310	790	0.1	0.008	0.0	0.000	1.41	0.0030	0
7	2	4	82	3.2	8.17	51	120	0.025	520	0.2	0.000	0.0	0.000	0.21	0.0000	0
8	3	8	82	3.0	8.59	50	25600	0.000	1600	0.2	0.000	0.0	0.000	0.29	0.0000	0
9	4	14	82	3.8	7.89	32	2700	0.076	490	1.3	0.000	0.0	0.039	1.03	0.0000	0
10	5	4	82	3.2	7.20	39	2400	0.220	960	0.2	0.000	0.0	0.000	0.70	0.0000	0
11	6	10	82	3.1	8.19	17	3800	0.120	988	0.5	0.000	0.0	0.005	0.61	0.0007	0
12	7	15	82	3.0	7.28	80	1440	0.710	560	0.3	0.000	0.0	0.008	0.67	0.0009	0
13	8	4	82	9.4	8.51	11	5300	0.160	1130	0.1	0.000	0.0	0.000	0.28	0.0015	0

Appendix Table III-ld. Gladys McCall, 310-ft well--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	6	11	81	4.73	10.00	137	28	26.0	2520	34.0	216	300	0.29	4400	10600
2	7	1	81	1.25	3.00	305	29	24.0	1190	21.0	216	140	0.21	2070	6400
3	8	4	81	7.07	16.00	186	33	33.0	1040	20.2	73	126	0.18	1990	5300
4	9	1	81	5.95	5.60	192	30	23.0	920	16.4	92	120	0.15	1670	4700
5	10	6	81	0.00	1.60	311	31	23.0	920	17.6	54	87	0.15	1570	4800
6	11	3	81	1.94	15.00	308	19	23.0	820	12.0	62	81	0.15	1460	2500
7	12	3	81	0.31	0.32	308	17	22.0	800	4.6	56	82	0.14	1360	5250
8	1	5	82	0.00	3.60	311	21	19.0	720	8.2	64	78	0.14	1300	4200
9	2	4	82	4.83	5.60	296	13	21.0	750	8.4	57	84	0.15	1260	4000
10	3	8	82	0.59	4.20	311	13	26.0	720	8.4	75	80	0.15	960	4400
11	4	14	82	1.76	6.20	311	22	23.0	730	6.0	61	71	0.16	1350	3800
12	5	4	82	.	0.80	305	.	21.5	672	5.8	54	86	0.19	1250	3800
13	6	10	82	.	3.00	299	.	23.5	720	6.2	54	91	0.12	1220	4400
14	7	15	82	.	1.20	299	.	26.0	720	7.6	73	83	0.16	1230	5400
15	8	4	82	.	0.90	311	.	27.0	744	6.0	67	76	0.17	1210	3300

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Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	6	11	81	4.4	7.20	15.0	1630	1.80	750.0	0.5	0.00	0.0	0.005	0.81	0.0002	0
2	7	1	81	2.8	7.50	0.0	710	2.40	64.0	0.6	0.000	0.0	0.001	0.33	0.0000	0
3	8	4	81	0.4	7.98	0.0	6100	0.18	191.0	0.6	0.005	0.1	0.037	0.30	0.0000	0
4	9	1	81	0.8	7.85	0.0	620	1.28	109.0	0.5	0.000	0.0	0.000	0.18	0.0002	0
5	10	6	81	0.8	7.73	3.9	540	1.22	64.0	0.6	0.000	0.0	0.000	0.35	0.0005	0
6	11	3	81	1.2	7.69	14.0	500	1.78	47.0	0.6	0.013	0.0	0.000	0.41	0.0006	0
7	12	3	81	0.8	8.33	4.0	500	0.63	6.2	1.0	0.000	0.3	0.000	1.00	0.0000	0
8	1	5	82	1.2	7.61	49.0	460	1.30	6.3	0.7	0.008	0.0	0.000	0.00	0.0020	0
9	2	4	82	1.2	7.61	33.0	30	1.03	1.2	0.9	0.000	0.0	0.002	0.09	0.0000	0
10	3	8	82	0.8	7.67	14.0	8200	0.00	2.8	1.0	0.000	0.0	0.000	0.07	0.0000	0
11	4	14	82	1.2	7.89	6.4	520	2.00	1.0	3.3	0.000	0.0	0.000	0.32	0.0000	0
12	5	4	82	0.6	7.60	13.2	460	2.32	1.2	1.0	0.000	0.0	0.000	0.70	0.0000	0
13	6	10	82	0.8	7.86	9.0	500	2.00	1.3	1.7	0.000	0.0	0.000	0.18	0.0005	0
14	7	15	82	0.6	7.53	9.0	420	1.66	1.5	1.2	0.000	0.0	0.000	0.02	0.0000	0
15	8	4	82	2.2	7.90	24.0	460	1.93	1.5	1.2	0.000	0.0	0.000	0.06	0.0011	0

Appendix Table III-1e. Gladys McCall, 660-ft well--ground.

Obs	M	D	Yr	Rain	Tbty	Dt	TA	TW	Na	K	Mg	Ca	Mn	Cl	SC
1	6	11	81	4.73	3.2	130	28	26	804	6.6	40.0	40	0.08	1330	4200
2	7	1	81	1.25	3.0	128	29	25	750	6.6	29.0	44	0.05	2300	4100
3	8	4	81	7.07	16.0	564	33	27	720	2.8	29.0	48	0.05	1250	3400
4	9	1	81	5.95	26.0	549	30	23	720	3.6	40.0	52	0.06	1200	3500
5	10	6	81	0.00	1.2	305	31	23	790	4.7	26.0	42	0.06	1170	3900
6	11	3	81	1.94	7.0	305	19	23	760	4.9	31.0	42	0.07	1220	2300
7	12	4	81	0.31	0.4	747	17	23	820	4.6	28.0	46	0.05	1280	5250
8	1	5	82	0.00	3.0	610	21	20	770	3.8	31.0	46	0.04	1220	3900
9	2	4	82	4.83	5.2	671	13	21	780	3.4	27.0	46	0.06	1190	3800
10	3	8	82	0.59	4.4	585	13	26	740	4.5	39.0	44	0.07	1120	6000
11	4	14	82	1.76	4.2	442	22	22	750	3.4	26.0	43	0.06	1240	4200
12	5	4	82	.	1.0	495	.	21	716	3.6	24.0	46	0.08	1180	3600
13	6	10	82	.	1.8	573	.	23	740	3.4	23.4	52	0.02	1150	4100
14	7	15	82	.	1.1	579	.	26	762	4.2	40.0	52	0.09	1170	5400
15	8	4	82	.	3.2	588	.	27	784	4.2	29.0	40	0.03	1180	3400

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Obs	M	D	Yr	O ₂	pH	C	CaCO ₃	NH ₄	SO ₄	Ba	Cd	Pb	As	B	Hg	Cr
1	6	11	81	6.0	7.00	16.0	210	0.25	43.0	0.0	0.000	0.0	0.013	0.32	0.0000	0
2	7	1	81	2.8	7.10	0.0	270	1.35	20.0	0.8	0.000	0.0	0.001	0.16	0.0000	0
3	8	4	81	0.4	8.33	0.0	2400	0.16	23.0	0.8	0.000	0.1	0.053	0.21	0.0000	0
4	9	1	81	2.2	8.11	0.0	240	0.78	20.0	0.7	0.000	0.0	0.000	0.23	0.0019	0
5	10	6	81	1.2	7.85	15.7	260	1.06	22.0	0.8	0.000	0.0	0.000	0.22	0.0000	0
6	11	3	81	1.0	7.87	0.0	240	1.41	0.0	0.9	0.014	0.0	0.000	0.32	0.0006	0
7	12	4	81	1.0	8.42	13.0	217	1.28	6.2	0.7	0.000	0.1	0.000	0.34	0.0000	0
8	1	5	82	1.0	8.03	33.0	220	1.20	2.4	0.5	0.008	0.0	0.000	0.00	0.0010	0
9	2	4	82	1.0	7.91	26.0	15	1.26	4.9	0.8	0.000	0.0	0.000	0.03	0.0000	0
10	3	8	82	0.6	7.57	19.0	6000	0.00	0.0	0.6	0.000	0.0	0.000	0.05	0.0000	0
11	4	14	82	1.6	8.19	2.2	300	1.40	0.8	2.4	0.000	0.0	0.000	0.11	0.0000	0
12	5	4	82	0.6	7.70	9.0	200	1.16	1.2	0.6	0.000	0.0	0.000	0.48	0.0000	0
13	6	10	82	0.8	7.71	9.0	260	1.40	1.4	1.0	0.000	0.0	0.000	0.24	0.0004	0
14	7	15	82	0.6	7.57	12.0	280	1.01	1.5	0.8	0.000	0.0	0.000	0.11	0.0004	0
15	8	4	82	2.0	7.82	19.0	240	1.46	1.5	0.7	0.000	0.0	0.000	0.10	0.0016	0

APPENDIX III-2

Log of Well Activities at Rockefeller Refuge

<u>DATE</u>	<u>CONDITION</u>
July 10, 1981	Washed hole 56 ft to bottom.
July 10, 1981	Circulated and conditioned hole to run logs.
July 13, 1981	Broke circulation slowly and circulated.
July 13, 1981	Ran 14 stands of drill pipe; no mud returns.
July 13, 1981	Circulated with 100 stroke/min; lost mud.
July 17, 1981	Circulated and conditioned hole with
July 17, 1981	2400 sacks Texas light cement with 40% silica flour.
	1900 sacks Class A cement with 40% silica flour.
	1/4 # sack Quick seal.
July 17, 1981	450 bbl of cement return.
July 17, 1981	Cement starts flowing from annulus.
July 17, 1981	Well shut in for cement to set.
July 21, 1981	Mud additions: 489 sacks bulk barite and 135 bbl liquid mud.
July 22, 1981	Displaced 11.5#/gal mud with 14.5#/gal mud.
July 28, 1981	Mud additions: 10 sacks gel, 8 sacks caustic, 15 sacks Lignosulf, and 10 sacks lignite.
July 29, 1981	Mud additions: 60 sacks barite, 10 sacks gel, 5 sacks caustic, and 22 sacks lignosulf.
July 30, 1981	Washed and reamed hole from 14,975 ft to 15,080 ft.
July 30, 1981	Mud additions: 45 sacks barite, 15 sacks caustic, and 85 sacks lignosulf.
July 31, 1981	Circulated bottoms up.
July 31, 1981	Mud additions: 2487 sacks barite, 10 sacks gel, 20 sacks caustic, 41 sacks lignosulf, and 3 sacks sodium chromate.
Aug. 1, 1981	Circulate.
Aug. 1, 1981	Mud additions: 60 sacks barite and 1 sack sodium chromate.
Aug. 2, 1981	Mud additions: 30 sacks barite and 13 sacks gel, 10 sacks caustic, 15 sacks lignite, and 1 sack sodium chromate.
Aug. 7, 1981	Washed and reamed from 15,203 to 15,289 ft.
Aug. 7, 1981	Added 499 sacks barite, 62 sacks gel, 10 sacks caustic, and 25 sacks lignosulf.
Aug. 10, 1981	Reamed 15,255 to 15,328 ft.
Aug. 10, 1981	Added 30 sacks barite.
Aug. 11, 1981	Reamed 15,328 to 15,349 ft.
Aug. 11, 1981	Added 498 sacks barite (bulk), 30 sacks barite, 15 sacks gel, 10 sacks caustic, 15 sacks lignosulf, 20 sacks lignite, and 1 sack lime.
Aug. 12, 1981	Reamed 15,270 to 15,349 ft.
Aug. 12, 1981	Added 500 sacks barite (bulk), 45 sacks barite, 5 sacks gel, 20 sacks caustic, 60 sacks lignosulf, 15 sacks lignite, and 1 sack lime.
Aug. 14, 1981	Reamed 15,364 to 15,370 ft.
Aug. 14, 1981	Circulate

DATECONDITION

Aug. 14, 1981	Washed and reamed from 15,312 to 15,380 ft.
Aug. 14, 1981	Added 489 sacks barite (bulk), 93 sacks barite, 25 sacks caustic, 30 sacks spersen, and 45 sacks XP-20.
Aug. 15, 1981	Added 14 sacks XP-20, 48 sacks gel, and 3 sacks caustic.
Aug. 16, 1981	5 to 8% iron cuttings in formation.
Aug. 16, 1981	Added 25 sacks resinex, 2 sacks sodium chromate, 13 sacks gel, and 76 sacks XP-20.
Aug. 17, 1981	Added 502 sacks barite.
Aug. 18, 1981	Added 100 barrels of 17.2#/gal black majic (30 bbl in pipe, 70 bbl in annulus).
Aug. 18, 1981	Commingled black majic mud.
Aug. 18, 1981	Added 35 sacks gel, 5 sacks sodium chromate, 5 sacks caustic, 15 sacks resinex, 25 cans D.D., and 100 bbl black majic.
Aug. 19, 1981	Washed from 15,448 to 15,508 ft.
Aug. 19, 1981	Added 38 sacks barite, 6 sacks gel, 18 sacks caustic, 52 sacks spersene, 44 sacks resinex, 4 drums bit lube, and 2 sacks sodium chromate.
Aug. 20, 1981	Added 448 sacks barite (bulk), 2 sacks sodium chromate, 4 sacks caustic, 27 sacks spersene, 21 sacks resinex, and 5 drums bit lube.
Aug. 21, 1981	Washed 95 ft to bottom.
Aug. 21, 1981	Added 499 sacks baroid (bulk), 9 sacks gel, 3 sacks sodium chromate, 2 sacks caustic, 33 sacks spersene, and 15 sacks resinex.
Aug. 22, 1981	Added 56 sacks barite, 28 sacks caustic 40 sacks spersene, 5 sacks XP-20, 3 sacks sodium chromate, and 33 sacks resinex.
Aug. 23, 1981	Raised mud weight in suctionpit from 14#/gal to 17#/gal.
Aug. 23, 1981	Broke circulation.
Aug. 23, 1981	Broke circulation.
Aug. 23, 1981	Circulated with 500 psi, 34 spm, increase pressure to 1200 psi.
Aug. 26, 1981	Circulated and conditioned mud.
Aug. 27, 1981	Added 1004 sacks barite, 10 sacks gel, 20 sacks caustic, 20 sacks lignosulf, 1 drum bit lube, and 70 sacks soltex.
Aug. 28, 1981	Added 35 sacks barite and 1 drum bit lube.
Aug. 29, 1981	Circulated and conditioned hole.
Aug. 29, 1981	Set cement plug from 15,620 to 14,900 ft.
Aug. 29, 1981	Circulating.
Aug. 29, 1981	Added 900 sacks barite (bulk), 35 sacks barite, 75 sacks gel, 12 sacks caustic, and 20 sacks lignosulf.
Aug. 30, 1981	Circulating after cementing back.
Aug. 30, 1981	Circulated at 14,312 ft.
Aug. 30, 1981	Circulating shale and cement in mud returns.
Aug. 31, 1981	Circulating at 15,055 ft.
Aug. 31, 1981	Washed and reamed hole from 15,213 to 15,500 ft.
Aug. 31, 1981	Circulated and conditioned mud.

DATECONDITION

Aug. 31, 1981	Added 35 sacks barite, 10 sacks gel, 8 sacks bicarb, 10 sacks resinex, and 1 sack chromate.
Sept. 1, 1981	Circulated and conditioned hole.
Sept. 1, 1981	Cemented hole with 17#/gal cement slurry. Displaced with 1200 psi.
Sept. 1, 1981	Circulated 5.5 hr.
Sept. 3, 1981	Circulated and conditioned mud.
Sept. 3, 1981	Circulated bottoms up; circulated out green cement.
Sept. 3, 1981	Circulating.
Sept. 3, 1981	Added 25 sacks gel, 30 sacks resinex, and 50 sacks soltex.
Sept. 8, 1981	Washed and reamed from 14,728 to 14,767 ft.
Sept. 8, 1981	Circulated bottoms up.
Sept. 8, 1981	Washed and reamed from 14,767 to 14,849 ft.
Sept. 8, 1981	Washed and reamed from 14,849 to 15,188 ft.
Sept. 8, 1981	Circulated.
Sept. 8, 1981	Washed and reamed from 15,188 to 15,198 ft.
Sept. 8, 1981	Added 11 sacks gel, 10 sacks caustic, 20 sacks lignosulf, 9 sacks soltex, 6 sacks sapp., and 19 sacks resinex.
Sept. 9, 1981	Washed and reamed from 15,198 to 15,290 ft.
Sept. 9, 1981	Circulating.
Sept. 9, 1981	Circulating and building mud weight to 17.2#/gal.
Sept. 9, 1981	Washed and reamed from 15,290 to 15,295 ft.
Sept. 9, 1981	Added 1002 sacks bulk barite, 35 sacks barite, 10 sacks lignosulf, 6 sacks sapp., 12 sacks resinex, and 8 sacks soltex.
Sept. 10, 1981	Circulated and conditioned mud.
Sept. 10, 1981	Added 55 sacks barite, 20 sacks lignosulf, 20 sacks soltex, and 3 sacks chromate.
Sept. 15, 1981	Added 5 sacks gel, 3 sacks caustic, 10 sacks lignosulf, 1 drum bit lube, 10 sacks soltex, and 10 sacks resinex.
Sept. 16, 1981	Circulating bottoms up. Pressure to 1200 psi.
Sept. 16, 1981	Added 40 sacks barite, 10 sacks gel, 15 sacks spersene, 10 sacks soltex, and 1 drum bit lube.
Sept. 17, 1981	Washed and reamed hole from 15,296 to 15,376 ft.
Sept. 17, 1981	Added 70 sacks barite, 10 sacks gel, 10 sacks caustic, 65 sacks lignosulf, 1 drum bit lube, 10 sacks resinex, and 3 sacks chromate.
Sept. 18, 1981	Added 80 bbl black majic (50 outside & 30 inside drilling string).
Sept. 18, 1981	Added 1 bbl black majic every hour.
Sept. 18, 1981	Added 974 sacks barite.
Sept. 19, 1981	Soaking with black majic.
Sept. 20, 1981	Circulating out black majic pill; circulated mud.
Sept. 20, 1981	Pumped 190 barrels of black majic in hole.
Sept. 20, 1981	Permitted black majic to soak.
Sept. 20, 1981	Added 10 sacks caustic, 50 sacks lignosulf, and 1 sack chromate.

DATECONDITION

Sept.22, 1981	Permitted black majic to soak.
Sept.22, 1981	Ran 700 grain shot.
Sept.24, 1981	Added 35 sacks barite, 2 sacks caustic, and 10 sacks lignosulf.
Sept.25, 1981	Washed and reamed hole from 15,295 to 15,380 ft.
Sept.25, 1981	Circulated bottoms up.
Sept.25, 1981	Added 35 sacks barite, 5 sacks gel, 2 sacks caustic, and 20 sacks lignosulf.
Sept.26, 1981	Added 5 sacks gel, 5 sacks caustic, 35 sacks lignosulf, and 3 sacks chromate.
Sept.27, 1981	Added 500 sacks barite (bulk), 35 sacks barite, 35 sacks gel, 11 sacks caustic, and 10 sacks soltex.
Sept.29, 1981	Circulating.
Sept.30, 1981	Circulating.
Sept.30, 1981	Washed and reamed from 15,446 to 15,471 ft.
Sept.30, 1981	Added 6 sacks gel and 20 sacks lignosulf.
Oct. 1, 1981	Added 35 sacks barite, 5 sacks gel, 35 sacks lignosulf, 2 sacks chromate, and 20 bbl protectomajic.
Oct. 2, 1981	Added 35 sacks barite, 10 sacks gel, 3 sacks caustic, 15 sacks lignosulf, and 20 sacks protectomajic.
Oct. 3, 1981	Washed 50 ft to bottom.
Oct. 3, 1981	Added 35 sacks barite, 8 sacks gel, 6 sacks caustic, 20 sacks lignosulf, and 2 sacks chromate.
Oct. 4, 1981	Formation: 70% anhydrite, 25% sand, 5% shale.
Oct. 4, 1981	Added 39 sacks gel, 6 sacks caustic, 30 sacks lignosulf, and 8 sacks nut plug.
Oct. 6, 1981	Added 496 sacks barite.
Oct. 7, 1981	Added 2 sacks XP-20, 496 sacks barite, 14 sacks caustic, 17 sacks resinex, and 10 bbl black majic.
Oct. 8, 1981	Washed and reamed hole 15,644 to 15,730 ft.
Oct. 8, 1981	Added 48 sacks barite, 8 sacks caustic, 4 sacks spersene, 2 sacks XP-20, and 5 bbl protectomajic.
Oct. 9, 1981	Added 521 sacks barite, 2 sacks caustic, 19 sacks spersene, 3 sacks XP-20, and 10 bbl black majic.
Oct. 10, 1981	Added 24 sacks gel, 16 sacks caustic, 21 sacks spersene, 17 sacks XP-20, 4 sacks sodium chromate, and 15 bbl black majic.
Oct. 11, 1981	Added 519 sacks barite, 15 sacks gel, 6 sacks caustic, 30 sacks lignosulf, 12 sacks resinex, 10 sacks soltex, and 25 sacks chromate.
Oct. 12, 1981	Circulated and conditioned mud; pore pressure estimated at 16.9#/gal.
Oct. 12, 1981	Added 1042 sacks barite, 10 sacks gel, 13 sacks caustic, 72 sacks lignosulf, 25 bbl protectomajic, 20 sacks soltex, and 3 sacks chromate.
Oct. 15, 1981	Circulated and conditioned hole.
Oct. 15, 1981	Added 335 sacks barite, 36 sacks gel, 28 sacks caustic, 15 sacks spersene, 17 sacks XP-20, 70 bbl protectomajic, 22 sacks resines, and 26 sacks soltex.

DATECONDITION

Oct. 15, 1981	Washed 30 ft to bottom.
Oct. 17, 1981	Circulated and conditioned mud.
Oct. 17, 1981	80 bbl black majic displaced with/17#/gal mud.
Oct. 17, 1981	Added 1094 sacks barite, 9 sacks gel, 13 sacks lime, 13 sacks resinex, 5 sacks mica, 44 sacks nut plug, 23 sacks clay, 5 sacks caustic, 8 sacks XP-20, 1 sack bicarb, and 15 sacks soltex, 80 bbl black majic.
Oct. 18, 1981	Black majic too contaminated to separate from system so all was mixed into circulating mud.
Oct. 19, 1981	Pumped 20 bbl SAM-4, 354 sx trinity class "H" with/40% silica flour, 1% CFR-2, 12.5#/sack hidense, .27% D-Air-1, 1.12#/sack kel, 0.6% halide 22-A, 0.9% HR-12; bumped w/2400 psi.
Oct. 19, 1981	Added 5 sacks gel, 5 sacks speresene, 7 sacks resinex, 5 sacks clay, and 1 sack nut plug.
Oct. 21, 1981	Added 70 sacks barite.
Oct. 29, 1981	Added 20 sacks caustic, 15 sacks protectomajic, 4 sacks mylo preserv, and 8 sacks drispact.
Oct. 30, 1981	Washed to bottom from 15,663 to 15,826 ft.
Oct. 30, 1981	Cut mud weight to 14.0#/gal.
Oct. 30, 1981	Added 400 sacks bulk barite and 3 sacks drispack.
Oct. 30, 1981	Conditioned mud.

APPENDIX IV
Sweet Lake Array Events

APPENDIX IV-1

Key to Event Log Information

Origin Time (UTC)	Expressed in Universal Time Coordinated (UTC), beginning with the Julian Day, then the hour, minute, second, and hundredths seconds of the calculated origin time of the event.
Latitude (N)	The north latitude of the epicenter, expressed in degrees, minutes, and seconds.
Longitude (W)	The west longitude of the epicenter, expressed in degrees, minutes, and seconds.
Depth (km)	The calculated depth to the hypocenter, expressed in km.
+/(km)	Estimated error in depth calculation.
M _L	Richter Local Magnitude. Only listed for naturally-occurring events.
M _D	Duration Magnitude. Only listed for naturally-occurring events.
Error Ellipse (XxY)	Ellipse of one standard deviation about the calculated epicenter, expressed in km. The first value is the length of the X-axis and the second value is the length of the Y-axis.
X-Axis Azimuth	Degrees clockwise from north of the orientation of the X-axis of the error ellipse.
Comments	Added information about the particular listed event, as follows: E Naturally-occurring earthquake E? Possible natural earthquake B Geophysical blasting (Oil Exploration) S Possible offshore slump event C Depth constrained to given value I Event occurred inside the network O Event occurred outside the network F Event occurred too far away for a good location estimate U Unknown source P Poor solution (Numbers) First - Wave velocity that best locates the event, in km/sec. Second - Number of stations used in the location of the event.

APPENDIX IV-1

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER, 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MM:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
01	305:19:03:55.72	29 25 43.30	94 06 24.12	00.00	0.00	--	--	00.68 KM x 01.85 KM	54.49	U,C,O,F,.342,5
02	306:17:49	TOO SMALL TO LOCATE								
03	306:17:52	TOO SMALL TO LOCATE								
04	306:17:51:28.21	29 32 37.60	93 30 06.84	THREE STATION SOLUTION						U,C,O,F,.342,3
05	306:18:24	TOO SMALL TO LOCATE								
06	306:18:25	TOO SMALL TO LOCATE								
07	306:18:31	TOO SMALL TO LOCATE								
08	306:18:29:32.99	29 34 43.60	93 29 49.20	THREE STATION SOLUTION						U,C,O,F,.342,3
09	306:18:33	TOO SMALL TO LOCATE								
10	306:18:32:02.49	29 25 51.60	93 37 37.20	THREE STATION SOLUTION						U,C,O,F,.342,3
11	306:18:34:03.94	29 24 15.10	93 40 10.90	THREE STATION SOLUTION						U,C,O,F,.342,3
12	306:18:37	TOO SMALL TO LOCATE								
13	306:18:38	TOO SMALL TO LOCATE								
14	306:18:35:28.19	29 24 22.60	93 39 48.90	THREE STATION SOLUTION						U,C,O,F,.335,3
15	306:18:40:51.53	30 01 08.40	93 09 47.88	THREE STATION SOLUTION						E?,C,I ,.342,3
16	306:18:42	TOO SMALL TO LOCATE								
17	306:18:41:49.58	29 25 14.50	93 39 07.20	THREE STATION SOLUTION						U,C,O,F,.342,3
18	306:20:59:36.36	29 59 11.70	93 08 18.24	THREE STATION SOLUTION						E?,O ,.342,3
19	308:16:56:09.64	30 01 12.72	93 31 09.84	THREE STATION SOLUTION, OCCURRED DURING TAPE CHANGE						U,C,O,F,.342,3
20	308:16:56:17.90	30 13 18.10	93 39 06.48	THREE STATION SOLUTION, OCCURRED DURING TAPE CHANGE						U,C,O,F,.330,3
21	309:09:54:37.51	29 55 37.50	93 23 59.20	01.29	3.96	--	--	00.47 KM x 01.27 KM	155.00	E?,O,F,.342,5

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
-----	-----	-----	-----	-----	---	---	-----	-----	-----
22 309:09:56:55.83	29 59 29.70	93 11 18.60	00.00	0.09	--	--	00.17 KM x 01.04 KM	131.54	E?,0 .342,5
23 310:16:10:59.47	29 03 52.20	94 07 18.12	00.00	0.00	--	--	00.22 KM x 00.71 KM	38.47	U,C,D,F,.343,5
24 313:00:10:00.38	30 00 24.84	93 15 05.04	01.62	0.00	--	--	00.00 KM x 00.01 KM	170.97	E?,0 .,339,5
25 313:00:11:45.02	29 58 15.90	93 27 36.00	02.07	1.55	--	--	00.23 KM x 00.79 KM	164.07	E?,0 .342,5
26 313:00:11:47.42	29 58 53.40	93 27 10.40	06.72	0.29	--	--	00.14 KM x 00.46 KM	166.03	E?,0 .342,5
27 313:00:12:59.56	30 04 11.64	93 18 21.60	03.34						E?,0 .342,4
28 313:00:14:48.74	30 00 22.68	93 11 37.30	01.34						E?,0 .342,3
29 313:00:19:18.47	30 01 01.56	93 12 53.20	00.98	0.23	--	--	00.02 KM x 00.23 KM	140.93	E?,0 .342,5
30 313:00:23:15.08	30 01 26.04	93 10 54.80	01.38	0.27	--	--	00.03 KM x 00.15 KM	113.27	E?,I .342,5
31 313:00:25:56.22	30 01 38.64	93 09 39.96	02.35	0.19	--	--	00.04 KM x 00.12 KM	92.37	E?,I .342,5
32 313:00:36:13.60	30 06 51.48	93 04 48.00	00.00	0.02	--	--	00.16 KM x 00.99 KM	121.51	E?,0 .342,5
33 313:00:40:09.88	30 07 28.92	93 09 00.72	00.00	0.04	--	--	00.38 KM x 02.29 KM	93.36	E?,0 .335,5
34 313:01:09:59.37	29 59 10.30	93 03 50.40	04.32						E?,0 .342,4
35 321:00:03:22.34	30 09 22.32	92 58 58.40	00.35	0.98	--	--	00.03 KM x 00.24 KM	134.09	E?,0 .342,5
36 326:13:53:19.00	30 57 21.20	92 40 30.30	00.42						E?,D,F .342,4
37 331:21:27:15.45	30 02 11.76	93 07 37.56	00.00						E?,I,C .342,4
38 332:18:35:07.28	30 00 47.52	93 06 41.04	00.03						B?,C,I .342,3
39 332:19:05:42.89	30 00 45.36	93 06 38.16	00.03						B?,C,I .342,3
40 332:19:13:19.40	30 00 47.88	93 06 41.04	00.03						B?,C,I,(0.342,3)
01 335:20:14:19.70	28 53 58.50	93 50 44.50	00.20	0.08	--	--	00.36 KM x 00.62 KM	26.92	U,D,F,0.335,5

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MN:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
02	338:01:40:08.63	28 52 03.00	93 57 03.60	00.00	0.00	--	--	00.82 KM x 11.46 KM	32.63	U,O,C,F,.330,5
03	338:02:00:49.93	29 02 12.84	93 34 38.60	00.00	0.00	--	--	01.00 KM x 01.14 KM	100.07	U,O,C,F,.320,5
04	342:20:13:01.38	29 59 59.20	93 07 59.52	01.84	0.02	--	--	.0007 KM x 0.001 KM	106.13	E?,O,O.342,6
05	342:20:24:38.03	30 00 03.96	93 07 59.88	01.89	0.10	--	--	00.02 KM x 00.05 KM	78.77	E?,O,O.342,5
06	343:13:47:01.14	30 00 07.92	93 08 43.80	04.88	0.07	--	--	00.02 KM x 00.04 KM	98.84	E?.I,O.342,7
07	353:07:32:34.78	30 03 51.84	93 10 37.50	01.68	0.15	--	--	00.05 KM x 00.11 KM	91.07	E?,O,I.53,5*
08	358:08:10:33.67	29 55 59.10	92 56 08.52	00.00	0.01	--	--	00.53 KM x 04.88 KM	27.42	E?,O,.342,5
09	358:08:16:13.39	29 58 09.12	92 53 18.90	00.00	0.01	--	--	00.43 KM x 02.16 KM	13.67	E?,O,.342,6
10	358:08:27:40.40	29 58 04.08	92 53 35.80	00.00	0.01	--	--	00.50 KM x 02.61 KM	14.61	E?,O,.342,6
11	365:07:40:46.69	29 54 45.00	93 06 16.92	08.01	0.01	--	--	.0044 KM x 00.02 KM	80.38	E?,O,.342,4
01	004:11:00:24.97	29 53 43.8	93 22 52.3	00.00	0.00	--	--	00.13 KM x 01.57 KM	146.26	U,O,C,(O.342,5)
02	008:19:44:12.17	29 27 27.3	93 52 20.6	00.00	0.00	--	--	00.14 KM x 13.99 KM	48.07	U,O,C,P,(O.342,3)
03	013:20:26:26.15	31 22 39.0	94 42 02.52	00.00	0.00	--	--	58.25 KM x 02.37 KM	45.62	U,O,C,P,(O.342,5)
04	013:20:56:31.52	31 12 51.8	92 34 58.0	00.00	0.00	--	--	01.46 KM x 06.00 KM	21.07	U,O,C,P,(O.342,5)
05	013:21:03:30.66	30 23 22.9	91 15 36.3	00.00	0.00	--	--	06.33 KM x 00.34 KM	167.57	U,O,C,P,(O.330,5)
06	014:19:09:23.66	31 24 10.0	92 30 03.6	00.00	0.00	--	--	01.76 KM x 05.06 KM	22.34	U,O,C,P,(O.342,5)
07	014:20:21:16.13	29 34 33.2	93 29 35.1	00.00	0.00	--	--	00.23 KM x 00.95 KM	35.23	U,O,C,(O.330,3)
08	014:20:38:47.25	29 49 33.6	93 21 45.0	00.00	0.00	--	--	00.55 KM x 00.88 KM	45.89	U,O,C,(O.342,3)
09	014:21:42:57.67	29 44 53.1	90 59 53.5	00.00	0.00	--	--	08.65 KM x 00.42 KM	08.46	U,O,C,(O.342,3)
10	015:01:44:05.08	29 25 36.8	94 07 54.48	00.00	0.00	--	--	00.56 KM x 00.91 KM	55.52	U,O,C,(O.342,6)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
11 017:19:53:56.82	31 00 22.32	92 38 38.0	00.03	0.06	--	--	00.66 KM x 01.60 KM	25.15	U,O,C,(0.330,6)
12 021:15:01:44.75	30 05 11.4	93 09 53.64	00.00	6.87	--	-1.53	01.89 KM x 08.41 KM	88.36	E?,O,C,P,(0.342,5)
13 031:01:55:54.96	29 06 47.52	93 23 23.6	00.00	0.00	--	--	00.65 KM x 00.85 KM	105.70	U,O,C,F,(0.342,5)
14 031:02:02:01.37	30 04 47.28	93 05 49.2	06.36	0.32	--	-1.02	00.06 KM x 00.58 KM	107.70	E?,O,(0.342,5)
15 031:01:59:58.95	29 18 09.0	93 15 56.5	13.26	2.72	--	--	00.18 KM x 00.75 KM	100.54	U,O,(0.342,6)
16 031:02:12:11.41	29 56 38.4	93 09 33.48	00.49	0.00	--	-0.77	00.00 KM x 00.00 KM	93.11	E?,O,(0.342,3)
01 033:13:58:14.18	29 59 47.0	93 07 17.76	00.00	0.00	--	-1.09	00.04 km X 00.05 km	114.41	E?,O,C,(0.342,3)
02 033:14:23:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?
03 033:20:51:41.23	30 02 15.72	93 11 33.3	00.00	0.05	--	+0.85	00.03 km X 00.08 km	115.22	E?,I,(0.342,5)
04 033:20:52:12.53	30 00 14.4	93 09 37.8	00.00	0.00	--	-0.70	00.02 km X 00.06 km	101.34	E?,O,P,(0.342,3)
06 033:21:16:08.85	29 46 27.8	93 27 36	00.00	0.02	--	--	00.81 km X 02.95 km	141.64	E?,O,C,(0.342,5)
07 033:21:25:26.30	30 31 19.2	93 24 38.5	00.00	0.03	--	--	01.99 km X 04.40 km	154.70	E?,O,C,(0.342,5)
09 033:21:47:48.91	30 00 37.08	93 16 24.6	00.00	0.01	--	-0.19	00.10 km X 00.84 km	166.90	E?,O,(0.342,6)
10 033:22:09:12.84	29 59 18.6	93 09 16.56	02.51	0.20	--	-0.64	00.08 km X 00.18 km	114.10	E?,O,(0.342,6)
11 033:22:15:44.28	30 02 15.72	93 12 11.5	01.27	0.48	--	-0.65	00.04 km X 00.19 km	173.31	E?,I,(0.342,6)
12 033:22:30:26.74	30 01 57.36	93 00 27.72	00.00	0.12	--	-1.27	00.09 km X 00.99 km	165.98	E?,O,(0.342,6)
13 033:22:53:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?
14 033:23:53:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?
15 033:23:54:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?
16 034:00:26:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
17 034:00:30:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?
18 034:00:31:11.23	29 52 07.68	93 13 27.8	00.00	0.00	--	--	00.35 km X 00.44 km	31.20	E?,0,(0.342,3)
19 034:00:34:	POSSIBLE EVENT, TOO SMALL TO LOCATE								E?
20 034:00:59:29.30	29 51 16.2	93 00 05.4	00.00	0.00	--	-1.53	00.14 km X 02.12 km	55.12	E?,0,(0.342,6)
21 034:01:09:29.12	30 00 10.8	92 56 30.1	01.85	0.07	--	--	00.01 km X 00.00 km	175.34	E?,0,(0.342,3)
22 034:01:09:08.74	30 02 11.04	92 48 54.7	00.00	0.00	--	-1.33	00.07 km X 00.24 km	87.38	E?,0,(0.342,3)
23 034:01:10:27.25	30 01 56.64	92 46 17.0	00.00	0.00	--	-1.55	00.12 km X 00.37 km	88.64	E?,0,C,(0.342,3)
24 034:01:13:02.45	30 01 02.28	93 02 40.92	00.56	0.02	--	-1.94	00.00 km X 00.00 km	138.73	E?,0,(0.342,3)
25 034:01:13:26.68	30 01 20.28	93 02 21.84	00.00	0.00	--	-1.80			E?,0,(0.342,4)
26 034:01:59:07.76	29 43 51.60	93 27 47.5	00.00	0.00	--	--	00.15 km X 10.28 km	43.27	U,0,(0.342,3)
27 034:02:41:26.69	29 59 02.04	93 12 15.4	00.00	0.45	--	-1.07	00.63 km X 02.35 km	128.39	E?,0,(0.342,6)
28 034:14:46:07.69	30 02 21.48	93 10 20.6	00.00	0.00	--	-1.01	00.00 km X 00.00 km	104.26	E?,1,(0.342,3)
29 034:18:51:33.88	30 07 10.56	93 11 34.8	00.00	0.00	--	--			U,0,(0.342,3)
30 035:02:08:16.01	29 19 29.20	93 58 57.3	00.00	0.00	--	--	02.44 km X 02.50 km	45.00	U,0,C,(0.342,5)
31 044:17:41:06.23	31 00 02.88	92 39 49.3	00.00	0.00	--	--	01.44 km X 00.15 km	111.40	U,0,C,(0.342,5)
32 047:13:25:11.69	30 06 24.48	94 44 30.1	03.35	1.44	--	--	54.50 km X 01.23 km	3.53	U,0,(P,5)
33 048:01:51:00.61	29 51 23.70	93 25 36.8	01.24	0.18	--	--	01.17 km X 02.42 km	147.26	E?,0,(P,7)
34 053:21:48:05.70	29 24 45.00	93 34 43.3	00.00	0.01	--	--	01.27 km X 01.62 km	32.89	U,C,0,(0.342,5)
35 054:14:15:14.61	30 10 11.2	93 02 49.56	03.19	1.06	--	--	00.11 km X 01.83 km	111.78	U,0,(0.330,6)
01 061:21:33:03.90	29 48 06.1	93 18 20.5	05.06	0.11		-0.06	00.01 km X 00.12 km	117.04	S?,0,(0.342,5)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER, 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
02 062:01:57:15.98	29 26 03.48	93 49 41.5	00.00	0.01			01.31 KM X 06.23 KM	45.38	U,C,O,(0.342,5)
03 081:21:51:25.77	28 49 20.6	94 56 53.8	00.00	0.00			04.20 KM X 00.32 KM	143.42	U,C,O,(0.342,7)
04 082:03:35	POSSIBLE EVENT DETECTED AT CLB, TOO SMALL TO LOCATE								
05 082:03:38	TWO POSSIBLE EVENTS DETECTED AT CLB, TOO SMALL TO LOCATE								
06 082:03:39:49.53	29 59 52.8	93 08 31.56	01.55	1.86		-0.86	00.64 KM X 01.24 KM	107.96	E?,O,(0.342,5)
07 082:03:47:46.45	29 51 49.6	93 17 48.4	00.00			-2.25			E?,C,O,(0.342,3)
08 082:03:51:33.26	30 00 55.8	93 07 41.16	00.00			-0.26			E?,I,C,(0.342,3)
09 082:03:52	TWO POSSIBLE EVENTS DETECTED AT CLB, TOO SMALL TO LOCATE								
10 082:03:53	POSSIBLE EVENT AT CLB, TOO SMALL TO LOCATE								
11 082:03:54	POSSIBLE EVENT AT CLB, TOO SMALL TO LOCATE								
12 082:03:57	TWO POSSIBLE EVENTS AT CLB, TOO SMALL TO LOCATE								
13 082:03:58	POSSIBLE EVENT AT CLB, TOO SMALL TO LOCATE								
14 082:04:09	POSSIBLE EVENT AT CLB,CPF, TOO SMALL TO LOCATE								
15 082:04:10	POSSIBLE EVENT AT CLB,CPF, TOO SMALL TO LOCATE								
16 082:04:01:02.96	28 26 53.8	92 07 57.72	00.00						U,C,O,(0.342,3)
17 082:04:03:14.04	28 26 45.9	92 10 52.60	00.00						U,C,O,(0.342,3)
18 082:04:05:23.34	29 46 31.8	91 25 47.20	12.15(?)						U,O,P,(0.342,6)
19 082:04:22:09.55	29 59 08.88	93 10 07.32	00.00			-2.53			E?,O,C,(0.342,3)
20 082:06:54	POSSIBLE EVENT AT CLB,HUS, TOO SMALL TO LOCATE								
21 082:08:35	POSSIBLE EVENT AT CLB, TOO SMALL TO LOCATE								

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MN:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- M (KM) L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
22	082:09:06:45.47	30 08 09.6	93 28 43.3	00.00		-1.52			E?,0,(0.342,3)
23	082:09:11:11.18	30 24 20.8	93 52 11.2	00.00	0.00		01.08 KM X 02.78 KM	120.28	E?,P,0,(0.342,7)
24	082:09:19:31.12	29 57 43.9	93 09 43.92	00.00		-0.56			E?,0,C,(0.342,3)
25	082:09:23:06.23	30 10 14.1	93 10 28.9	00.00	0.02	+0.55	00.30 KM X 02.60 KM	81.75	E?,0,(0.342,7)
26	082:09:58:17.32	29 58 17.7	93 10 26.7	00.00	0.15	-1.50	00.19 KM X 00.79 KM	110.87	E?,0,(0.342,6)
27	082:10:18:02.33	29 35 43.8	93 13 30.3	00.00	0.00		01.17 KM X 07.48 KM	101.06	E?,0,P,(0.342,6)
28	082:10:23:18.27	29 15 20.8	93 08 22.92	00.00	0.01		03.52 KM X 04.55 KM	179.92	E?,0,P,(0.342,5)
29	082:11:02:02.12	29 38 13.2	93 06 05.04	00.00					E?,C,0,(0.342,3)
30	082:21:04:17.92	29 52 46.9	93 07 03.36	04.77	0.16	-0.92	00.03 KM X 00.30 KM	80.66	E?,0,(0.342,6)***
31	082:21:08:04.81	29 59 15.3	93 07 04.08	00.00		-0.83			E?,0,(0.342,3)***
32	082:21:12:37.82	29 57 27.7	93 06 35.64	08.43(?)		-1.03			E?,0,P,(0.342,3)
33	082:21:13:24.40	29 51 09.36	93 16 08.4	00.00	0.01	-1.21	00.66 KM X 06.02 KM	127.11	E?,0,P,(0.342,5)
34	082:21:24:26.73	29 48 12.20	93 16 28.2	05.53	1.24	-1.33	00.17 KM X 01.48 KM	113.81	E?,0,(0.342,5)
35	082:21:27:00.36	29 46 09.48	93 09 06.84	07.46(?)		-0.57			E?,0,P,(0.342,3)
36	082:21:43:53.13	29 59 14.60	92 57 55.0	02.70	0.86	-0.79	00.19 KM X 02.20 KM	12.41	E?,0,(0.342,6)
37	082:22:00:18.21	29 49 44.7	93 00 22.32	00.00	0.00	-0.74	00.31 KM X 03.35 KM	60.21	E?,0,(0.342,6)
38	082:22:04:31.56	29 55 12.7	93 05 47.4	03.91	0.02	-1.24			E?,0,(0.342,3)
39	082:22:21:09.96	29 58 32.1	93 12 22.6	00.00	0.03	-0.96	00.09 KM X 00.38 KM	124.81	E?,0,(0.342,5)
40	082:22:30:21.22	29 35 00.96	93 44 18.9	14.26	10.51	-0.75	01.68 KM X 02.53 KM	103.23	E?,0,P,(0.330,6)
41	082:23:09:42.63	29 51 50.0	92 54 43.5	00.00	0.00	-1.18	00.18 KM X 01.25 KM	39.02	E?,0,(0.342,5)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MM:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
42	082:23:11:20.80	30 00 47.88	93 09 26.64	00.00	0.44			+0.19 00.05 KM X 00.09 KM	86.43	E,I,(0.342,5)***
43	082:23:13:34.48	29 56 00.6	92 56 32.6	00.00						E?,O,(0.342,3)
44	082:23:14	EMERGENT DISTURBANCE ON 6 STATIONS, UNRESOLVABLE LOCATION								
45	082:23:19:43.72	29 49 33.6	93 14 27.9	00.00	0.00			-0.78 00.32 KM X 03.00 KM	117.41	E?,O,(0.342,6)
46	082:23:24	POSSIBLE EVENT ON CLB, CPF, TOO NOISY TO LOCATE								
47	082:23:31	POSSIBLE EVENT ON CLB, CPF, TOO NOISY TO LOCATE								
48	082:23:33:21.19	29 45 01.44	93 14 54.6	05.09(?)						E?,O,(0.342,3)
49	088:07:06	POSSIBLE EVENT ON CLB, CPF, TOO NOISY TO LOCATE								
01	094:03:15:46.49	29 27 05.4	93 05 17.88	07.50	11.41			01.20 KM X 01.59 KM	111.86	S?,O,P,(0.342,5)
02	094:03:23:59.19	29 30 30.9	93 07 04.44	20.82	0.61			00.16 KM X 00.31 KM	83.33	S?,O,P,(0.342,5)
03	094:12:57:17.44	29 38 20.7	93 10 01.92	10.71(?)						S?,O,P,(0.342,3)
04	097:02:02	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
05	098:00:54	POSSIBLE EVENT ON CLB, JCF, TOO NOISY TO LOCATE								
06	100:03:14:10.50	30 02 24.36	93 08 02.40	00.00	0.49			+0.17 0.09 KM X 00.34 KM	69.65	E,I,(0.342,6)
07	100:03:17:30.28	29 59 55.60	93 06 51.12	00.64				-0.56		E,I,(0.342,3)
08	100:03:24:30.07	30 02 14.28	93 06 37.8	00.72	0.41			+0.36 00.08 KM X 00.35 KM	104.98	E,I,(0.342,6)
09	100:03:24:19.69	29 59 59.6	93 13 05.52	00.00				+0.06		E,O,(0.342,3)
10	100:04:09:14.29	29 58 08.4	93 03 37.08	01.40	0.90			+0.04 00.11 KM X 00.94 KM	41.41	E,O,(0.342,5)
11	100:04:08:24.69	28 04 27.84	94 09 55.44	00.52	0.74			-0.24 01.16 KM X 05.92 KM	23.89	U,O,P,(0.342,7)
12	100:04:27:47.79	29 51 00.36	93 03 38.52	00.00	0.01			+0.05 00.33 KM X 03.94 KM	69.20	E?,O,(0.342,7)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- M (KM) L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
13 100:04:39:21.55	29 49 07.32	93 09 03.24	00.00	0.00		+0.50 00.05 KM X 00.63 KM	92.40	E,0,(0.342,7)**
14 100:04:41:23.46	29 47 45.60	93 09 05.04	00.00	0.00		-0.04 00.42 KM X 04.99 KM	93.45	E?,0,(0.345,5)
15 100:06:36:29.99	29 27 33.40	92 52 13.80	00.00	0.00		+0.01 01.78 KM X 02.42 KM	61.33	E?,0,(0.342,5)
16 100:06:43:01.12	29 59 40.20	93 09 42.84	02.83			+0.09		E,0,(0.342,4)
17 100:14:10	POSSIBLE EVENT ON CLB,JCF, NOT ON TAPE*** +0.84(?)FROM DRUM RECORDS							
18 107:12:03	POSSIBLE EVENT ON CLB,CPF, TOO SMALL TO LOCATE							
19 107:12:17:47.24	30 04 28.56	93 07 41.88	06.60	8.83		<0.00 00.61 KM X 07.53 KM	80.55	E,0,(0.342,5)
20 107:12:18:01.62	30 02 21.84	93 11 04.56	05.10					E,I,(0.342,3)
01 107:12:05:59.49	30 00 46.08	93 08 33.36	05.64			-0.10		E?,I,(0.342,3)
02 107:12:08	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE							
03 107:12:08:40.93	30 03 08.28	93 09 38.52	02.14	00.05		-0.04 00.01 KM X 00.01 KM	82.72	E,I,(0.342,5)
04 107:12:09:13.52	30 02 28.68	93 09 27.72	03.18	00.74		-0.48 00.17 KM X 00.42 KM	60.37	E,I,(0.342,5)
05 107:12:10:12.15	30 01 40.80	93 07 17.04	02.63			-0.91		E?,I,(0.342,3)
06 107:12:10:01.58	30 11 18.20	93 14 15.70	00.00	00.01		01.10 KM X 12.11 KM	62.49	E?,0,P,(0.342,5)
07 107:12:11:17.79	30 04 30.00	93 07 08.40	00.00			<-1.0		E?,0,(0.342,3)
08 107:12:11:37.54	30 04 34.32	93 07 56.28	01.89	01.16		-0.27 00.23 KM X 01.33 KM	83.66	E,0,(0.342,5)
09 107:12:12:19.24	30 02 27.24	93 08 44.16	00.00			<-1.0		E?,I,(0.342,4)
10 107:12:13:51.57	29 59 50.20	93 07 49.44	00.00	00.57		+0.11 00.03 KM X 00.08 KM	112.68	E,0,(0.342,6)
11 107:12:14	POSSIBLE EVENT, TOO NOISY TO LOCATE							

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
21	107:12:18:34.89	30 02 10.68	93 07 04.80	06.04	0.35			<0.00 00.03 KM X 00.13 KM	81.87	E,I,(0.342,5)
22	107:12:20:24.05	30 01 32.88	93 09 57.60	00.26	0.27			<0.00 00.01 KM X 00.03 KM	88.01	E,I,(0.342,7)
23	107:12:24:06.19	30 04 26.04	93 06 42.12	00.93	0.81			-1.25 00.12 KM X 00.59 KM	104.75	E,O,(0.342,6)
24	107:12:24:09.38	30 05 18.24	93 04 14.16	01.82	0.16			-1.41 00.03 KM X 00.22 KM	120.45	E,O,(0.342,5)
25	107:12:24:30.74	30 02 22.56	93 06 05.04	05.00	0.10			-0.89 00.02 KM X 00.07 KM	119.35	E,O,(0.342,6)
26	107:12:25:16.93	30 01 50.16	93 09 15.12	00.00	0.16			+0.07 00.03 KM X 00.06 KM	71.67	E,I,(0.342,5)
27	107:12:26:02.74	30 00 46.80	93 09 07.92	01.67	0.24			+0.05 00.10 KM X 00.12 KM	166.30	E,I,(0.342,6)
28	107:12:27:00.84	30 01 26.40	93 08 56.04	01.61				<0.00		E,I,(0.342,3)
29	107:12:27:11.90	30 00 14.04	93 13 08.76	00.87				<0.00		E,O,(0.342,3)
12	107:12:29:01.39	30 01 32.16	93 09 29.16	03.57				+0.36		E?,I,(0.342,3)
13	107:12:29:32.11	29 59 32.20	93 11 44.80	00.46	00.02			+0.45 00.00 KM X 00.01 KM	125.22	E,O,(0.342,5)
14	107:12:30:02.37	30 02 56.04	93 10 57.70	05.27				<-1.0		E?,I,(0.342,3)
15	107:12:30:25.70	30 00 08.64	93 09 48.96	02.02	00.37			<0.00 00.08 KM X 00.16 KM	106.64	E,O,(0.342,6)
16	107:12:30:59.43	30 02 42.72	93 09 51.12	01.62	00.60			<-1.0 00.08 KM X 00.17 KM	94.83	E,I,(0.342,5)
17	107:12:31:01.64	30 00 03.96	93 11 26.50	05.13				<-1.0		E?,O,(0.342,3)
18	107:12:31:42.53	30 00 50.40	93 04 50.52	00.69				<-1.0		E?,O,(0.342,3)
19	107:12:32:04.04	30 03 51.48	93 08 13.20	05.63	00.38			<-1.0 00.08 KM X 00.38 KM	85.40	E,O,(0.342,5)
20	107:12:33	TWO POSSIBLE EVENTS, TOO NOISY TO LOCATE								
21	107:12:34:02.25	30 00 45.00	93 09 41.76	05.50				<-1.0		E?,I,(0.342,3)
22	107:12:34:00.54	30 04 54.84	93 00 27.00	02.35				<-1.0		E?,O,(0.342,3)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
23	107:12:35:01.04	30 01 46.56	93 06 02.88	05.71			<-1.0			E?,I,(0.342,3)
24	107:12:36:53.57	29 59 17.80	93 10 22.80	01.26	01.46		<-1.0	00.29 KM X 02.43 KM	148.92	E,D,P,(0.342,5)
25	107:12:37:01.95	30 01 44.04	93 09 44.64	05.71			<-1.0			E?,I,(0.342,3)
26	107:12:40:44.95	30 01 43.32	93 09 16.56	05.48			<-1.0			E?,I,(0.342,3)
30	107:12:43:08.98	29 59 29.70	93 08 58.92	03.24			+0.19(?)	POSSIBLY A MULTIPLE EVENT		E,D,(0.342,3)
31	107:12:44:57.87	29 55 18.40	93 11 32.2	00.82	2.23		+0.12	00.12 KM X 01.04 KM		E,D,(0.342,5)
32	107:12:45:37.25	29 56 33.3	93 13 05.88	00.00			-0.16			E,D,(0.342,3)
33	107:12:47	POSSIBLE MULTIPLE EVENTS ON 6 STATIONS, CANNOT LOCATE								
34	107:12:47:56.79	29 59 42.7	93 13 08.76	00.00	0.03		+0.35	00.11 KM X 01.41 KM	163.76	E,D,(0.342,5)
35	107:12:50-51	POSSIBLE MULTIPLE EVENTS ON 6 STATIONS, CANNOT LOCATE								
36	107:12:52-55	SEVERAL POSSIBLE EVENTS ON ONE TO THREE STATIONS, CANNOT LOCATE								
37	107:12:51:39.33	30 08 17.16	93 07 58.44	01.83	0.97		-0.26	00.09 KM X 00.84 KM	86.92	E,D,(0.342,6)
38	107:12:55:22.59	30 01 04.44	93 10 09.48	00.94			-0.67	00.04 KM X 00.07 KM	70.61	E,I,(0.342,5)
39	107:12:56:01.20	29 58 53.7	93 10 10.50	02.63	0.30		-0.23	00.06 KM X 00.33 KM	99.80	E,D,(0.342,5)
40	107:12:55:51.01	29 52 55.2	93 13 17.7	14.08	1.09			00.12 KM X 01.31 KM	113.03	F?,D,(0.342,5)
41	107:13:00:02.68	29 58 33.9	93 10 08.4	01.36	0.29		+0.27	00.03 KM X 00.07 KM	119.82	E,D,(0.342,6)
42	107:13:01:09.24	30 01 11.64	93 07 22.8	01.18	0.84		<0.00	00.13 KM X 00.33 KM	107.89	E,I,(0.342,5)
43	107:13:01:16.05	30 00 48.6	93 07 22.44	00.00	0.22		-0.56	00.06 KM X 00.09 KM	109.03	E,I,(0.342,5)
44	107:13:02	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
45	107:13:01:34.24	30 01 26.76	92 52 26.0	00.00			<-1.00			E,D,P,(0.342,3)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
46 107:13:02:34.95	29 57 20.10	93 16 44.00	00.00	0.01		<-1.00	00.40 KM X 04.83 KM	155.03	E,O,(0.342,5)
47 107:13:05	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
48 107:13:07	POSSIBLE EVENT ON CLB, TOO SMALL TO LOCATE								
49 107:13:07:31.92	29 59 45.90	92 55 10.50	01.88	2.18		-0.30	00.44 KM X 02.77 KM	05.17	E,O,(0.342,6)
50 107:13:09:02.04	30 03 28.80	93 05 51.72	01.84	0.45		-0.07	00.13 KM X 00.44 KM	120.66	E,I,(0.342,7)
51 107:13:08:50.08	29 53 42.70	93 18 04.32	00.00	0.01			00.30 KM X 04.05 KM	142.39	E?,O,P,(0.342,5)
52 107:13:10:14.52	29 59 05.28	93 10 11.60	01.15	0.19		+0.25	00.02 KM X 00.09 KM	110.55	E,O,(0.342,7)
53 107:13:11	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
54 107:13:13:	30 04 21.36	92 56 39.40	04.14			<-1.00			E,O,(0.342,3)
55 107:13:17:21.33	30 03 20.16	93 03 16.56	01.82	0.50		-0.55	00.12 KM X 01.19 KM	140.31	E,O,(0.342,5)
56 107:13:22:03.97	30 00 38.52	93 08 03.84	01.56			-0.01			E,I,(0.342,3)CLOSE TO WELL
57 107:13:23:47.77	30 03 16.56	93 02 46.68	03.25			+0.60(?)	POSSIBLY A MULTIPLE EVENT		E,O,(0.342,3)
58 107:13:24:07.88	30 05 12.48	93 07 14.52	08.39			<-1.00			E,O,(0.342,3)
59 107:13:27	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
60 107:13:28:05.56	29 59 52.4	93 06 55.08	01.41			-0.04			E,I,(0.342,3)
61 107:13:32:50.25	29 57 24.10	93 13 59.10	00.00			<-1.0			E,O,(0.342,3)
62 107:13:35	POSSIBLE EVENT, TOO EMERGENT AND SMALL TO LOCATE								
63 107:13:37	POSSIBLE EVENT, TOO NOISY AND EMERGENT TO LOCATE								
64 107:13:39:46.49	30 00 04.32	93 06 54.72	00.52	0.76		-0.26	00.03 KM X 00.11 KM	111.71	E,I,(0.342,5)
65 107:13:45	POSSIBLE EVENT ON JCF, CLB, HWS, TOO EMERGENT TO LOCATE (Md<-1.00)								

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

NO	ORIGIN TIME(UTC) DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
66	107:13:46:57.88	30 05 06.72	93 04 23.52	01.32	0.41		-0.78	00.05 KM X 00.27 KM	121.43	E,0,(0.342,5)
67	107:13:47:35.46	29 57 02.16	92 49 46.90	05.70	0.77		-0.94	00.40 KM X 00.70 KM	13.49	E?,0,(0.342,6)
68	107:14:05:09.79	30 00 14.04	93 08 32.64	02.27			<-1.00			E,I,(0.342,3)CLOSE TO WELL
69	107:14:07	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE (Md<-1.00)								
70	107:14:29	POSSIBLE EVENT ON CLB, TOO SMALL TO LOCATE (Md<-1.00)								
71	107:14:48:26.94	29 59 39.80	93 03 34.56	00.00			<-1.00			E,0,(0.342,3)
72	107:15:45	POSSIBLE EVENT ON CLB, CPF, JCF, TOO EMERGENT TO LOCATE (Md<=-1.00)								
73	107:16:00	POSSIBLE EVENT ON HWS, CLB, TOO SMALL TO LOCATE (Md<-1.00)								
74	107:19:32	POSSIBLE EVENT ON CLB, TOO SMALL TO LOCATE (Md<-1.0)								
75	108:06:10	POSSIBLE EVENT ON CLB, JCF, TOO SMALL TO LOCATE (Md<-1.00)								
76	111:13:07:21.36	30 03 37.80	93 05 55.68	01.49	0.65		+0.03	00.08 KM X 00.36 KM	110.00	E,0,(0.342,5)
77	111:13:12:55.08	29 58 39.30	93 07 09.84	00.44			+0.05			E,0,(0.342,4)
78	111:13:15	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
79	111:13:29:54.08	29 58 09.48	93 07 23.52	00.00			-0.55			E,0,(0.342,3)
80	111:14:58	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
81	111:15:01	POSSIBLE EVENT ON CLB, CPF, TOO SMALL TO LOCATE								
82	112:03:57:31.12	30 07 39.72	93 01 58.44	01.85	3.95		-0.71	00.34 KM X 02.58 KM	124.46	E,0,(0.342,5)
83	112:03:59	POSSIBLE EVENT ON CLB, TOO SMALL TO LOCATE								
84	112:05:03	POSSIBLE EVENT ON CLB, TOO SMALL TO LOCATE								
85	117:15:20:04.41	29 59 24.00	93 06 37.44	00.00			+0.14			E,0,(0.342,3)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- M (KM) L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
86 117:15:23:00.10	29 59 07.44	93 04 43.32	02.70		+0.14			E,0,(0.342,3)
87 119:03:17:38.75	30 01 01.20	93 05 48.48	03.59		-0.06			E,I,(0.342,3)
01 134:00:10:55.51	30 01 33.60	93 10 30.00	01.08 00.85		-0.12	00.11 KM X 00.26 KM	118.66	E,I,(0.342,5)
02 134:00:13:16.06	30 01 40.08	93 09 56.16	00.88 01.59		-0.14	00.19 KM X 00.24 KM	107.81	E,I,(0.342,5)
03 134:00:13:57.30	30 26 25.40	93 42 08.64	00.00 00.00			01.40 KM X 01.67 KM	140.65	E?,0,(0.342,6)
04 134:00:30:42.39	30 02 05.28	93 17 41.60	00.00		<-1.0			E?,0,(0.342,3)
05 134:00:52:31.81	30 11 56.40	93 32 26.10	00.00 00.00			00.43 KM X 00.74 KM	28.21	E?,0,(0.342,6)
06 134:00:57:02.47	30 02 25.80	93 16 31.00	00.00 00.10			00.96 KM X 10.91 KM	10.59	E?,0,(0.342,5)
07 134:01:13:26.23	29 58 03.36	93 08 04.2	00.99		<-1.0			E?,0,(0.342,4)
08 134:01:20:16.24	30 03 47.88	93 09 10.44	00.98 00.17		<-1.16	00.01 KM X 00.05 KM	78.32	E?,0,(0.342,5)
09 134:01:28:23.86	30 09 31.68	93 06 13.32	01.22 07.62		<-1.0	00.23 KM X 01.84 KM	108.10	E?,0,(0.342,5)
10 134:01:34	POSSIBLE EVENT ON CPF, TOO SMALL TO LOCATE							
11 134:01:37:04.50	30 00 09.72	93 08 54.24	00.13 00.38		+0.12	00.01 KM X 00.03 KM	105.29	E,0,(0.342,6)
12 134:01:39:25.56	30 01 37.56	93 09 22.68	01.57 00.14		-1.15	00.04 KM X 00.11 KM	93.18	E,I,(0.342,6)
13 134:01:43	POSSIBLE EVENT ON JCF, TOO SMALL TO LOCATE							
14 134:02:49:22.30	30 02 11.4	93 10 08.76	00.00 00.07		+0.10	00.03 KM X 00.05 KM	90.36	E,I,(0.342,7)
15 134:02:49:20.92	30 13 31.8	93 09 45.0	00.00 00.01		<0.00	00.49 KM X 05.75 KM	86.72	E?,0,(0.342,6)
16 134:02:55:10.90	30 02 32.64	93 05 46.32	00.00 00.21		+0.24	00.06 KM X 00.29 KM	119.77	E,0,(0.342,7)
17 134:02:59:31.17	30 04 09.84	93 05 26.88	00.72 00.51		+0.42	00.06 KM X 00.55 KM	109.61	E,0,(0.342,5)
18 134:03:13:56.41	29 44 48.4	93 05 32.28	08.06 02.51			00.28 KM X 03.58 KM	81.17	E?,0,(0.342,6)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
19 134:04:00:07.59	29 46 57.7	93 14 18.2	00.00 00.00				00.14 KM X 01.84 KM	108.72	E?,0,(0.342,6)
20 134:04:53:00.17	30 00 33.84	93 05 33.72	00.00 00.07			+0.03	00.02 KM X 00.02 KM	174.90	E,I,(0.342,6)
21 134:16:13	POSSIBLE EVENT, TOO NOISY TO LOCATE								
01 170:20:06:23.03	30 02 16.8	93 08 58.2	00.48 00.24			-0.13	00.02 KM X 00.05 KM	103.75	E,I,(0.342,6)
02 180:19:12:14.64	29 54 53.2	92 56 40.9	07.00 00.21				00.09 KM X 00.53 KM	34.17	E?,0,(0.342,6)
03 180:19:16:55.54	29 58 07.68	93 00 03.6	02.28 00.32				00.10 KM X 01.13 KM	23.85	E?,0,(0.342,6)
04 180:19:17:09.35	29 58 31.4	93 01 13.8	04.24 00.19				00.04 KM X 00.44 KM	24.52	E?,0,(0.342,5)
05 180:19:17:31.47	29 58 01.2	93 00 42.84	03.66 00.90				00.24 KM X 02.48 KM	26.87	E?,0,(0.342,6)
06 181:19:56:40.29	30 00 11.88	93 05 21.84	02.68 00.75			+1.04	00.20 KM X 00.45 KM	12.95	E?,I,P,(0.342,6)
01 183:15:00:32.40	29 59 50.60	92 55 32.50	09.90 04.09				01.59 KM X 07.46 KM	5.14	U,0,P,(0.342,5)
02 183:19:46:44.31	30 02 08.88	92 56 38.40	00.00						U,0,P,(0.342,3)
03 196:19:16	POSSIBLE EVENT, TOO NOISY TO LOCATE								
04 196:19:20	POSSIBLE EVENT, TOO NOISY TO LOCATE								
05 196:19:25:15.15	30 01 17.04	93 09 21.24	04.92			+0.01			E?,I,(0.342,3)
06 196:19:29:17.42	30 01 14.16	93 08 39.12	04.99			-0.56			E?,I,(0.342,3)
07 196:19:44:10.41	29 57 56.50	93 10 38.60	06.52			-0.67			E?,0,(0.342,3)
08 196:19:46:16.19	29 59 18.90	93 06 25.20	00.00			-0.59			E?,0,(0.342,3)
09 197:09:06:03.33	29 57 53.60	93 03 39.96	02.33 00.44			+0.56	00.11 KM X 02.00 KM	47.84	E?,0,(0.342,6)
10 197:09:15:54.72	29 58 03.72	93 03 42.12	01.90 00.43			+1.12	00.15 KM X 02.43 KM	46.61	E?,0,(0.342,5)
11 197:09:27:08.19	29 57 36.70	93 04 26.04	02.00 01.15			+0.47	00.37 KM X 04.62 KM	56.27	E?,0,(0.342,5)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME UTC NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
12 197:19:44:11.57	29 54 10.80	92 55 38.20	04.11	03.49			01.53 KM X 07.12 KM	33.88	U.O.P.(0.342.6)
13 198:15:22:07.12	29 58 56.20	93 04 46.20	00.00	00.85	+0.77		00.47 KM X 04.09 KM	48.98	E?,0,(0.342.5)
14 198:15:28:11.32	30 03 24.84	93 07 51.96	00.00	00.08	+0.11		00.10 KM X 00.44 KM	92.18	E?,1,(0.342.5)
15 198:15:28:51.99	30 02 44.16	93 06 12.60	00.55		+0.11				E?,0,(0.342.3)
16 198:15:29:17.63	30 04 54.48	93 06 14.04	06.89	00.33	+0.03		00.06 KM X 00.16 KM	111.33	E?,0,(0.342.5)
17 198:15:29:42.24	29 58 18.40	93 10 59.80	02.33	03.56	+0.13		00.68 KM X 01.70 KM	125.63	E?,0,(0.342.5)
18 198:15:30:25.30	30 03 54.36	93 07 33.24	02.49	00.49	-0.25		00.06 KM X 00.17 KM	102.10	E?,0,(0.342.5)
19 198:15:33:38.55	30 02 40.92	93 06 57.24	00.85	01.49	+0.14		00.11 KM X 00.31 KM	107.76	E?,1,(0.342.6)
20 198:15:36:39.17	30 01 31.80	93 07 13.44	00.00	00.26	+0.41		00.07 KM X 00.18 KM	97.72	E?,1,(0.342.6)
21 198:15:37	TWO OR MORE OVERLAPPING EVENTS, UNRESOLVABLE LOCATIONS (SMALL, LOCAL?)								
22 198:15:40:49.36	30 00 10.80	93 05 20.76	00.00	00.06	+0.24		00.05 KM X 00.07 KM	166.60	E?,1,(0.342.6)
23 198:15:42:22.93	30 02 31.92	93 07 15.96	02.12	01.16	+0.43		00.19 KM X 00.51 KM	98.97	E?,1,(0.342.5)
24 198:15:47:12.98	30 02 09.60	93 05 58.92	03.52		-0.56				E?,0,(0.342.3)
25 198:15:49:22.28	30 00 14.40	93 05 00.96	00.00		+0.24				E?,0,(0.342.3)
26 198:15:51:39.44	30 00 10.08	93 03 57.60	00.00	00.00	+0.27		00.00 KM X 00.02 KM	5.43	E?,0,(0.342.5)
27 198:15:52:33.76	30 00 02.52	93 04 50.16	00.51	01.91	+0.39		00.04 KM X 00.91 KM	19.72	E?,0,(0.342.5)
28 198:15:53:36.07	30 00 13.68	93 04 04.80	00.00	00.02	+0.07		00.03 KM X 00.14 KM	1.89	E?,0,(0.342.6)
29 198:15:54:19.24	30 00 46.08	93 03 15.84	00.17		-0.29				E?,0,(0.342.3)
30 198:15:55	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
31 198:15:59:51.12	29 58 40.00	93 04 28.92	03.96		+0.59				E?,0,(0.342.3)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
32 198:16:03	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
33 198:16:03:49.67	30 01 39.72	93 03 49.32	01.09			+0.44			E?,0,(0.342,3)
34 198:16:05	POSSIBLE EVENT ON CLB, HWN, TOO SMALL TO LOCATE								
35 198:16:12:12.31	30 02 19.32	93 04 51.24	01.81	00.05		+1.13	00.02 KM X 00.06 KM	132.63	E?,0,(0.342,5)
36 198:20:15:15.53	30 05 26.16	93 03 14.76	00.03	04.35			00.48 KM X 01.96 KM	134.46	B,0,(P,6)
37 199:13:14:25.27	30 03 20.16	93 07 57.72	00.00	00.07		-0.15	00.07 KM X 00.19 KM	105.55	E?,1,(0.342,6)
38 199:13:16:39.03	30 03 57.96	93 10 41.10	02.07	00.76		-0.01	00.12 KM X 00.18 KM	104.85	E?,0,(0.342,6)
39 199:13:19:54.78	30 03 27.36	93 10 03.72	00.92	00.79		+0.12	00.06 KM X 00.13 KM	96.58	E?,0,(0.342,6)
40 199:13:21:03.55	30 01 53.40	93 10 05.52	00.00	00.02		+0.28	00.00 KM X 00.01 KM	114.12	E?,1,(0.342,6)
41 199:13:22:09.74	30 03 23.76	93 09 19.80	00.91	00.46		+0.09	00.02 KM X 00.08 KM	109.65	E?,0,(0.342,5)
42 199:13:24	POSSIBLE EVENT ON CPF, HWN, TOO SMALL TO LOCATE								
43 199:13:28:17.09	30 01 32.88	93 10 53.70	02.76			-0.22			E?,1,(0.342,3)
44 199:14:24:17.36	30 09 06.48	93 04 32.16	05.92	00.14		+0.31	00.02 KM X 00.12 KM	110.73	E?,0,(0.342,6)
45 199:14:25:45.59	30 03 54.00	93 07 08.04	03.44	00.01		-0.18	00.00 KM X 00.00 KM	110.95	E?,0,(0.342,5)
46 199:14:27:01.55	30 09 57.96	93 04 22.08	02.77	02.98		+0.39	00.12 KM X 00.98 KM	113.57	E?,0,(0.342,6)
47 199:14:31:36.28	30 09 16.56	93 05 31.92	00.00	00.00		+0.21	00.09 KM X 00.65 KM	109.24	E?,0,(0.342,6)
48 199:14:48	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
49 199:14:49:59.74	29 54 12.60	93 03 54.72	05.52			-0.89			E?,0,(0.342,3)
50 199:14:52:13.53	29 58 01.56	93 07 13.08	00.89	01.09		-0.10	00.08 KM X 00.43 KM	97.08	E?,0,(0.342,5)
51 199:14:53	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
52 199:14:54	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
53 199:14:54:33.46	29 59 24.00	93 04 46.20	02.67						E?,0,(0.342,3)
54 199:14:55:00.40	29 58 28.50	93 05 13.20	03.46						E?,0,(0.342,3)
55 199:14:55:32.29	29 51 29.80	93 12 17.20	00.00						E?,0,(0.342,3)
56 199:14:57:00.35	29 59 53.50	93 03 50.76	02.72			+0.27			E?,0,(0.342,3)
57 199:14:57:37.85	30 02 27.96	93 09 56.16	00.00			-0.09			E?,1,(0.342,3)
58 199:14:58	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
59 199:14:59	POSSIBLE EVENT ON CLB, CPF, TOO SMALL TO LOCATE								
60 199:15:00:33.31	29 59 13.90	93 03 40.32	04.65			-0.27			E?,0,(0.342,3)
61 199:15:02:29.8E	29 55 08.40	93 00 39.60	01.97	00.14		-0.34	00.03 KM X 00.30 KM	47.47	E?,0,(0.342,5)
62 199:15:04	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
63 199:15:05	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE								
64 199:15:06	POSSIBLE EVENT ON CLB, SFY, TOO SMALL TO LOCATE								
65 199:15:06:46.15	29 58 23.50	93 04 22.44	00.00	00.00		+0.34	00.14 KM X 01.22 KM	49.50	E?,0,(0.342,6)
66 199:15:09:41.24	30 01 22.44	93 07 17.76	03.32			+0.35			E?,1,(0.342,3)
67 199:15:13:20.46	30 00 45.00	93 06 09.00	03.12						E?,1,(0.342,3)
68 199:15:13:25.86	30 00 55.80	93 06 01.80	03.44			-0.11			E?,1,(0.342,3)
69 199:15:14:57.40	30 01 02.28	93 06 16.20	02.18			+0.60	(?POSSIBLE MULTIPLE EVENT)		E?,1,(0.342,3)
70 199:15:21:52.88	30 03 38.52	93 03 38.16	00.00			-1.13			E?,0,(0.342,3)
71 199:15:24:14.41	30 03 30.60	93 03 24.84	00.00			-1.45			E?,0,(0.342,3)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
72 199:15:34:03.04	29 59 23.60	93 09 29.16	02.45	00.11		-0.01	00.03 KM X 00.11 KM	104.80	E?,0,(0.342,5)
73 199:15:36:30.54	29 59 33.00	93 08 21.48	03.66			-0.38			E?,0,(0.342,3)
74 199:15:37	TWO POSSIBLE EVENTS, TOO SMALL TO LOCATE								
75 199:15:37:55.02	30 00 14.04	93 06 16.92	02.35			-0.66			E?,1,(0.342,3)
76 199:15:38:24.85	29 56 27.90	93 11 25.80	02.91	03.27			00.26 KM X 01.59 KM	112.08	E?,0,(0.342,5)
77 199:15:38:27.93	29 52 19.20	93 14 58.50	01.01						E?,0,(0.342,4)
78 199:15:39:28.59	29 52 50.10	93 14 55.30	04.16	00.24		+0.56	00.02 KM X 00.26 KM	116.45	E?,0,(0.342,5)
79 199:15:43:18.27	29 53 34.80	93 13 59.80	00.00	00.00		+0.73	00.04 KM X 00.32 KM	117.81	E?,0,(0.342,5)
80 199:15:51:13.07	29 53 40.90	93 10 28.20	00.00						E?,0,(0.342,3)
81 199:15:55:24.22	30 02 08.88	93 07 17.40	02.67			-0.93			E?,1,(0.342,3)
82 199:15:59:45.34	29 57 08.64	93 10 33.60	03.43			<0.00			E?,0,(0.342,3)
83 199:16:10:18.75	29 49 35.00	92 48 18.00	00.00	00.00			00.66 KM X 01.31 KM	34.59	U,0,P,(0.342,5)
84 199:16:44:41.10	29 52 46.50	93 01 01.20	05.86	00.96			00.28 KM X 02.20 KM	57.26	U,0,(0.342,5)
85 199:16:53:36.41	29 55 03.72	93 02 53.88	03.67	02.83			00.72 KM X 07.46 KM	58.91	E?,0,(0.342,5)
86 202:00:10:05.70	30 07 35.04	93 02 11.04	05.37			+0.09			E?,0,(0.342,3)
87 202:00:32:34.63	30 05 39.84	93 05 57.12	00.00	00.02			00.15 KM X 01.30 KM	105.66	E?,0,(0.342,3)
88 202:00:33:56.07	30 07 02.28	93 04 28.20	00.00						E?,0,(0.342,3)
89 202:01:11:45.68	29 58 09.84	93 04 36.84	00.27	01.77		+0.35	00.16 KM X 01.03 KM	53.41	E,0,(0.342,6)
90 206:15:38:37.42	29 59 51.70	93 08 57.12	01.26	00.79		<0.00	00.22 KM X 00.41 KM	103.93	E,0,(0.342,5)
91 206:15:43:02.06	29 59 17.50	93 10 53.40	03.80			<-1.0			E?,0,(0.342,3)

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME: UTC NO DAY:HR:MM:SEC	LATITUDE(N) DG MM SEC	LONGITUDE(W) DG MM SEC	DEPTH (KM)	+/- M (KM) L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
92 206:15:43:30.90	30 00 38.88	93 11 54.60	01.43		<-1.0			E?,0,(0.342,3)
93 206:15:46:22.37	30 01 05.88	93 06 58.68	00.00	00.12	-0.44	00.04 KM X 00.09 KM	95.53	E,I,(0.342,5)
94 206:15:46:25.61	29 59 25.00	93 12 51.80	03.42		-0.56			E?,0,(0.342,3)
95 206:15:46:51.98	30 01 36.84	93 09 48.60	00.09		+0.02			E?,I,(0.342,3)
96 206:15:47:	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE							
97 206:15:48:44.23	30 00 26.28	93 10 48.30	00.55	00.91	<0.00	00.30 KM X 01.01 KM	110.37	E?,0,(0.342,5)
98 206:15:49:42.29	30 00 37.44	93 11 40.50	01.71	00.80	+0.15	00.14 KM X 01.13 KM	1.80	E?,0,(0.342,5)
99 206:15:50	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE							
100 206:15:51	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE							
101 206:15:52:03.47	30 03 14.04	93 05 15.72	06.36		+0.21			E?,0,(0.342,3)
102 206:15:53	POSSIBLE EVENT, TOO EMERGENT TO LOCATE							
103 206:15:54:27.56	30 02 35.52	93 07 42.24	04.39		-0.31			E?,I,(0.342,3)
104 206:20:24:02.88	29 56 53.80	93 08 11.04	00.00		+0.32			E?,0,(0.342,3)
105 206:20:26:43.38	29 55 43.60	93 09 25.20	04.92		+0.25			E?,0,(0.342,3)
106 208:06:18	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE							
107 208:06:34:09.79	30 03 10.44	93 14 06.72	10.94(?)					E?,0,(0.342,3)
108 208:08:31:10.54	30 00 27.72	93 08 43.80	03.77		-1.31			E?,I,(0.342,3)
109 208:18:23:43.30	29 59 53.50	93 02 19.32	09.27(?)		+0.44			E?,0,(0.342,3)
110 210:23:47:44.81	30 00 48.60	93 06 31.68	01.30		-0.55	00.09 KM X 00.14 KM	91.03	E,I,(0.342,5)
111 211:02:31	POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE							

SWEET LAKE ARRAY EVENT LOG FOR NOVEMBER 1981 THROUGH JULY 1982

ORIGIN TIME(UTC) NO DAY:HR:MN:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(X*Y)	X-AXIS AZIMUTH	COMMENTS
112 211:17:30									POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE
113 211:17:44:28.54	30 02 48.84	93 05 27.24	04.63			-0.79			E?,0,(0.342,3)
114 211:17:46									POSSIBLE EVENT ON CPF, CLB, TOO SMALL TO LOCATE
115 211:17:46:01.19	30 05 17.88	93 00 55.80	04.37			<-1.0			E?,0,(0.342,3)
116 211:17:47:20.32	30 04 11.64	93 03 42.48	01.80	00.10		-0.10	00.01 KM X 00.05 KM	134.24	E?,0,(0.342,5)
117 211:17:48:54.26	30 04 58.80	93 02 26.16	00.50	02.41		+0.01	00.07 KM X 00.29 KM	141.70	E?,0,(0.342,6)
118 211:17:50:10.94	30 04 32.16	93 01 53.40	04.37	02.59		<0.00	00.59 KM X 02.81 KM	156.91	E?,0,(0.342,5)
119 211:18:30:02.17	30 02 13.56	93 16 32.80	04.68						E?,0,(0.342,3)
120 211:18:36:45.89	29 55 02.64	93 06 42.48	01.18	03.78		-0.04	00.22 KM X 01.13 KM	81.96	E?,0,(0.342,5)
121 211:18:45:59.72	29 55 26.70	93 04 12.72	02.04			<0.00			E?,0,(0.342,3)
122 212:12:37:01.09	29 51 03.96	93 10 36.10	05.72	00.57			00.05 KM X 00.38 KM	103.72	E?,0,(0.342,5)
123 212:12:39:05.22	29 50 32.60	93 04 33.24	04.85						E?,0,(0.342,4)
124 212:12:55:45.88	29 47 07.08	93 05 43.08	00.00						E?,0,(0.342,4)
125 212:13:26:54.64	29 54 21.60	93 07 15.24	00.00	00.02			00.15 KM X 01.21 KM	88.15	E?,0,(0.342,6)
126 212:13:34:57.60	29 56 42.70	93 11 21.80	00.00						E?,0,(0.342,3)
127 212:13:46:38.11	29 55 57.70	93 10 28.50	00.00	00.03			00.23 KM X 01.14 KM	106.58	E?,0,(0.342,5)
128 212:13:54:08.21	29 58 29.60	93 08 06.72	00.94	00.08		+0.63	00.01 KM X 00.04 KM	98.60	E?,0,(0.342,5)
129 212:13:56:48.14	29 58 33.20	93 10 46.20	00.00			+0.76			E?,0,(0.342,3)

APPENDIX IV-2

Sweet Lake

Possible Events Detected for August, September, and October 1982

<u>Date</u>	<u>Julian Day</u>	<u>Hour: Minute</u> <u>UTC</u>	<u>Comments</u>
02 Aug.	214	02:17	Event ?
		08:00	Event ?
		21:28	Event ?
		21:29	Event ?
05 Aug.	217	15:22	Event ? Long-period
		17:02	Event ? Long-period
		17:03	Event ? Long-period
		21:45	Event ? Long-period
07 Aug.	219	01:00-01:07	Several small events
		03:58	?
		21:16	Teleseism
		23:01	Possible Event
08 Aug.	220	07:04	Possible Event
		07:12	Possible Event
09 Aug.	221	04:14-18:30	29 Possible Events
10 Aug.	222	16:33	Possible Event
		16:34	Possible Event
		16:48	Long-period arrivals
11 Aug.	223	00:23	Noise ?
		00:25	Possible Event
		02:45	Noise ?
		03:16	Noise ?
		07:30	Event ?
		07:32	Event ?
		17:11	Event ?
		17:38	Event ?

<u>Date</u>	<u>Julian Day</u>	<u>Hour: Minute</u> <u>UTC</u>	<u>Comments</u>
14 Aug.	226	01:00	Noise ?
		04:28	Noise ?
		05:46	Event ?
		08:11	Event ?
		08:12	Event ?
		09:30	Noise ?
		10:58	Noise ?
		12:13	Event ?
		15:15	Noise ?
		15:17	Event ?
		22:29	Event ?
15 Aug.	227	08:30	Event ?
16 Aug.	228	18:00-20:00	Numerous small possible events
18 Aug.	230	04:02	Teleseism (distant event)
19 Aug.	231	16:04	Teleseism, large event
20 Aug.	232	17:04	Long-period arrivals
21 Aug.	233	05:56	Possible Event
		01:47	Possible Event
		05:16	Possible Event
		05:56	Possible Event
		07:42	Possible Event
26 Aug.	238	15:13	Long-period arrivals
28 Aug.	240	22:26	Possible Event
29 Aug.	241	13:36	Sonic Boom ? Long-period (Simultaneous arrivals)
31 Aug.	243	17:00-1900	Several possible events
03 Sept.	246	21:39-2209	Several possible events
07 Sept.	250	14:48	Long-period arrivals
		19:16	Long-period arrivals
09 Sept.	252	00:52	Possible Event
		06:32	Noise ?
11 Sept.	254		Microseism swarm from tropical storm Chris lasting all day

<u>Date</u>	<u>Julian Day</u>	<u>Hour: Minute</u> <u>UTC</u>	<u>Comments</u>
15 Sept.	258	20:31	Long-period arrivals
16 Sept.	259	14:12	Possible event ? Long-period
		23:11	Possible event ? Long-period
		13:53	Possible event ? Long-period
17 Sept.	260	01:35	Long-period event
20 Sept.	263	03:21	Possible event
		03:30	Possible event
		03:39	Possible event
		04:00	Possible event
		04:01	Possible event
		04:03	Possible event
		04:05	Possible event
		04:09	Possible event
		04:11	Possible event
		04:15	Possible event
		16:47	Possible event
22 Sept.	265	09:30	Noise ?
23 Sept.	266	14:12	Possible event (local ?)
27 Sept.	270	14:01	Noise ?
28 Sept.	271	06:00	Noise ?
05 Oct.	278	21:27-21:44	6 Possible events
15 Oct.	288	17:02	Long-period arrivals
		17:03	Long-period arrivals
		17:05	Long-period arrivals
17 Oct.	290	13:27	Noise ?
18 Oct.	291	15:02	Event ? Long-period
		18:08	Event ?
19 Oct.	292	14:00	Long-period arrivals
21 Oct.	294	15:11	Noise ?
26 Oct.	299	19:42	Telephone line down due to broken wire at telephone office

<u>Date</u>	<u>Julian Day</u>	<u>Hour: Minute</u> <u>UTC</u>	<u>Comments</u>
27 Oct.	300	15:39	Broken telephone wire repaired
		19:32	Long-period arrivals
		19:34	Long-period arrivals
		20:36	Long-period arrivals
		20:38	Long-period arrivals
29 Oct.	302	16:41	Possible event, followed by many smaller events
31 Oct.	304	02:44	Possible event
		06:06	Teleseism (distant event)

APPENDIX V

Rockefeller Refuge Array Events

APPENDIX V-1

Key to Event Log Information

Origin Time (UTC)	Expressed in Universal Time Coordinated (UTC), beginning with the Julian Day, then the hour, minute, second, and hundredths seconds of the calculated origin time of the event.
Latitude (N)	The north latitude of the epicenter, expressed in degrees, minutes, and seconds.
Longitude (W)	The west longitude of the epicenter, expressed in degrees, minutes, and seconds.
Depth (km)	The calculated depth to the hypocenter, expressed in km.
+/- (km)	Estimated error in depth calculation.
M _L	Richter Local Magnitude. Only listed for naturally-occurring events.
M _D	Duration Magnitude. Only listed for naturally-occurring events.
Error Ellipse (XxY)	Ellipse of one standard deviation about the calculated epicenter, expressed in km. The first value is the length of the X-axis and the second value is the length of the Y-axis.
X-Axis Azimuth	Degrees clockwise from north of the orientation of the X-axis of the error ellipse.
Comments	Added information about the particular listed event, as follows: E Naturally-occurring earthquake E? Possible natural earthquake B Geophysical blasting (Oil Exploration) S Possible offshore slump event C Depth constrained to given value I Event occurred inside the network O Event occurred outside the network F Event occurred too far away for a good location estimate U Unknown source P Poor solution (Numbers) First - Wave velocity that best locates the event, in km/sec. Second - Number of stations used in the location of the event.

APPENDIX V-1

Rockefeller Refuge Array Event Log
for
1 November 1981 to 31 October 1982

ORIGIN TIME (UTC) NO DAY:HR:MN:SEC	LATITUDE(N) DG MN SEC	LONGITUDE(W) DG MN SEC	DEPTH (KM)	+/- (KM)	M L	M D	ERROR ELLIPSE(XxY)	X-AXIS AZIMUTH	COMMENTS
1 301:17:32:47.28	29 40 41.0	92 55 26.0	5.58	0.56			-0.42 00.43 km X 01.19 km	71.62	E,O
2 301:17:34:44.49	29 41 08.8	92 55 28.0	4.77	0.31			-0.37 00.16 km X 00.45 km	67.63	E,O
3 348:08:32	TOO SMALL TO LOCATE								E?
4 348:09:33:46.76	29 43 41.10	92 50 06.72	02.21	2.95			-0.56 00.99 km X 01.24 km	102.62	E?,P,I,(P+S,5)
5 355:15:33:47.48	29 43 23.50	92 48 49.60	02.05	0.55			-1.1 00.44 km X 00.76 km	29.16	E?,P,O,(P+S,5)
6 081:13:21:07.71	29 40 52.6	92 49 01.92	0.39	0.11			-1.21 00.01 km X 00.04 km	46.09	E?,O,(0.342,6)
7 111:15:45:30.77	29 44 36.20	92 49 02.64	8.02(?)						E?,O,(0.342,3)
8 111:15:49	POSSIBLE EVENT DETECTED AT STATION ALP, TOO SMALL TO LOCATE								
9 111:16:30	POSSIBLE EVENT DETECTED AT STATION ALP, TOO SMALL TO LOCATE								
10 111:17:49:41.98	29 39 46.00	92 58 02.64	03.58						E?,O,(0.342,3)
11 114:00:03	POSSIBLE EVENT DETECTED AT STATION ALP, TOO SMALL TO LOCATE								
12 114:00:06	POSSIBLE EVENT DETECTED AT STATION ALP, TOO SMALL TO LOCATE								
13 114:00:15:21.52	29 39 56.80	92 46 36.80	04.92(?)						E?,O,(0.342,3)
14 115:15:26	POSSIBLE EVENT DETECTED AT STATION ALP, TOO SMALL TO LOCATE								
15 115:16:56	POSSIBLE EVENT DETECTED AT STATION ALP, TOO SMALL TO LOCATE								
16 123:13:36:05.32	29 43 31.0	92 51 30.2	03.57	0.17			-1.43 00.04 km X 00.05 km	143.40	E?,O,(P-WAVE,5)
17 125:02:21	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
18 125:09:47	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
19 128:13:14	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
20 128:13:15	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
21 130:10:43	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
22 131:02:19:23.13	29 45 54.3	92 53 17.1	03.06			-1.38			E?,O,(0.342,3)
23 134:01:57	POSSIBLE EVENT ON ALP, FLR, TOO SMALL TO LOCATE								
24 134:05:05	POSSIBLE EVENT ON ALP, FLR, TOO SMALL TO LOCATE								
25 134:05:19	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
26 153:21:59:54.11	29 42 55.0	92 50 13.9	02.93			-2.07			E?,I,(0.342,3)
27 158:21:11:30.96	29 42 29.8	92 50 30.1	05.73			-1.01			E?,I,(0.342,3)
28 164:13:38	POSSIBLE EVENT ON ALP, TOO SMALL TO LOCATE								
29 169:15:58	POSSIBLE EVENT ON ALP, FLR, TOO SMALL TO LOCATE								
30 179:09:35	POSSIBLE EVENT ON ALP, FLR, TOO SMALL TO LOCATE								
31 187:20:36:08.27	29 42 12.6	92 48 28.00	05.59			-0.72			E?,O,P,(0.342,3)
32 209:15:42:59.02	29 41 47.40	92 50 16.40	00.96			-1.11			E?,I,(0.342,3)
33 261:20:15	POSSIBLE EVENT ON LEV, HQS, TOO SMALL TO LOCATE								
34 273:16:16:06.01	29 44 10.30	92 51 38.10	05.80(?)			<-1.0			WELL NOISE?,I,(0.342,3)

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