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TECHNICAL SUPPORT FOR GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES IN LOUISIANA

ANNUAL REPORT
for the period
1 January 1991 to 31 December 1991

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PREFACE

Tasks in this report were performed by the Louisiana Geological Survey under the U.S. Department of Energy (DOE) contract no. DE-FC07-85NV10425 for the period of 1 January 1991 through 31 December 1991. Previous information about this continuing program was covered in final form in preceding annual reports. During this contract period, microseismic activity and land surface subsidence were monitored at the Gladys McCall (Cameron Parish, Louisiana), Hulin (Vermilion Parish, Louisiana), and Pleasant Bayou (Brazoria County, Texas) well sites. Preliminary studies on the co-location of medium to heavy oil with geopressured brine resources in south Louisiana also were performed. The project personnel involved were C. G. Groat (Project Coordinator), Chacko J. John (Principal Investigator), Don Stevenson and Bridget Jensen (microearthquake monitoring), and Dianne Lindstedt (subsidence monitoring).

This report is a progress report as it discusses program components, provides monitoring data, and presents interpretations. All aspects of this program will be continued for next year (1992), except microseismic monitoring at Gladys McCall and the co-location studies; both of which were discontinued on 31 December 1991 as requested by DOE. Project data obtained in 1992 will be presented in the subsequent annual report.

MICROEARTHQUAKE MONITORING

by

Bridget Jensen

ABSTRACT

Since September 1978, microseismic networks have operated continuously around U.S. Department of Energy (DOE) geopressured-geothermal well sites to monitor any microearthquake activity in the well vicinity. Microseismic monitoring is necessary before flow testing at a well site to establish the level of local background seismicity. Once flow testing has begun, well development may affect ground elevations and/or may activate growth faults, which are characteristic of the coastal region of southern Louisiana and southeastern Texas where these geopressured-geothermal wells are located. The microseismic networks are designed to detect small-scale local earthquakes indicative of such fault activation. Even after flow testing has ceased, monitoring continues to assess any microearthquake activity delayed by the time dependence of stress migration within the earth. Current monitoring shows no microseismicity in the geopressured-geothermal prospect areas before, during, or after flow testing.

INTRODUCTION

The first microseismic monitoring network around a DOE geopressured-geothermal well was established at Pleasant Bayou, Texas, in 1978. Teledyne-Geotech was contracted to perform the microseismic monitoring and tilt/subsidence surveys. For four years, DOE awarded contracts at this and other well sites to Teledyne-Geotech or Woodward-Clyde Consultants. Since 1982, DOE has awarded the seismic monitoring and subsidence surveys to the Louisiana Geological Survey (LGS) through Louisiana State University (LSU).

Microseismic monitoring establishes the nature of local seismic activity at a geopressured-geothermal well and once production has begun, determines whether well activities cause growth fault activation or induce changes in local fault movement rate. This section describes the results obtained from seismic monitoring during the 12-month period, beginning 1 January 1991 and ending 31 December 1991.

During this period three microseismic networks were in operation: Gladys McCall, Louisiana; Pleasant Bayou, Texas; and Hulin, Louisiana (figure 1). The Gladys McCall network (Cameron Parish) was on-line from the summer of 1980 through the end of 1991, at which time the network was dismantled after having operated for four years after the flow-testing cessation. The Pleasant Bayou network near Alvin, Texas, and the Hulin network, Vermilion and Iberia parishes, went on-line in October 1985. Flow testing is currently being performed at Pleasant Bayou. Flow testing has not yet been undertaken at Hulin.

REGIONAL GEOLOGY

The concern that geopressured-geothermal resource development may cause subsidence or fault activation is based partly on the geological characteristics of the Gulf Coast region, where this resource is abundantly available. The Gulf Coast geosyncline is a large linear basin, extending from northeastern Mexico to Alabama. As a result of river systems opening into the basin since the Mesozoic Era, large amounts of terrigenous clastic material from the North American continent have been deposited in this geosyncline on top of Paleozoic and Precambrian basement rocks. During the early Cretaceous Period, growth faulting initiated basinward of the shelf margin in response to these prograding sediments being deposited on unstable muds.

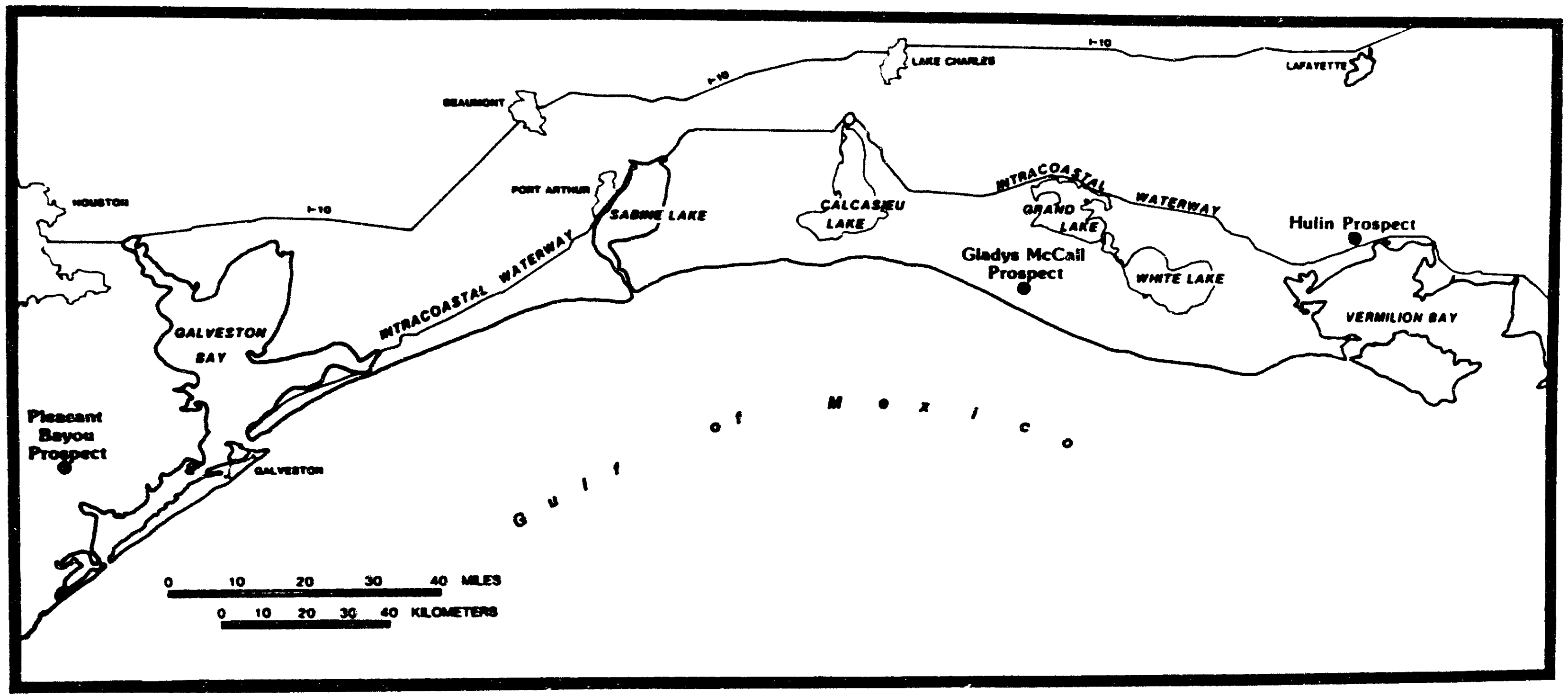


Figure 1. 1991 microseismic network locations: Louisiana and Texas.

The sedimentary stratigraphic signature of continental facies across shelf breaks consists of massive sandstones grading downward into interbedded sandstones and shales of variable thickness. This signature is typical of deep basin environments. Geopressured sediment typically occurs at the base of the thick sandstones, down into the interbedded sandstones and shales, and finally, in the deeper thick shales with thin or isolated sandstones.

To recover gas from geopressured-geothermal brines, large volumes of brine must be extracted from a geopressured zone. After gas extraction, the brine is disposed by subsurface injection at a shallower depth. A concern with this process is that such fluid extraction and reinjection may alter the subsurface pressures and allow fault movement, which would result in elevation changes at the surface and/or abnormal seismic events.

INSTRUMENTATION AND DATA ACQUISITION

The locations of the three seismic networks operated by LGS/LSU during [illegible] are shown in figure 1. Each network consisted of three of four seismographic field stations, with at least one station located within 3 km of the DOE well. Local maps of each seismic network are shown in figures 2, 3, and 4. Table 1 lists the coordinates of the field stations and well sites for each seismic network.

The seismic networks operated by LGS are designed and operated in the same manner. Data from each seismic station are transmitted via radio telemetry and phone lines to the central recording facility in Baton Rouge. Data are recorded in two formats. First, they are analog recorded on magnetic tape along with a time code synchronized with WWV and WWVB broadcasts. Second, data from at least two stations in each network are also recorded on visible paper records. From these visual and taped records, data of interest are found and transformed into digital format for easy manipulation.

Field Stations

Field stations consist of two types: geophone sites and multiplex sites. A single microseismic network has at least three geophone sites and one multiplex site. Figures 5 and 6, respectively, show schematic diagrams of a geophone site and a multiplex site.

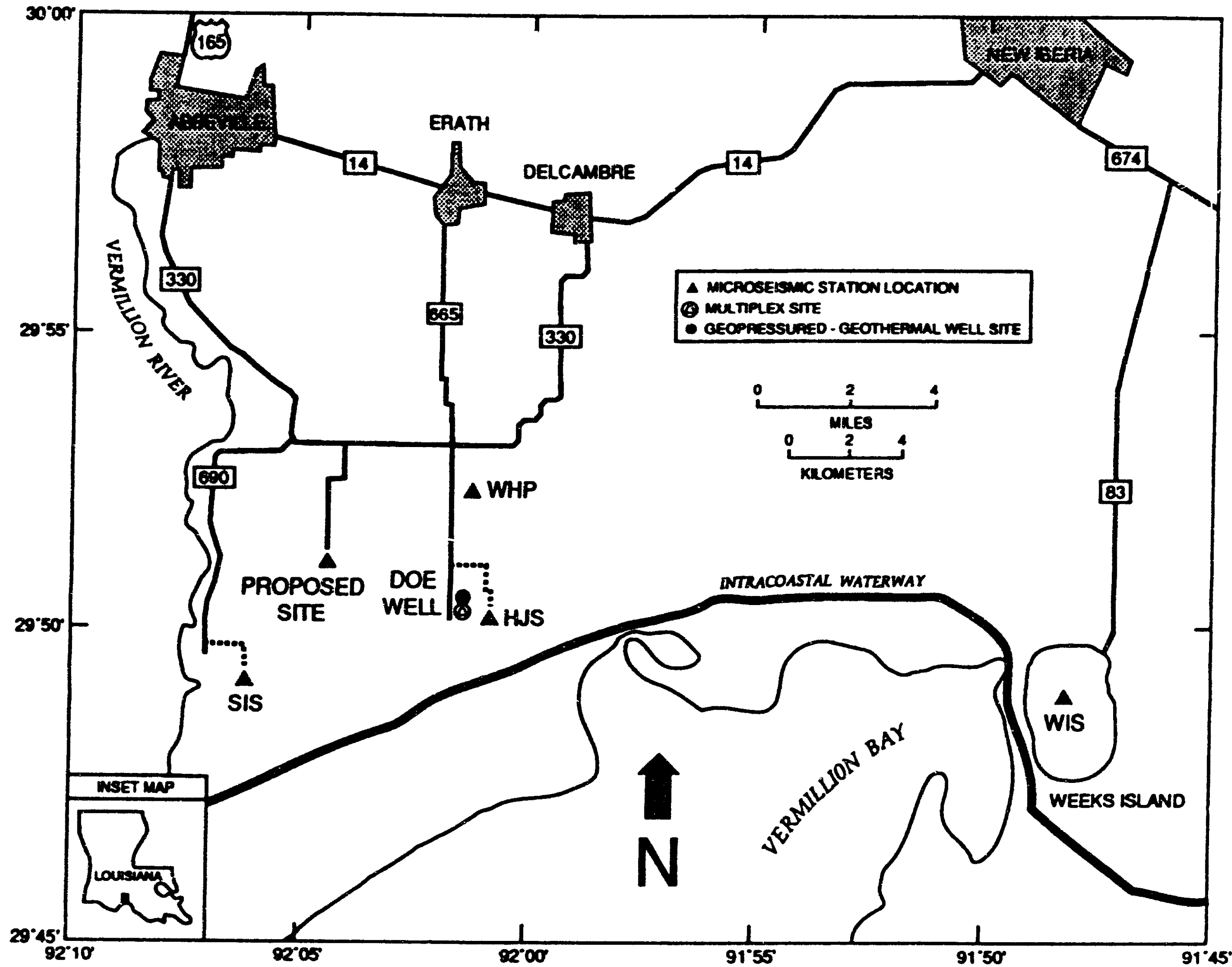


Figure 2. Map of Hulin microseismic monitoring site.

PLEASANT BAYOU MICROSEISMIC MONITORING SITE

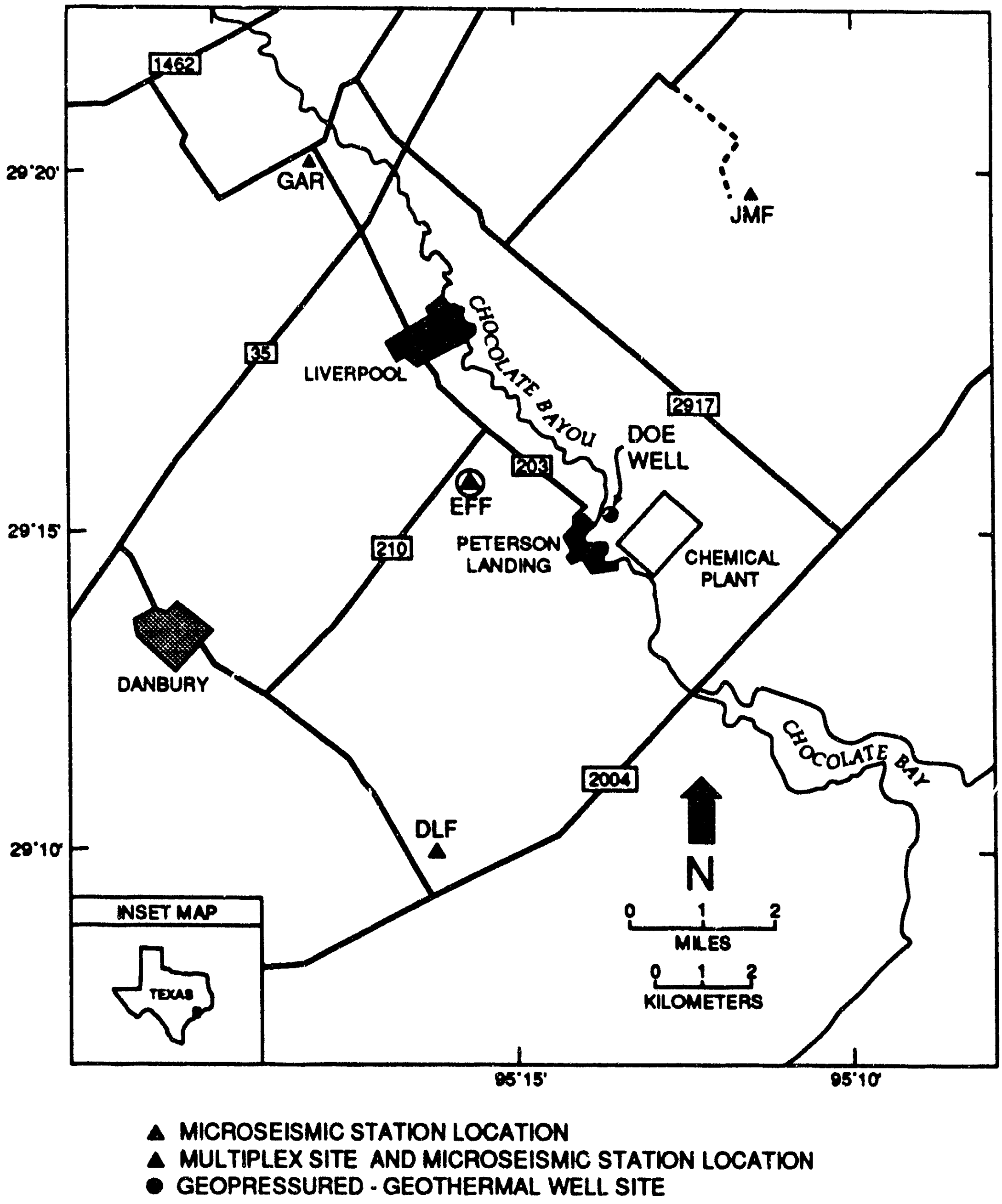


Figure 3. Map of Pleasant Bayou microseismic monitoring site.

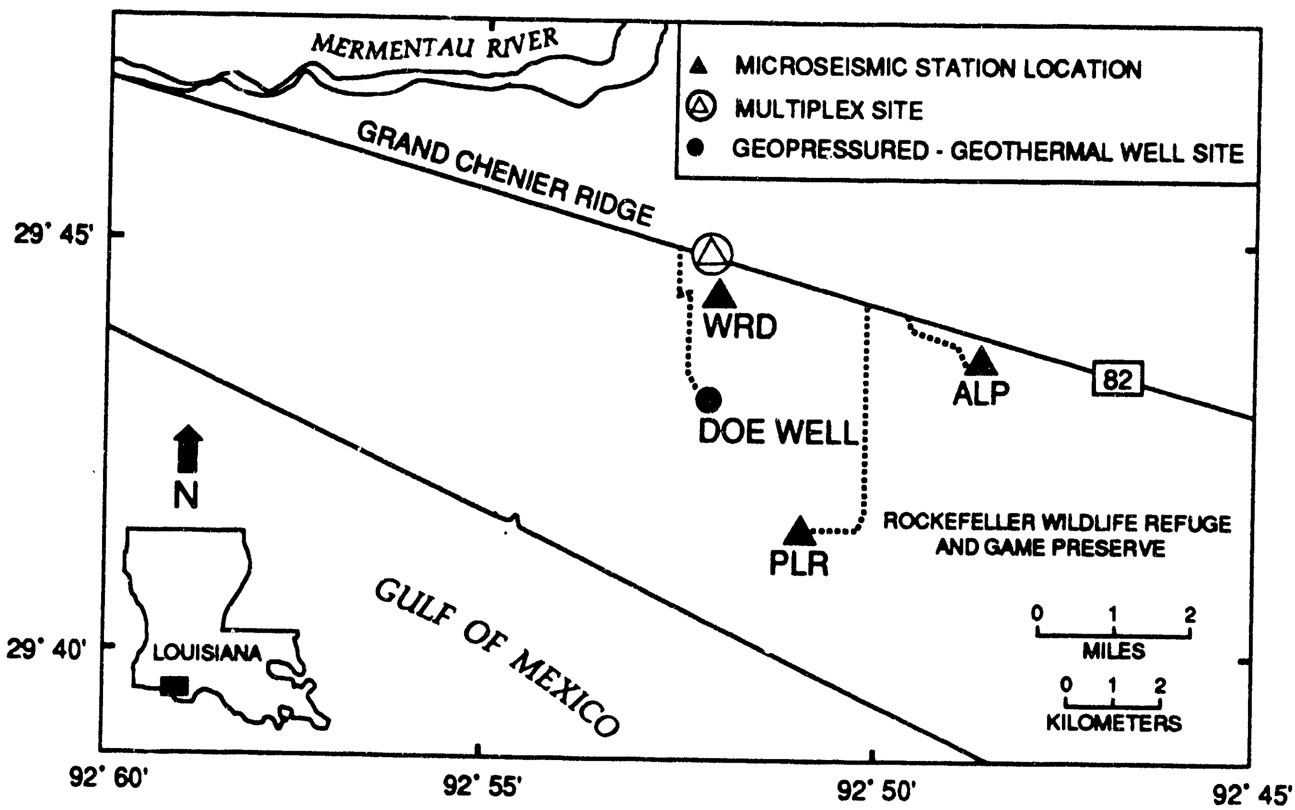


Figure 4. Map of Gladys McCall microseismic monitoring site.

Table 1. Coordinates of station and well sites for the Hulin, Gladys McCall, and Pleasant Bayou seismic monitoring networks.

Network	Site Name	North Latitude	West Longitude
Hulin			
	Well	29 51'07.4"	92 01'51.0"
	HJS	29 50'55.6"	92 01'20.1"
	WHP	29 52'20.9"	92 01'40.5"
	SIS	29 49'16.7"	92 06'08.9"
	WIS	29 48'23.4"	92 48'23.2"
Gladys McCall			
	Well	29 42'47.9"	92 52'12.0"
	PLR	29 41'14.0"	92 50'00.0"
	ALP	29 43'23.0"	92 28'32.0"
	WRD	29 43'52.4"	92 52'19.4"
	*HQS	29 44'31.0"	92 52'27.0"
Pleasant Bayou			
	Well	29 15'25.5"	92 13'48.4"
	DLF	29 10'29.4"	92 16'10.2"
	EFF	29 15'53.4"	92 16'10.2"
	GAR	29 20'13.8"	92 18'21.6"
	JMF	29 20'00.0"	92 12'06.0"

*Multiplex site only

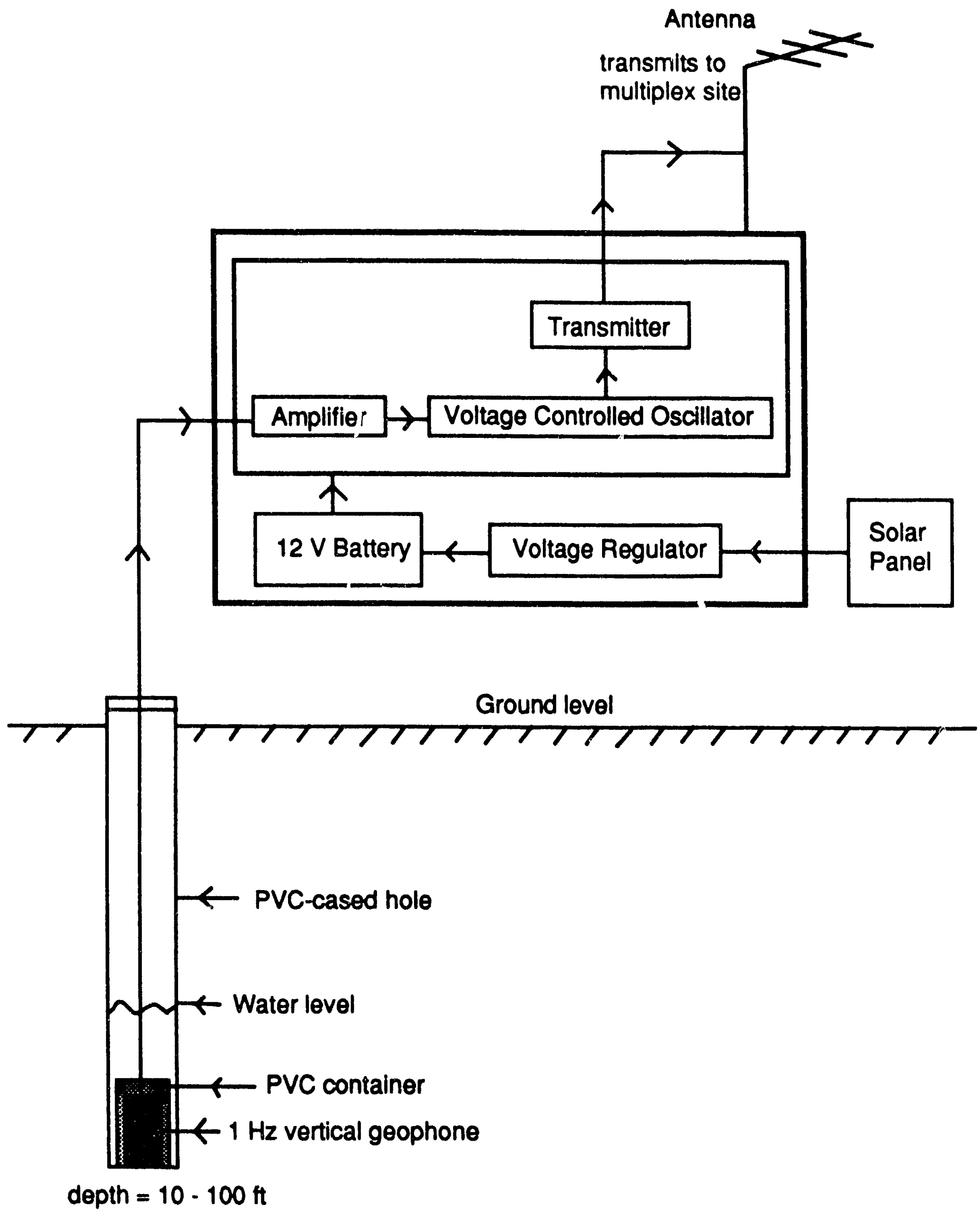


Figure 5. Schematic of seismometer field site.

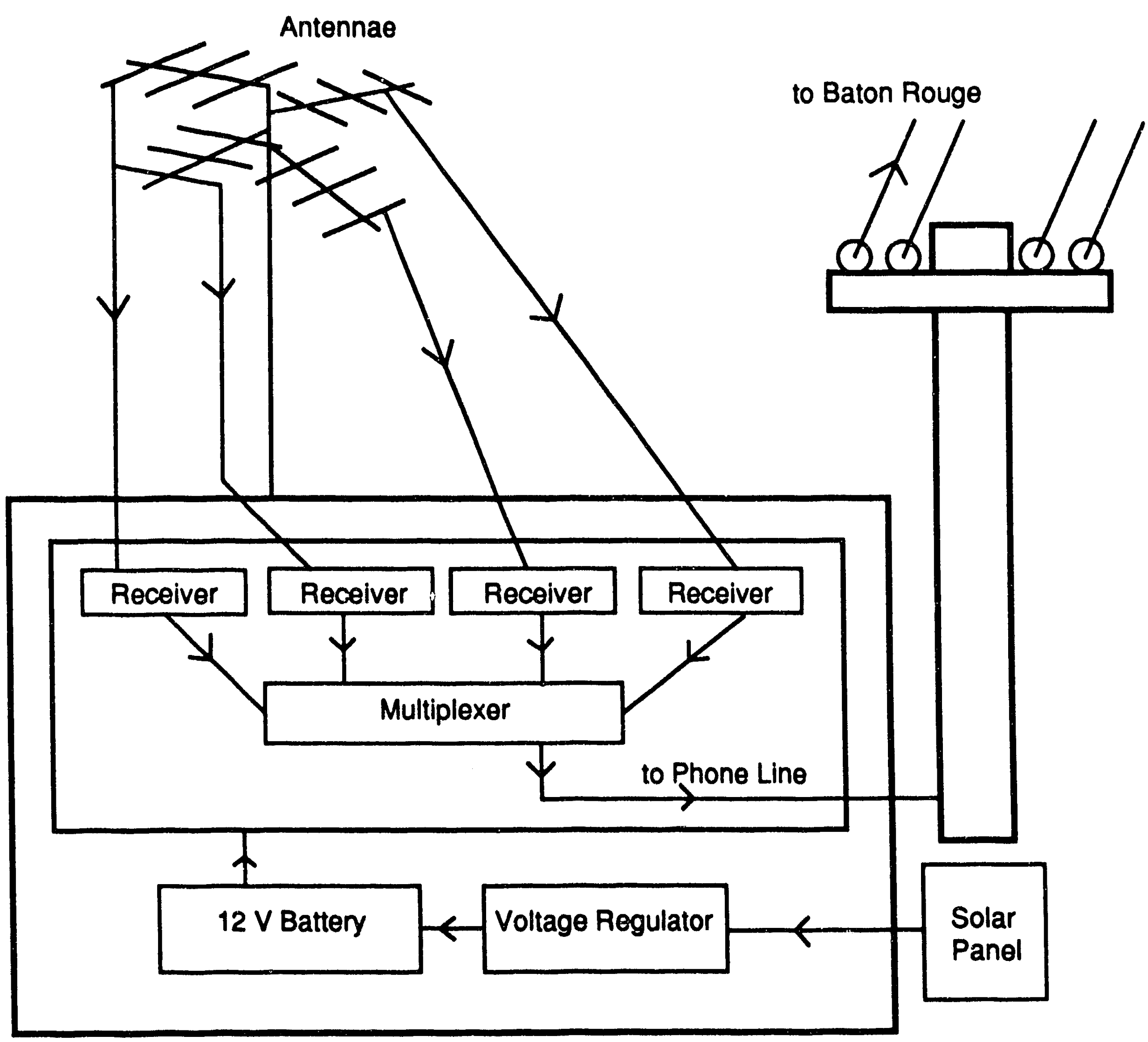


Figure 6. Schematic of multiplex site.

The seismometers, or geophones, used in this project are Mark Products L4 1-Hz borehole seismometers that record only vertical motion. Of the various seismometers with a frequency response appropriate for a microseismic network, this model is the most practical because of its small size that allows for easy deployment in 6-in.-diameter boreholes. Horizontal instruments or three-component instruments are not used for the following reasons. First, they would require larger diameter boreholes, which are difficult and expensive to drill. The second and most important consideration is that it would be difficult to emplace the instruments horizontally at the borehole base. Leveling of the horizontal seismometers is necessary in order for them to record earth motions accurately.

Borehole emplacement of the seismometers is recommended to reduce the adverse effects of surface cultural noise. The PVC-cased boreholes are typically 20 ft deep. However, the previous Hulin landowner had drilled the 100-ft well at the field station WHP prior to this project. Depths below approximately 20 ft were not achieved with the LGS drilling rig because of encounters with water-saturated, unconsolidated sediment. Because the bottoms of these wells are sometimes filled with salt water, the geophones are periodically checked for any signs of corrosion. However, the geophones have been sealed in PVC containers to prevent corrosion.

A seismometer is used to study ground motion, so the instrument must respond in a way that can be calibrated and recorded. The seismometer converts its mechanical response to ground motion into an electrical signal by means of a magnet and coil. The relative motion between the magnet and coil causes voltage across the coil's winding. Because the voltage is proportional to the velocity of the magnet relative to the coil, the seismometer actually measures the velocity of ground motion rather than the ground displacement.

The electrical signal output from the geophone is transmitted via cable to the telemetry package housed in a protective enclosure about 5 ft above ground. Alongside or on top of the enclosure are mounted one or two solar panels that charge the 12-volt marine battery. The battery is inside the protective enclosure along with a voltage regulator, a transmitter, and another box, inside of which is an amplifier and voltage-controlled oscillator.

The voltage regulator maintains a steady 12-volt charge, preventing it from overcharging and shortening the battery life span. If the battery was not charged by the solar panel, a geophone site could operate for about four days before it lost power. The seismic station can operate for about a week under continuous cloud cover because, even under such conditions, the solar panel still absorbs some light.

The first component of the telemetry package is a Teledyne-Geotech model 42.50 amplifier. It has 11 gain settings starting at 60 dB and rising to 120 dB in increments of 6 dB. The optimum gain settings for the instruments in this project are between 60 and 78 dB, depending on the site. Also built into the amplifier are high- and low-cut filters that effectively create a variable band-pass filter. Because the peak response of the geophone is at 1 Hz, the low-cut setting must be maintained at .2 Hz. This gain setting passes the frequencies that microseisms would excite in the geophone and allows the low-frequency seismic waves from teleseisms (distant earthquakes) to be detected. The high cut on our instruments is set at 25 Hz. At any higher frequency, noise would dominate the signal and potentially hide true seismic events.

The signal, as it is output from the seismometer and amplifier, is simply in the form of varying amounts of voltage. After the amplifier has boosted the voltage output from the seismometer, the signal is passed to the voltage controlled oscillator (VCO), Teledyne-Geotech model 46.22. At this stage, the signal is transformed to be transmitted as a frequency-modulated (FM) signal via radio and voice-grade telephone lines. To achieve this transformation, the VCO changes the signal from varying voltages to varying frequencies superimposed on a stable carrier frequency. For example, if the ground moves, the seismometer will respond with an output voltage that will be amplified and sent to the VCO. The VCO output will be a frequency slightly different from the carrier frequency. Deviation from the carrier depends on the amount of voltage input to the VCO. Each VCO has a specific carrier frequency, which allows all the signals to transmit simultaneously without interference. The frequencies specified for the VCO's are 680 Hz, 1,020 Hz, 1,360 Hz, 1,700 Hz, 2,040 Hz, 2,380 Hz, 2,720 Hz, and 3,060 Hz.

The outgoing VCO signal must be transmitted to the central site via radio using a very-high-frequency (VHF) FM transmitter, Monitron model TR210. At the multiplex site are several antennae and a series of

Monitron model R21F receivers, one for each remote geophone site (figure 6).

A multiplex site is powered by a solar panel, voltage regulator, and a 12-volt marine battery. The site combines all the FM radio signals created by the VCO's and sends them through the telephone lines using a Teledyne-Geotech model 46.31 multiplexer. This transmission method of data to Baton Rouge results in high, long-distance telephone costs but is still more economical than transmission via satellite and more efficient than radio links spanning the hundreds of miles over which the data must be transmitted. Unfortunately, when telephone lines are out of service, data transmission cannot be completed.

Central Recording Facility

The central recording facility in Baton Rouge receives the seismic data through telephone lines and records in two ways: 1) tape recording onto ½-in. analog magnetic tape and 2) visibly tracing onto long sheets of paper, 38 in. long by 12 in. high (figure 7). Both methods of recording are directly linked to a Kinemetrics model TF3 timing system, which provides a time code synchronized with the time broadcast by radio stations WWV and WWVB. The National Bureau of Standards provides this broadcasted information as the recognized standard for time.

The seismic data received over the telephone line are FM signals that record real time on a ½-in. analog magnetic tape. A single tape can record continuously for 48 hours. Each network has an assigned track for recording its multiplexed data. The time code is recorded on another track.

FM signals received over telephone lines must be converted into a form representative of the seismic motion before the seismic data can be recorded on paper. Signal discriminators demodulate FM signals. Each phone line into the central recording facility is transmitting data from four geophone sites, each with a carrier frequency. The discriminators decipher information from the carrier frequencies of their designated VCO's in the field. Each VCO is matched to a discriminator at the Baton Rouge facility where the original seismic signal is decoded from that VCO's carrier frequency.

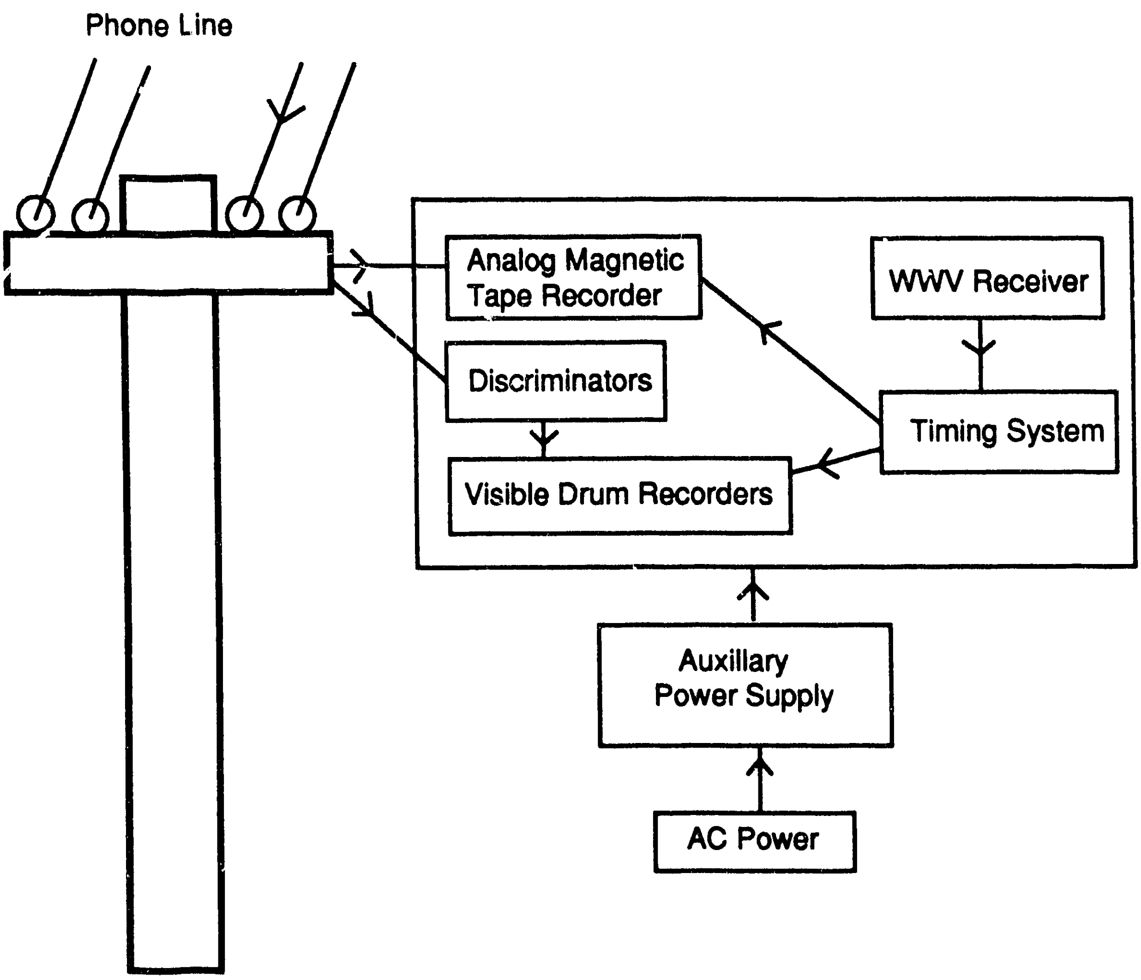


Figure 7. Schematic of central recording facility.

The signal is then sent to the helicorder, which places data in a visual format. Paper is wrapped around a drum that rotates continuously, each rotation being 15 minutes. A heated stylus traces the seismic signal from a geophone onto heat-sensitive paper. Each sheet of paper represents one day of data. At least two stations per network are recorded visually.

Visual and tape-recorded formats of data are necessary to digitize data. Any seismic activity recorded by the networks is first identified during the daily visual review of the paper records. If interesting activity is detected, data from certain stations and a specific time window can be retrieved.

DATA PRESENTATION AND ANALYSIS

The ground motion detected by a seismometer may have several types of sources. Sources are generally considered noise or true seismic events, i.e., earthquakes. The ratio of term signal to noise relates how much energy in the data is from noise sources compared to how much energy in the data is from true seismic events. Noise for one study may be considered data for another, depending on the focus of the project.

Seismic networks in this project monitor microearthquakes, so anything that is not a local microearthquake could be considered noise. However, we maintain records of any teleseism detected and other seismic signals from uncertain sources. We review paper records daily and study seismic signal character such as frequency content and duration. From this we determine whether the signals are noise or potential data.

Background Noise

Seismic noise can be categorized as either cultural or natural. Natural noise is associated with bad weather, including the effects of barometric changes and intense oceanic wave action that triggers oceanic microseisms. When storms are in the Gulf of Mexico or near a seismic network, most of the seismic records will be overwhelmed by continuous noise for a two to three second period (figures 8, 10b). Although this period can be filtered out in the analyzing process, such noise makes identifying any small, legitimate natural event difficult when initially reading records.

Typical sources of cultural noise are traffic, pumps, well activities, blasting, explosions, and sonic booms. Traffic noise is easily distinguished from natural events because its characteristics are not indicative of an earthquake. When a car, truck, or train is passing, the vibration amplitude slowly increases until after the vehicle has passed and then gradually decreases (figure 8). Earthquakes, on the other hand, show a sharp initial pulse rather than a gradual energy buildup. Pump noise is continuous and maintains constant frequency content. Seismic readings from blasting together with geophysical prospecting appear similar to small earthquakes. Blasting regularity, usually during daylight working hours, and identical seismic signatures from each blast indicate cultural origin (figure 9).

Gas or chemical explosions arrive impulsively at the seismometers as would an earthquake (figure 10). Because these blasts are usually directed upward, seisometers mainly detect vibrations from blast energy that is coupled to the ground from the atmosphere and only slightly from energy that travelled through the earth.

Teleseismic Events

Earthquakes occur somewhere in the world everyday. The seismic networks at the geopressured-geothermal wells in Louisiana and Texas sometimes record these teleseisms, or distant earthquakes (figure 11). During 1991, the network detected 64 teleseisms and one nuclear test (appendix A). The Pleasant Bayou and Hulin networks recorded teleseisms, mostly from Central America, a few times per month. Because the Gladys McCall network is located directly on the Louisiana coast, it did not detect as many Central American teleseisms. The smallest teleseism detected at any station was a magnitude 4.6 event located off the coast of Nicaragua. Only the Pleasant Bayou network detected the event. Later in the year, only the Hulin network detected a Nicaraguan earthquake of magnitude 4.7. Besides Central American earthquakes, events in South America, Indonesia, Alaska, and California are commonly seen on the seismic records of the three networks.

Local Events

The geopressured-geothermal seismic networks were established to monitor microseismic activity in the well vicinity, so local seismic activity is the real interest of this project. Seismic signals of local or regional origin are divided into two types: type I, body-wave events; and type II, surface-wave events.

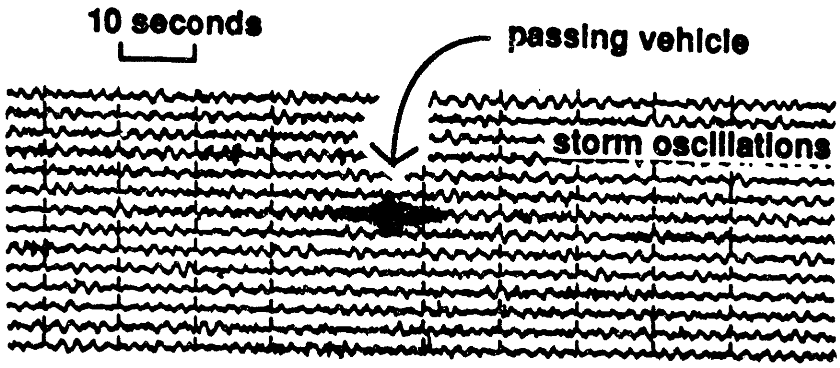


Figure 8. Example of noise because of atmospheric disturbance (storm) and a typical seismic signature of a passing vehicle.

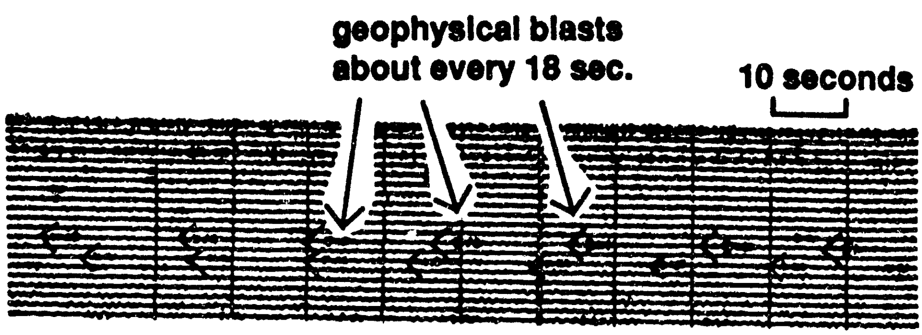
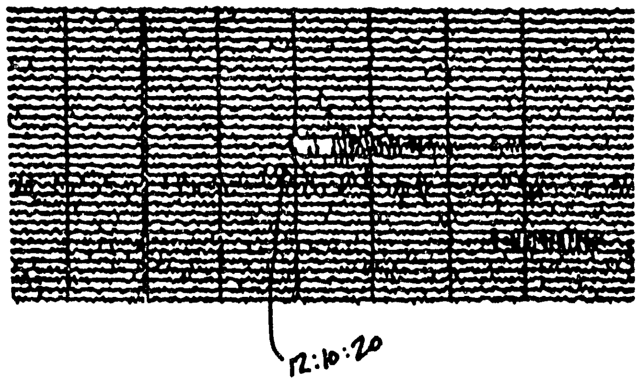
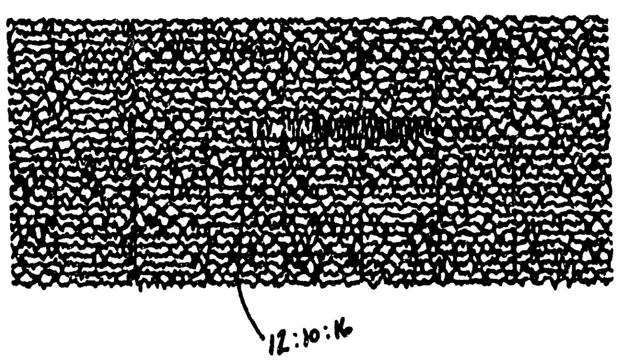


Figure 9. Example of seismic record with geophysical blasting. Each mark indicates a blast to the right.



a) station HJS



b) station WHP

Figure 10. Examples of impulsive seismic trace from a plastics plant explosion on 14 December 1991, recorded by Hulin network. White section due to pen moving so fast it did not mark paper. Note slow travel time: 4 seconds between stations only 2.75 km (1.7 mi) apart. Lower record from station WHP shows effects of approaching storm.

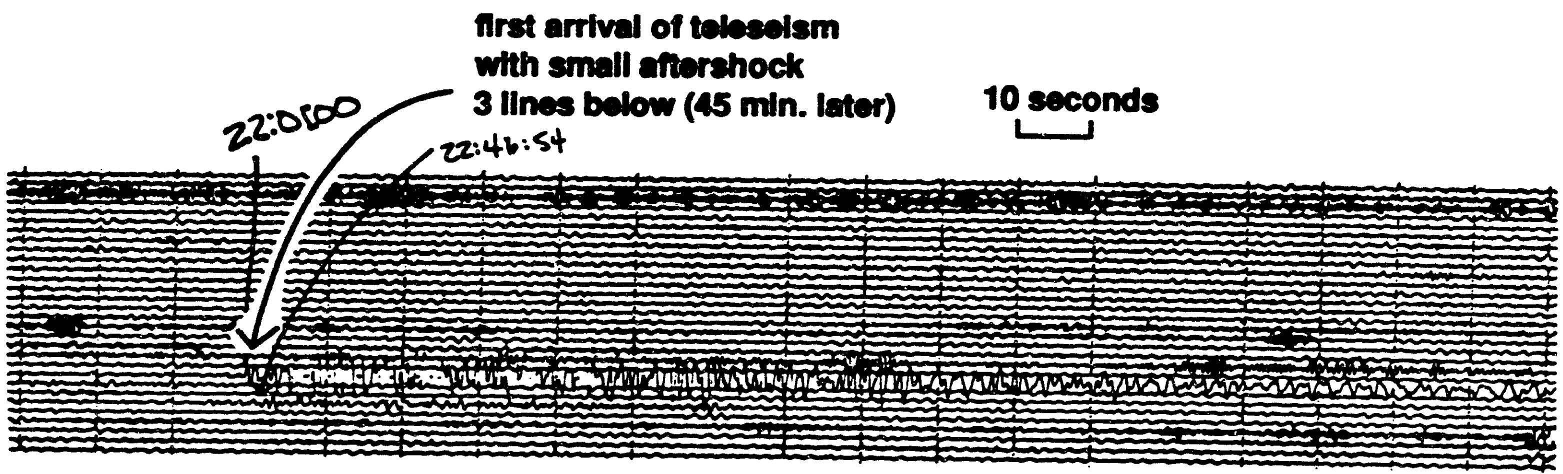


Figure 11. Example of teleseism, a magnitude 7.6 earthquake from Costa Rica on 22 April 1991.

Type I events are classified as microearthquakes and typically are characterized by a P-wave arrival (primary compressional/dilational, S-wave arrival (secondary, shear waves), and in some instances, a surface-wave arrival. Type I events display P-wave velocities ranging from 1.5 to 6.0 km/s (5,000 to 20,000 ft/s) and contain seismic signals typical of microearthquakes reported throughout the world. No local type I events have been noted during the last two reporting periods. Such events are known to occur, however, as demonstrated by the 16 October 1983 Lake Charles earthquake and its aftershocks.

Type II events continue to be recorded by all networks as in past reporting periods (appendix B). These surface-wave signals have impulsive and emergent first arrivals (figures 10a, b, and 12). Except for signals associated with known explosions, the origin of these events is still somewhat of a mystery, especially those with emergent arrivals. The most viable explanations for these type II events are that they are either leaking energy from microearthquakes within a near-surface, low-velocity layer (Ebinero et al. 1983) or acoustical transmissions travelling through the air (e.g., thunder, sonic booms, explosions) (Louisiana Geological Survey 1991). Both origin scenarios are relevant because they would produce waves that have similar velocities of .35 to .76 km/sec (1,150 to 2,495 ft/sec) and similar frequency contents.

DISCUSSION

During 1991, microseismic monitoring networks operated around three geopressured-geothermal prospects in Louisiana and Texas. The three stages of the seismic monitoring program were represented: 1) determination of the level of background seismicity prior to flow testing, 2) monitoring concurrent with flow testing, and 3) post-test monitoring of any residual response to flow testing.

At the Gladys McCall site, the well has been flow tested and has been shut in since October 1987. This post-testing phase of monitoring has shown no signs of local microseismic activity induced by the previous well activity. The number of type II events recorded by this network has diminished over the past year. This decrease does not signify a correlation between such events and well activity because the origin of these type II events is still uncertain. The Gladys McCall seismic network was dismantled in December 1991.

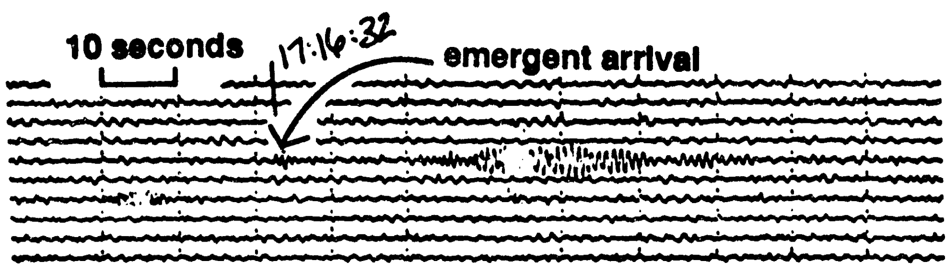


Figure 12. Example of emergent type II sonic event.

The pre-test monitoring phase at the Hulin prospect is ongoing to establish the level of local background seismicity. It seems that type II sonic events are not induced by flow testing because such events are recorded a few times a month by this network where flow testing has not begun yet.

At the Pleasant Bayou site, where flow testing is currently underway, the possibility of induced seismicity seems greatest. Extreme care is given to the daily data scan for any type I microseisms indicative of fault movement and for any abnormal pressure changes at the wellhead. Such pressure changes may indicate subsurface shifts caused by changes in pore pressure or fluid volume. After careful scrutiny of the seismic records, no local microseismic activity above the background noise was detected in 1991, except the type II events.

CONCLUSIONS

Microseismic monitoring at several DOE geopressured-geothermal prospects in Louisiana and Texas has continued since 1978. During this time, the characteristic seismic signals and teleseism recordings of this region have been noted. Two main signals are reported from networks: the type I, body-wave events, and type II, surface-wave events. No type I events were detected in any of the networks during 1991. Type II events continue to be recorded on all networks and travel very slowly, less than 1 km/sec. These events are of unknown origin and have been further subdivided into impulsive and emergent events. Some impulsive type II events are attributed to surface explosions; other impulsive events may have resulted from such industrial sources. Type II events' origins remain uncertain, especially emergent events; they are probably unrelated to geopressured-geothermal well activities.

Current monitoring networks show no induced microseismicity from activity at a single pair of production and disposal wells. The situation may be different, however, if an entire field of geopressured-geothermal wells were developed. The situation at the Pleasant Bayou network is somewhat different in that the neighboring Monsanto Chemical plant has a couple of disposal wells discharging into a similar depth range as the DOE disposal well. The volume of fluid disposed by these few extra wells does not approach the volume that one geopressured-geothermal well would dispose. Thus, it is difficult to make predictions about subsurface movements that could potentially result from large-scale, geopressured-geothermal development.

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SUBSIDENCE MONITORING

by

Dianne Lindstedt

INTRODUCTION

Subsidence monitoring around the Hulin geopressured-geothermal well site continued during the current reporting period (1 January 1991 to 31 December 1991). The subsidence monitoring portion of the study was designed to determine subsidence rates around the test well sites and to compare them with regional rates of subsidence to assess the effects of high-volume fluid withdrawal. This report presents the most recent results in this ongoing study.

Extraction of large quantities of underground fluids can affect surface elevation if enough fluid has been removed from the area. The resulting compaction in a reservoir can be detected as vertical movement on the surface. Potential fault reactivation and vertical movement through compaction over time are basic types of ground movement associated with subsurface subsidence caused by fluid withdrawal. For example, numerous international studies on groundwater and oil and gas extraction sites indicate that surface subsidence can range from 1 mm to 300 mm/yr because of fluid withdrawal (Emery and Aubrey 1991).

Some studies show that fluid withdrawal from oil and gas reservoirs appears to have localized influence on subsidence and can be as much as 130 cm above the reservoirs (Suhayda 1988). For example, near Golden Meadow field in Louisiana the water level rises twice the rate of the nearby gages (Turner 1988).

Though subsurface compaction has been shown to occur due to fluid removal geological and ecological processes in south Louisiana are also at work, which complicates our present study. Louisiana's coastal wetlands are eroding at a rate of about 31mi^2/yr (Dunbar et al. 1990) primarily because of subsidence, compaction of deltaic sediment, sea level rise, and human activities (Boesch et al. 1983, Dunbar et al. 1990, Britsch and Kemp 1990).

Because the geopressured-geothermal wells in this study are located in areas where land loss rates are high, local subsidence becomes more critical because rate increases due to additional activities may exacerbate wetland loss in localized areas. Continuous monitoring of bench marks around the well site will enable detection of vertical movement of the surface in the immediate area.

PREVIOUS STUDIES

Tide gage data indicate that subsidence ranges from 10 to 20 mm/yr in Louisiana (Suhayda 1988, Ramsey and Penland 1989), and sediment accumulates approximately 5 mm/yr (Suhayda 1988). Also, subsidence rates are lower in the chenier plain (from 6.3 to 6.95 mm/yr) than in the delta plain (from 8.0 to 13.3 mm/yr). With sea level rise about 2.3 mm/yr in the Gulf, subsidence rates are estimated to be from 5.3 to 10.9 mm/yr (Suhayda 1988, Ramsey and Penland 1989). Using tide gage data with leveling data, Holdahl (1973) determined subsidence rates ranging from 5 to 10 mm/yr in southwestern Louisiana. Figure 1 depicts regional subsidence rates for the Gulf Coast area, with southwestern Louisiana exhibiting rates from 4 to 5 mm/yr (Holdahl and Morrison 1974). Anomalously high subsidence (>5 mm/yr) rates occur around Houston, Texas, which is near the Pleasant Bayou site.

Turner (1988) found the highest rates of water level rise where sedimentation rates are the highest and where waterway construction and water management practices were the most intense. Conversely, the lowest rates occurred where the depth to the Pleistocene terrace was the shallowest and where sedimentation rates were the lowest.

Several factors cause subsidence in south Louisiana: compaction of deltaic sediment, river diversion, sediment deprivation, groundwater withdrawal, hydrocarbon extraction and other petroleum-related activities, coastal development, and human impact. The extent of which each is a contributing factor currently is not quantified, and it may vary among different geographical sections of the state such as river basins or hydrologic units, where geological factors such as faulting, geomorphology, Pleistocene depth, sediment age, and hydrologic setting may vary considerably.

Some documentation of subsidence has been attempted and quantified in south Louisiana. For example, Davis and Rollo (1969) documented subsidence due to groundwater extraction in Baton Rouge. Saucier (1963) calculated an annual subsidence rate of 1.2 mm based on radiocarbon dating in the New Orleans area. Drainage and landfilling there has caused consolidation of drained peat and underlying clays, secondary compression of peat and clay, and oxidation of the drained peat in the New Orleans area. Using data recorded

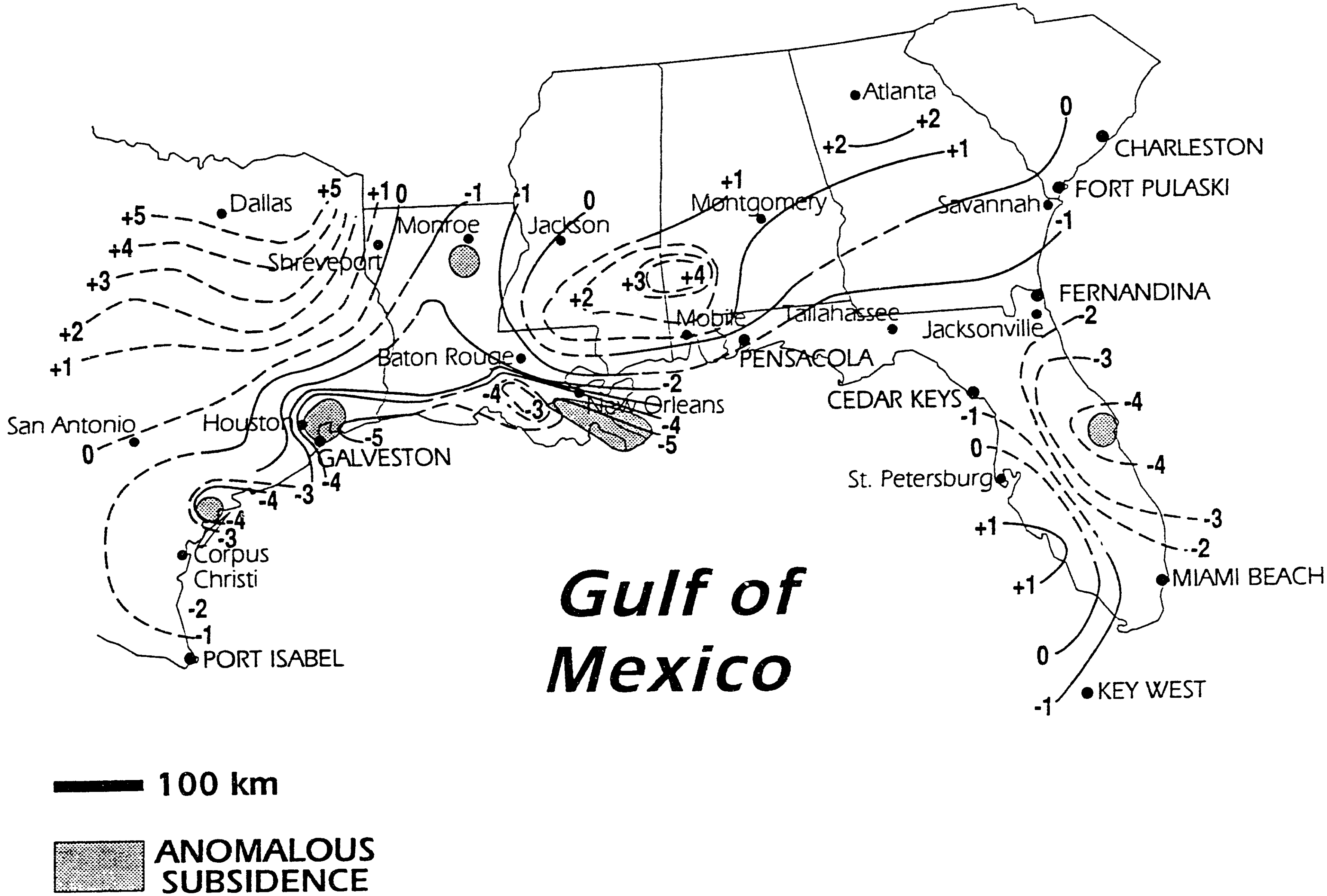

Figure 1. Contour map showing rates of elevation change in mm/yr in the northern Gulf of Mexico (Holdahl and Morrison 1974).

since the 1930s, tide gage stations at Eugene Island and Bayou Rigaud, Emery and Aubrey (1991) have reported subsidence rates from 9.6 to 10.5 mm/yr. The data also indicate an increase in subsidence rate since the 1960s. Studies in Louisiana have shown that land loss occurs at a rate of 30 to 40 mi^2/yr. (Dunbar et al. 1990, Gagliano 1981). Dunbar et al. (1990) and Britsch and Kemp (1990) acknowledge an increase in land loss rates during the 1970s; however, data that incorporates the early 1980s indicate the rate of loss is decreasing.

Because subsidence and land loss are interdependent and important in Louisiana, the test well sites for this study are located on the more stable chenier plain, where subsidence and related coastal erosion rates are lower than the delta plain. The Hulin site is located in a transition zone of the northwestern edge of the oldest delta lobe (the Maringuoin), where Holocene sediment thickness is about 0-5 ft (Fisk 1948). Pleistocene outcropping begins in this area. In contrast, the Gladys McCall site lies on 15-30 ft of Holocene deposits (Fisk 1948).

STUDY SITES

There are three geopressured-geothermal sites in the study: Gladys McCall and Hulin in southwestern Louisiana and Pleasant Bayou in southeastern Texas. These sites are in various stages of development.

Gladys McCall

The Gladys McCall test well site is located near the western edge of the Rockefeller Wildlife Refuge in Cameron Parish, Louisiana (figure 2). A benchmark monitoring network was established at this well site in September 1981 before testing began. During the course of this project, several monuments in the network have been installed (figure 3). The monuments were installed according to National Geodetic Survey (NGS) specifications for first-order leveling surveys and tied into the NGS network.

The Gladys McCall site is located on relatively stable but thin Holocene sediment and on the chenier plain, which was formed indirectly from deposits of the Mississippi River. Holocene sediment here is approximately 15-30 ft thick (4.5-6 m) (Fisk 1948).

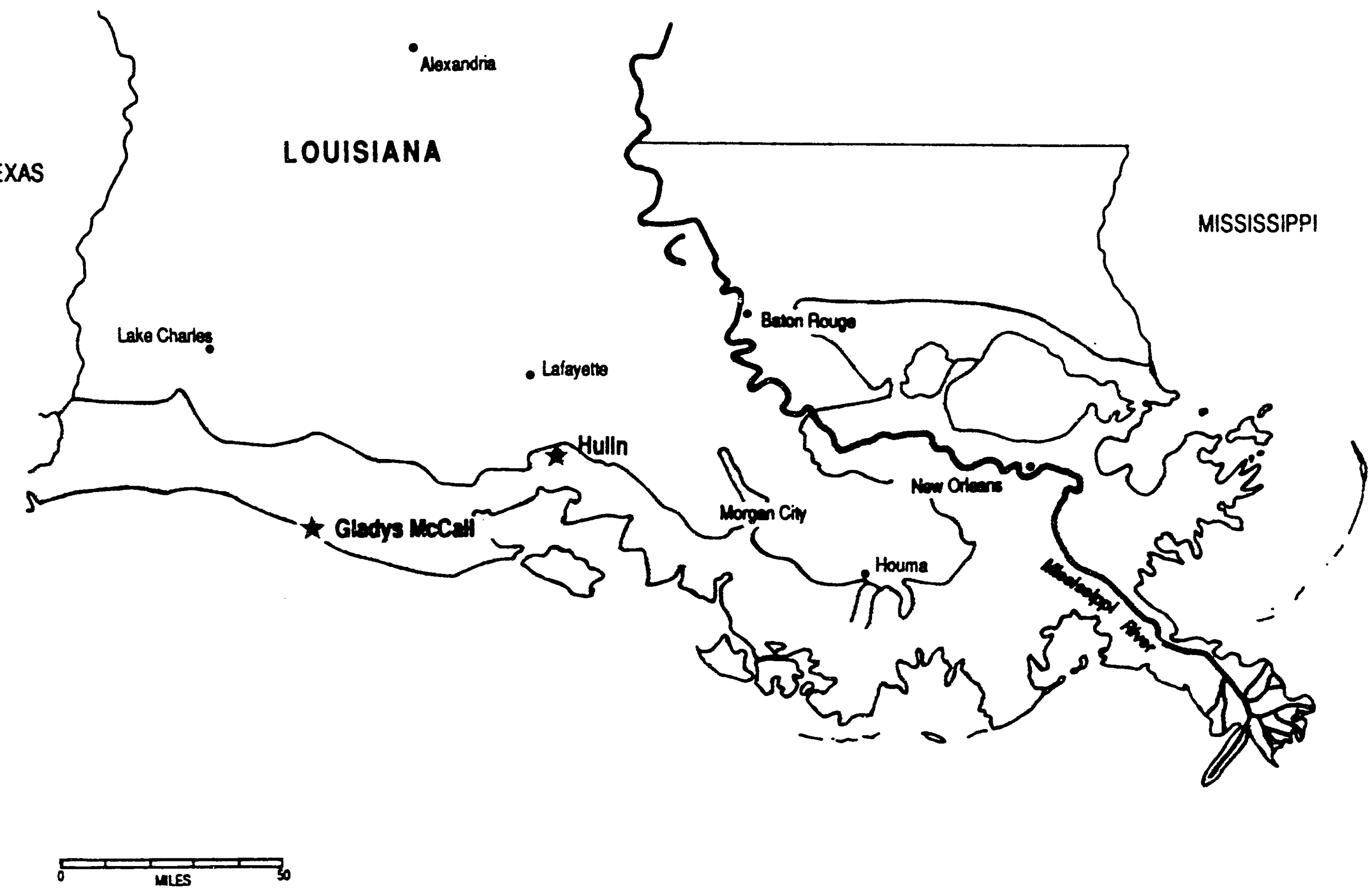

Figure 2. Locations of geopressured-geothermal wells in Louisiana. The shaded area depicts Louisiana's coastal zone boundary.

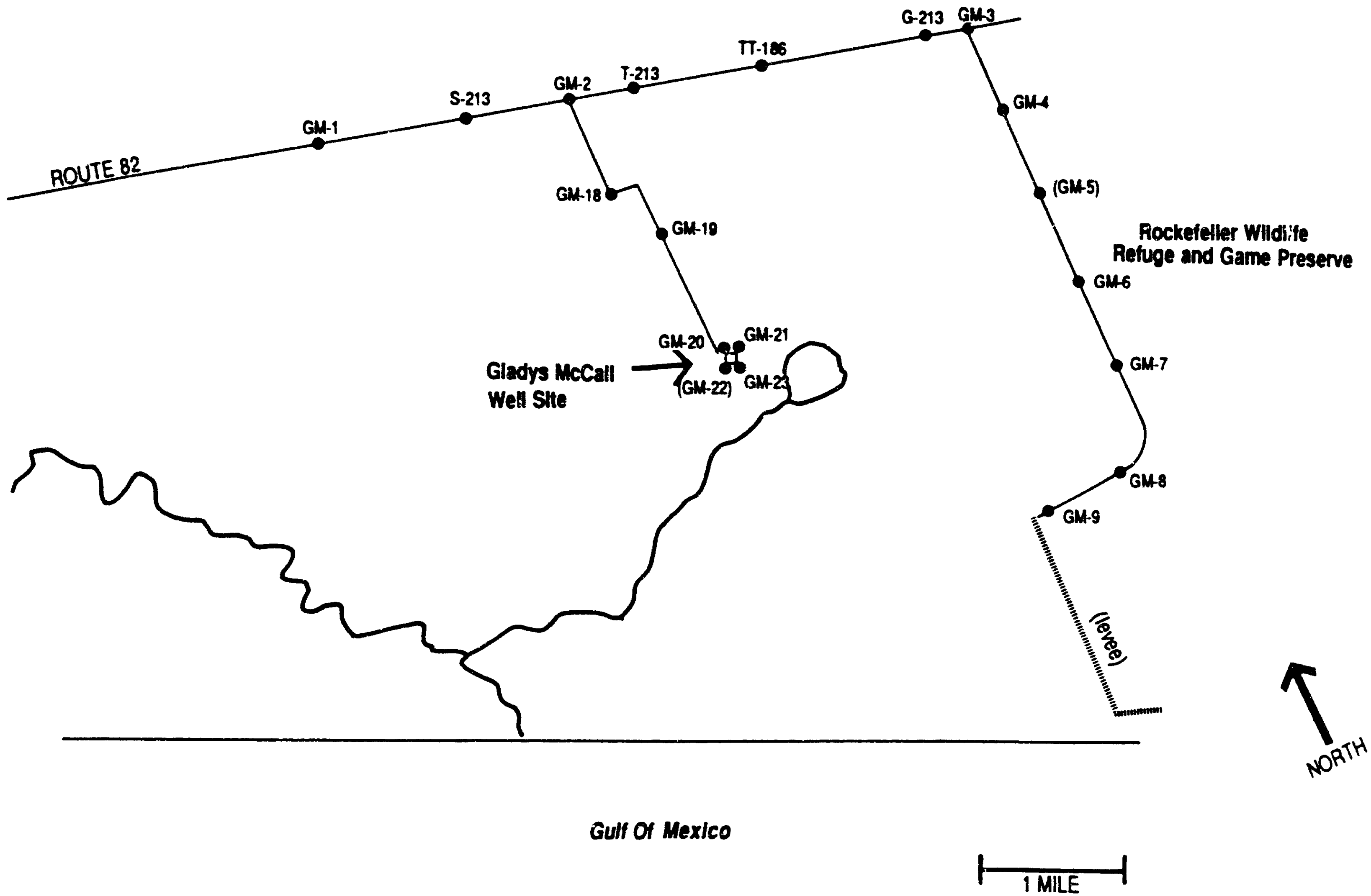

Figure 3. Location of Gladys McCall geopressured-geothermal well-monitoring network.

Pleasant Bayou

The Pleasant Bayou study area is located in Brazoria County, Texas. Chocolate Bayou merges into Pleasant Bayou just north of the test well site (figure 4). Twelve, class B monuments were established in this area in June 1984 (figure 4). The monuments also were installed according to NGS specifications for first-order leveling surveys and tied into the NGS network.

Hulin

The Hulin test well is located in Vermilion Parish, Louisiana, and is approximately six miles south of Erath, Louisiana (figures 2, 5). The well itself is located just south of the Louisiana coastal zone boundary on a very thin veneer of older Holocene sediment, where surface exposure of Pleistocene prairie can occur in the periphery of the Maringouin delta lobe. The older sediment is relatively more stable than younger deltaic sediment and should have lower subsidence rates than those on the delta plain mainly because of age (they have had more time to compact) and thickness (they are thinner than the delta-plain sediment). These sediments were deposited approximately 7,000 years ago during the formation of the Maringouin delta complex. This sediment is thin (0-5 ft or 0-2 m) (Fisk 1948) compared to the southeastern coastal region in Louisiana, where Holocene sediment is between 100 and 900 ft (30-275 m) thick (Kolb and Van Lopik 1958).

The well site is bound by leveed and drained agricultural/pasture land with freshwater wetlands within the area. Historical vegetation maps generated by the Technical Services section of the Coastal Management Division in Louisiana's Department of Natural Resources indicate the area was all freshwater marsh during the 1950s (figure 6). However, between 1956 and 1978 the area was drained and converted to agricultural/pasture land (figure 7). For the area shown in figures 6 and 7, virtually all of the fresh marsh in the immediate area has been lost agricultural and pasture development.

While long-term testing of fluid withdrawal at this site has not commenced, a short-term flow test was conducted from December 1989 to January 1990, which was during the interval between our leveling surveys.

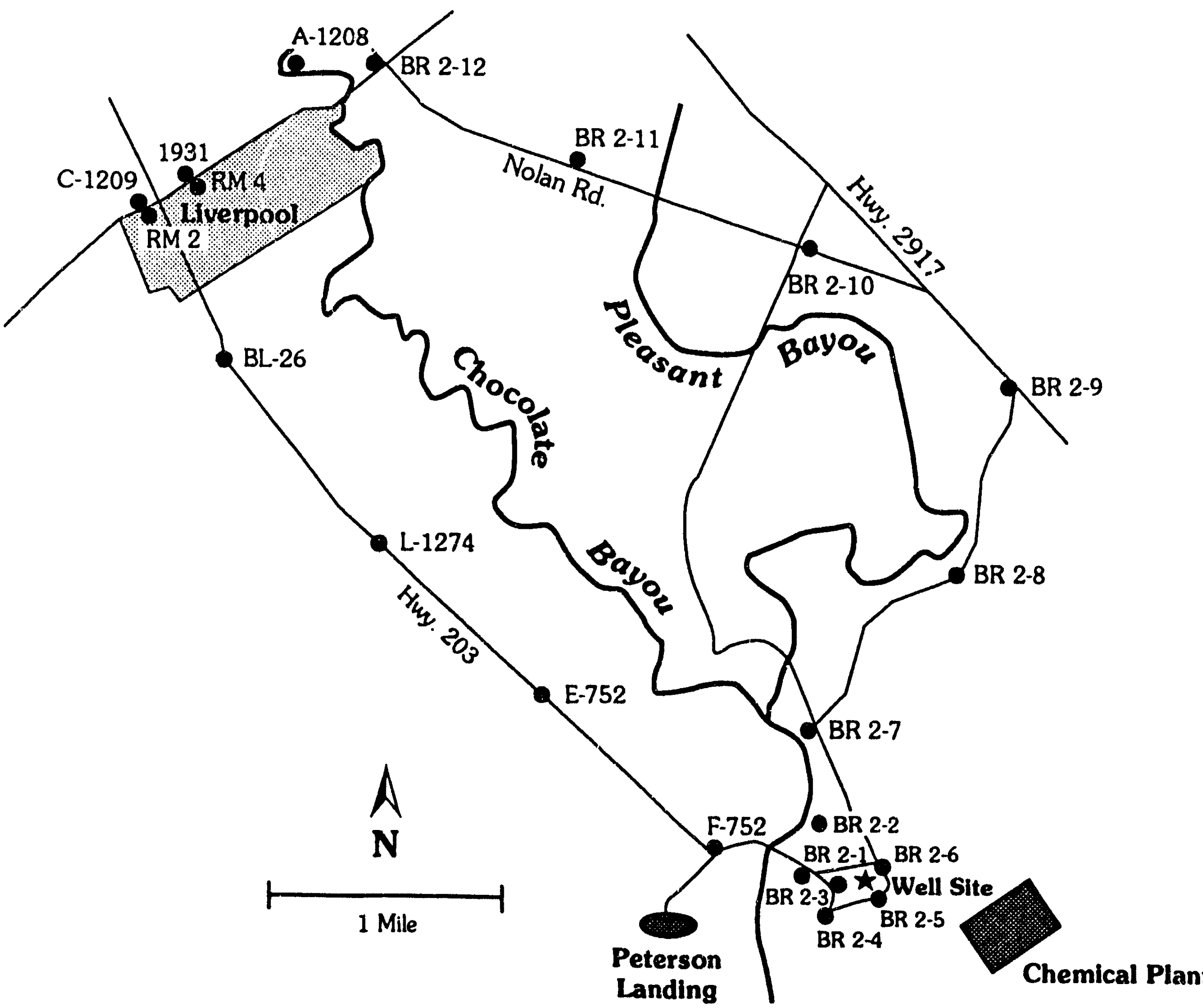

Figure 4. Location of Pleasant Bayou geopressured-geothermal well with benchmark locations.

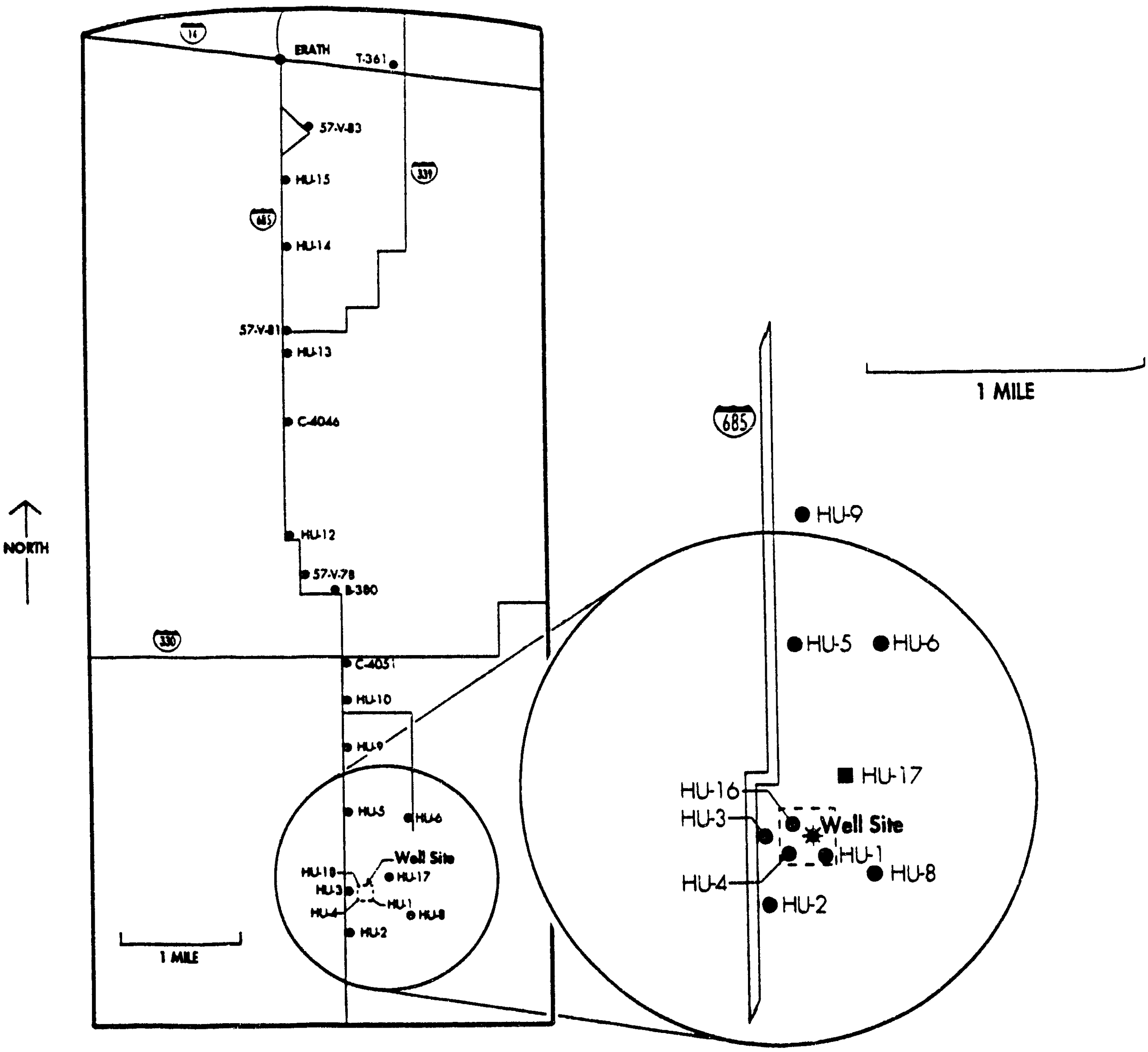

Figure 5. Location of Hulin geopressured-geothermal well with benchmark locations.

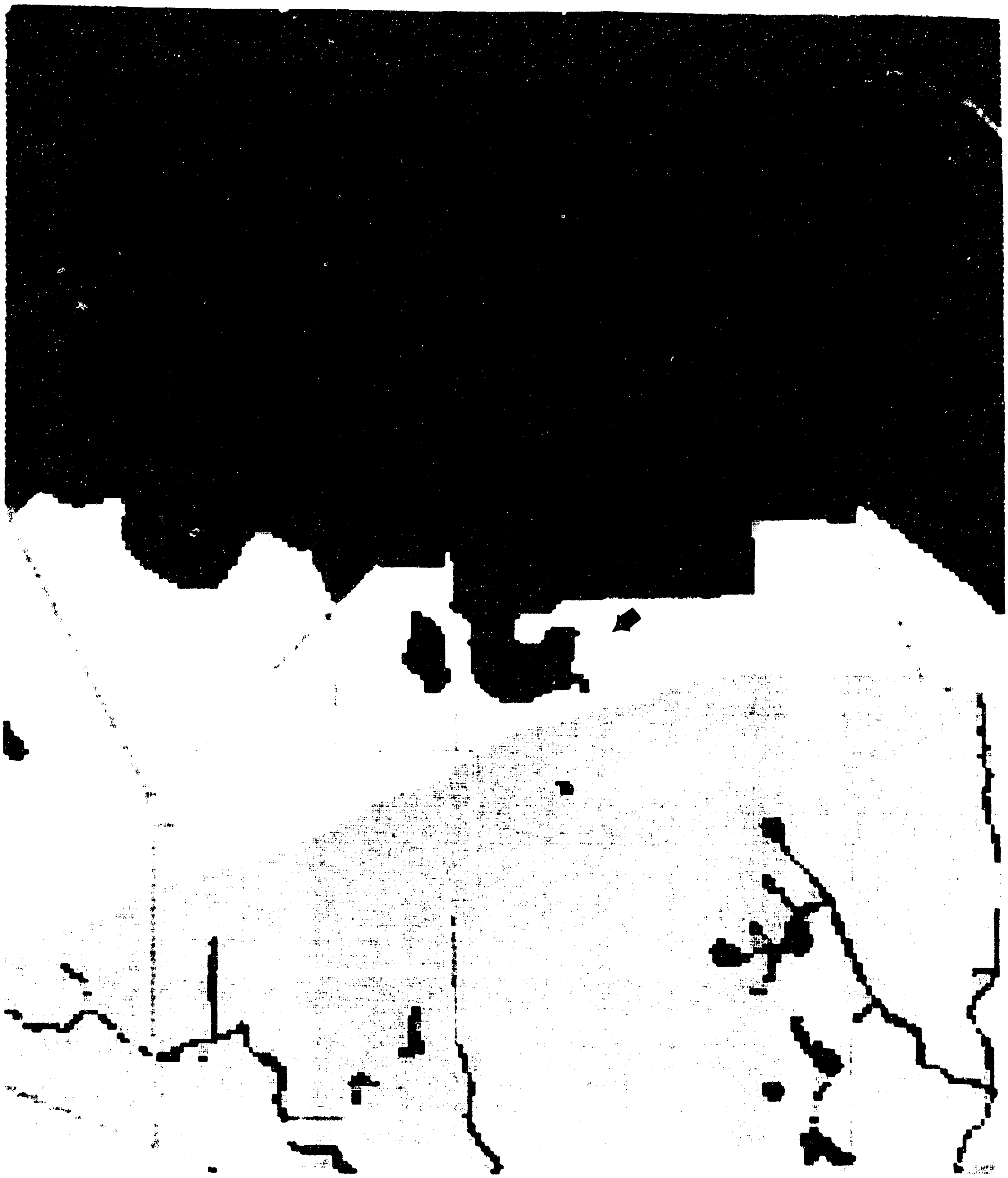

Figure 6. Habitat map of the Hulin site, 1956 (Technical Services Section, Coastal Management Division). Arrow indicates wellhead.

KEY

— Natural water

— Artificial water

— Fresh marsh

— Non-fresh marsh

— Forest

— Agricultural/pasture

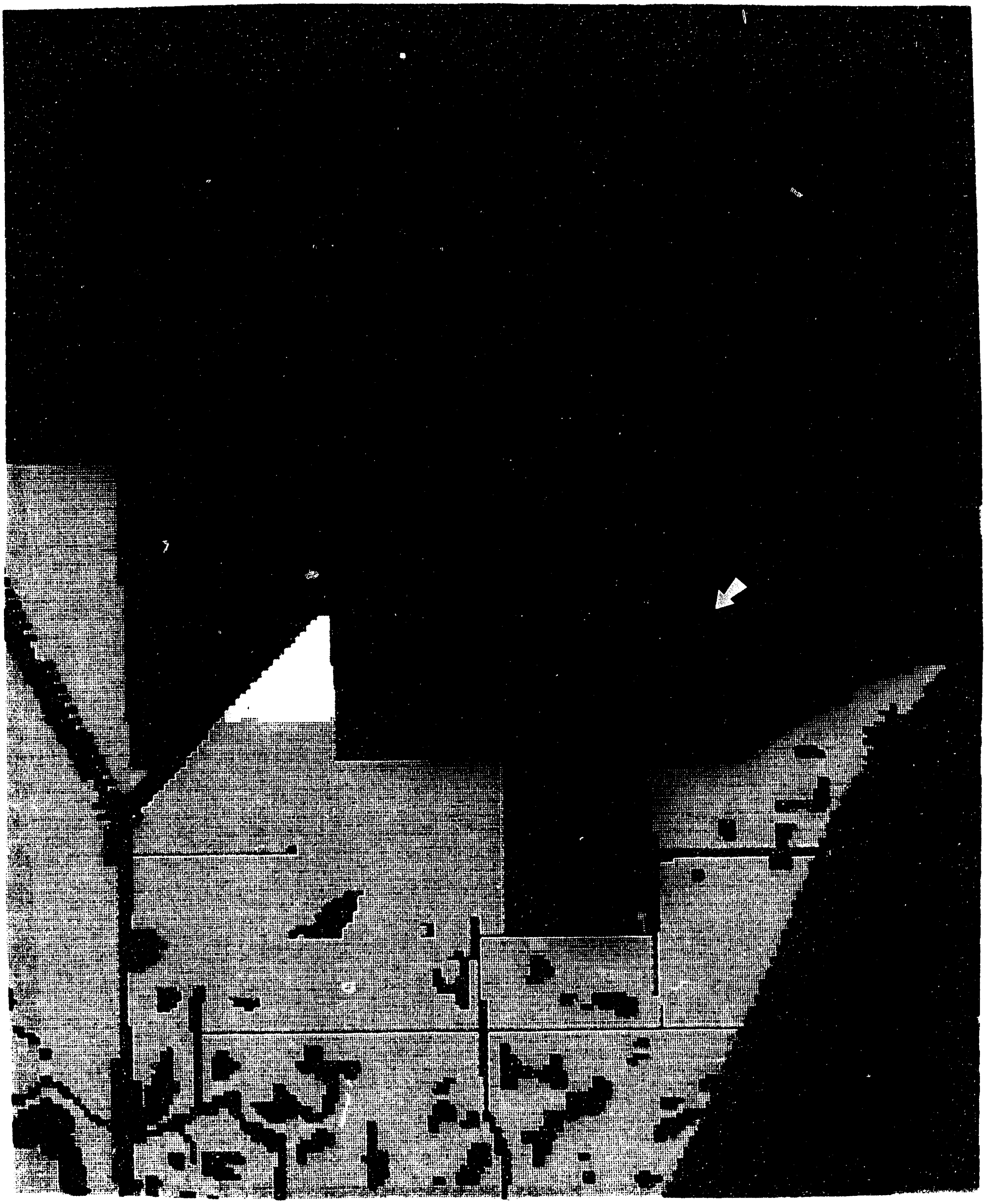

Figure 7. Habitat map of the Hulin site, 1978 (Technical Services Section, Coastal Management Division). Arrow indicates wellhead.

KEY

— Natural water

— Artificial water

— Brackish marsh

— Intermediate marsh

— Fresh marsh

— Shrub/scrub

— Shrub/scrub spoil

— Agricultural/pasture

— Developed

During this test, 40,163 bbl of brine and 1,246 MCF of gas were produced (Eaton Operating Co. 1990). The well is presently shut in until long-term testing can begin.

METHODS

For all study sites in the project, a first-order leveling network was established and tied into the National Geodetic (NGS) survey lines using class B monuments that were installed approximately 1 km apart near the Pleasant Bayou, Gladys McCall, and Hulin prospects. Class B refers to the NGS classification for monument quality. These bench marks consist of capped steel rods driven to 100 ft deep or to refusal.

A network of class B bench marks around each test site was established to monitor subsidence in the Hulin area (figure 5) and are approximately one km apart, with bench marks concentrated around the wellhead. This enables detection of relative vertical movement around the well site and at specified intervals from the site. The orientation and number of bench marks were limited by cost and distance from stable bench marks, which were used to originate the line.

In 1988, 17 class B monuments were established between the NGS line (T-361) along Highway 14 in Erath and the Hulin well site (figure 5). The orientation and number of bench marks were limited by cost and distance from NGS bench marks, which were used to begin the line. All bench marks with the prefix HU were installed for this project, while all others are either federal or state agency bench marks. These existing bench marks are listed in table 1 and were used during leveling. They contain information about the agency and year of installation.

Approximately every two years surveys are conducted to monitor the test sites. To determine local motion, a benchmark outside of the prospect area is held fixed during two or more surveys. Analysis on the benchmark elevations with repeated surveys in the network indicates movement relative to this fixed point. For example, during this reporting period, the bench mark T-361 at Hulin was held constant, and all elevation changes are relative to that bench mark. It is assumed that regional subsidence due to crustal movement is affecting this network somewhat uniformally over this short distance; therefore, crustal movement is affecting

Table 1. Elevations in meters of bench marks in the Hulin area for 1989 and 1991 leveling survey.

Station	1989 (m)	1991 (m)	Difference (mm)
T-361	1.607	1.607	0
57-v-83	1.744	1.758	14
HU-15	1.382	1.381	- 1
HU-14	1.660	1.656	- 4
57-v-81	2.604	2.596	- 8
HU-13	2.473	2.464	- 9
C-4046	2.755	2.744	-11
HU-12	1.986	1.971	-15
57-v-78	2.813	2.805	- 8
B-380	1.949	1.935	-14
C-4051	1.938	1.925	-13
HU-10	1.715	1.701	-14
HU-9	1.494	1.479	-15
HU-5	0.514	0.499	-15
HU-6	1.188	1.172	-16
HU-18	-------	1.202(new)	----
HU-17	0.788	0.772	-16
HU-1	0.626	0.611	-15
HU-2	1.354	1.342	-12
HU-3	1.020	1.006	-14
HU-4	0.704	0.689	-15
HU-8	0.776	(not recovered)	----
Wellhead	1.559	1.539	-20

the base bench mark and the network equally. Any elevation changes in the network are presumably due to local activity.

After installation, the bench marks were allowed one year for stabilization; in December 1989, they were leveled. The 1989 leveling survey serves as the baseline data for subsequent years of leveling around the Hulin site for the duration of the project.

In April 1991, first-order leveling was performed at this site using procedures and equipment identical to that used by NGS for first-order class I leveling. The leveling began at bench mark NGS-T-361 in Erath, Louisiana, and the most recent published elevation was used as a base line or starting point for the survey. T-361 is a very stable bench mark installed in 1982 and last releveled in 1986. During the 1991 survey, a new bench mark, HU-18, was set on a concrete slab in the well site to observe the subsidence of the ground surface.

Differences in elevation were calculated by subtracting the present year elevations from the baseline (1989) elevations, with bench mark T-361 held constant from the leveling. Any change in elevation is reflected as a positive (increase in elevation) or a negative (decrease in elevation) number. A negative value indicates an area where subsidence is occurring relative to the base bench mark, and a positive value indicates uplift. Annual subsidence rates have been calculated by dividing the difference in elevation by the time interval between leveling.

A paired t-test was conducted to determine if there were statistical differences in elevations among bench marks between the two years. A regression analysis was conducted to determine if elevation change and distance from the well site were related.

RESULTS

Gladys McCall

Releveling did not occur at the Gladys McCall well site during the current reporting period; therefore, no new data are presented for this well site.

Pleasant Bayou

There was no leveling survey conducted for this area during the study period, and no new data are presented for this test well site.

Hulin

The Hulin site was leveled in April 1991. All bench marks except HU-8 were recovered. After several hours of searching, surveyors were unable to locate this bench mark. In addition, a new bench mark, HU-18, was installed, with an initial level reading of 1.202 m. All data collected for the Hulin site are presented in appendix C. Table 2 and figure 8 summarize differences between 1989 and 1991.

Elevation differences at the Hulin study site ranged from 14 to -20 mm for the two-year period or from 7 to 10 mm/yr (table 2). The mean change in elevation for the study site was -11 mm or -5.5 mm/yr. The only bench mark with a positive change (an increase) in elevation was 57-v-83, which is the farthest from the well site and is also on the more stable Pleistocene. The wellhead had the greatest recorded subsidence rate for the two-year interval.

There were highly significant differences ($p < .01$) among elevations between the two periods of data collection, when a paired t-test was used to compare the elevation data ($t = -11.76$). Correlation ($r^2 = .67$, $p < .01$) between the elevation change and distance from the well when a regression analysis was performed was highly significant (figure 9).

Results of the present survey indicate rough estimates of the possible movement occurring in the area. These estimates are approximate because the time interval between leveling is very short (two years).

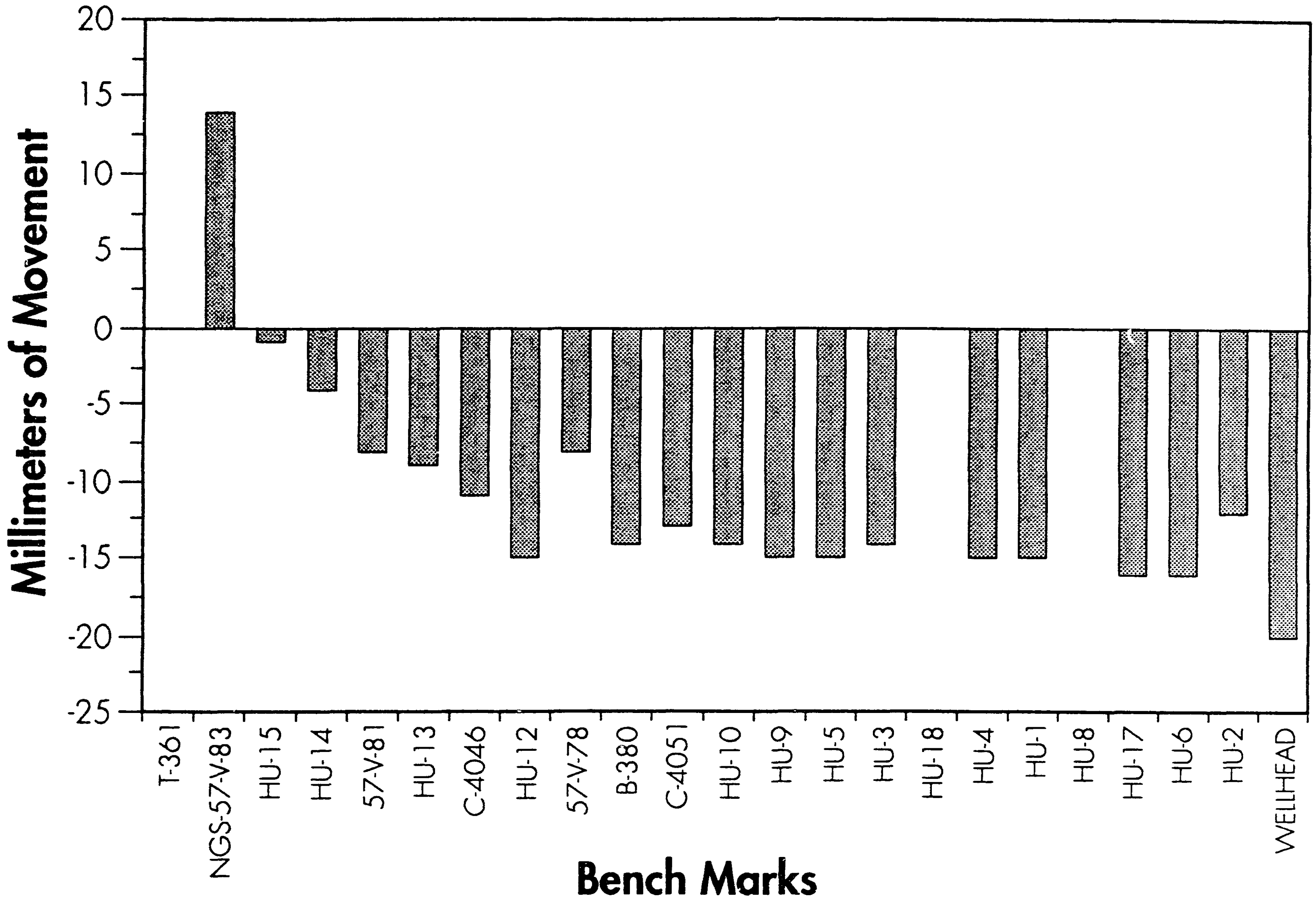

Figure 8. Elevation changes of bench marks at the Hulin site relative to T-361 (held constant). The direction of movement is indicated by positive (uplift) and negative (subsidence) values.

Table 2. Elevations in meters of bench marks in the Hulin area for 1989 and 1991 leveling survey.

Station	Distance (mi)	1989 (m)	1991 (m)	Difference (mm)	Difference (mm\yr)
T-361	7.5	1.607	1.607	0	0.0
57-v-83	7.25	1.744	1.758	14	7.0
HU-15	6.72	1.382	1.381	- 1	-0.5
HU-14	6.04	1.660	1.656	- 4	-2.0
57-v-81	5.32	2.604	2.596	- 8	-4.0
HU-13	5.15	2.473	2.464	- 9	-4.5
C-4046	4.48	2.755	2.744	-11	-5.5
HU-12	3.57	1.986	1.971	-15	-7.5
57-v-78	3.09	2.813	2.805	- 8	-5.0
B-380	2.69	1.949	1.935	-14	-7.0
C-4051	2.13	1.938	1.925	-13	-6.5
HU-10	1.7	1.715	1.701	-14	-7.0
HU-9	1.29	1.494	1.479	-15	-7.5
HU-5	0.48	0.514	0.499	-15	-7.5
HU-6	0.48	1.188	1.172	-16	-8.0
HU-18	0.002	-------	1.202(new)	----	----
HU-17	0.17	0.788	0.772	-16	-8.0
HU-1	0.002	0.626	0.611	-15	-7.5
HU-2	0.39	1.354	1.342	-12	-6.0
HU-3	0.04	1.020	1.006	-14	-7.0
HU-4	0.002	0.704	0.689	-15	-7.5
HU-8	0.05	0.776	(not rec)	----	----
Wellhead	0	1.559	1.539	-20	-10.0

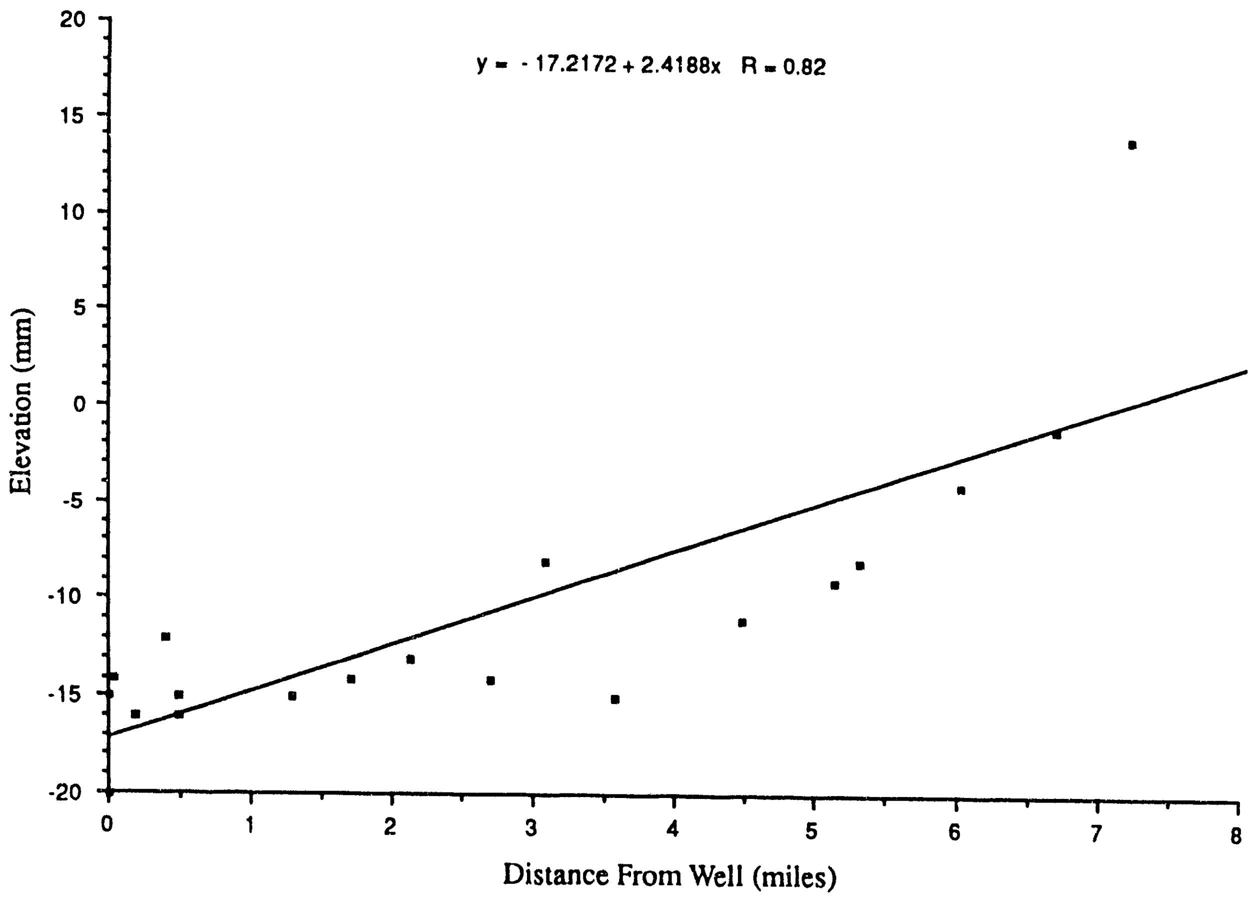

Figure 9. **Relationship between elevation change and distance from the well ($r^2 = .67$, $p < .01$).**

DISCUSSION

The most important aspect of subsidence monitoring is to determine the vertical movement near the well sites because increased local subsidence could affect coastal land loss. Because the low elevations of the study area are highly susceptible to minor changes in sea level rise and sediment compaction and supply, land loss rates are more likely to accelerate because of increased rates of subsidence no matter how small.

It is difficult to determine a specific trend in elevation change at the Hulin site with the data spaced only two years apart. This is a problem because subsidence, which is a natural process in this area, occurs over long periods of time and over longer geological cycles. In addition, very little real-time, geopressured-geothermal activity has occurred here since monitoring began. Two years of data are too short to assess a process that may occur over a longer time scale (approximately 20 years in this case) and does not allow for establishing a baseline effect for a major geological process.

There are several reasons that could be presented to explain the reported elevation changes in the Hulin area. The changes may be due to instrument error, human error, short- or long-term natural processes, or human-induced effects.

One important, long-term aspect of subsidence in the area is the effect of regional crustal subsidence on local subsidence rates. The data on regional crustal subsidence was last reported by Holdahl and Morrison (1974). When comparing regional subsidence rates with the rates of this study, it appears that the local subsidence rate is much higher at the well site than regional rates. Regional subsidence here is about 1.5 to 3 mm/yr (Holdahl and Morrison 1974), and local elevation change rates measured in this study are from 7 to -10 mm/yr, with a mean of -5.5 mm/yr. However, with sea level rise added to regional subsidence, the rates are only slightly higher than the expected 1 to 3 mm/yr.

An interesting aspect of the data collection for the first two years of data at Hulin is the statistically significant change in elevation between the two years and even more so the relationship between the elevation change and distance from the well. In this case, the difference in elevation decreases as distance from the well increases. This trend could indicate a possible connection between the short-term well activities and subsidence rates because of this elevation change and distance relationship. However, it is difficult to say this with such short-term data collection in addition to minimum activity occurring at this well. Data from the 1993 leveling could indicate a trend or begin to confirm variation in the background rates in the study area.

Other possible reasons to explain this correlation of elevation change and distance may be thickness of Holocene sediment and distance from the coast. For example, elevation change decreases as one travels north along this transition area from the thin Holocene sediment layer, which decreases into exposed Pleistocene sediment where the northernmost bench marks are located. In addition, much of the study area was formerly freshwater marsh that was drained for agricultural purposes in the past 30-40 years. On the short term, compaction of the organic sediment may be occurring or may be seasonally affected by moisture. Slight differences in elevation may occur in soils that are extremely wet during certain years or seasons and very dry in others. The well site is closest to the coast of all stations, except for HU-2. HU-4, HU-1, and HU-8, HU-3, and HU-18 are about the same distance from the coast as the well site.

CONCLUSION

Because very little geopressured-geothermal activity has occurred here it is uncertain as to whether elevation changes are due to that activity or, if it is a reflection of the local rate of subsidence and natural processes or other human-induced activities such as the conversion of wetlands to agricultural/pasture land. With the present data, it is difficult to extrapolate the reasons for the events to the variables that control the observed subsidence.

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CO-LOCATION OF MEDIUM-TO-HEAVY OIL FIELDS AND THE GEOPRESSURED-GEOTHERMAL RESOURCE IN SOUTH LOUISIANA

by

Chacko J. John

INTRODUCTION

The Louisiana Geological Survey (LGS) has been participating in the geopressured-geothermal research program sponsored by the U.S. Department of Energy (DOE) since its beginning in 1975. The research work being conducted under this program has been concentrated in the northern Gulf of Mexico basin. The ultimate goal is to determine the feasibility of using geopressured-geothermal brines that are saturated or near saturated with natural gas as an alternate energy resource. During this research program much geological, engineering, production, and environmental information has been gathered and published. Presently, there are three DOE geopressured-geothermal prospects in various stages of development. The Pleasant Bayou field (Brazoria County, Texas) is currently being produced at a rate of approximately 20,000 bbl/day and has a gas/brine ratio of about 24 SCF/STB. The Gladys McCall test well (Cameron Parish, Louisiana), presently shut in after almost 4½ years of continuous testing at an average rate of 20,000 bbl/day, produced 27.3 million bbl of brine and 676 million SCF of gas. The Superior Hulin test well (Vermilion Parish, Louisiana) is the deepest (20,725 ft) and hottest (338°F) well to be tested under this program. It was cleaned out and, after a short-term test, was shut in. We are currently awaiting funding for long-term testing.

The geopressured-geothermal research program is beginning a transition to commercialization (Negus-deWys and Dorfman 1991). Among the possible applications of this resource, the utilization of hot geopressured-geothermal brines to enhance secondary oil recovery in depleted fields containing deep wells penetrating thick geopressured-geothermal sandstone reservoirs holds promise because experiments using heated water have indicated greater recovery efficiencies (Meahl 1988, Negus-deWys et al. 1991). Hot brine reduces viscosity to result in less flow resistance and thereby increased oil recovery. The dissolved and associated free gas, if any, could be extracted from the original source brine for additional income. Results of such a project would have direct and relatively quick industry application and interest, which could lead to production in otherwise uneconomic and/or abandoned oil fields. With this object in mind, LGS, as part of its research tasks, undertook a preliminary investigation into the co-location of medium-to-heavy oils (API gravity less than 25°) in south Louisiana, with the geopressured-geothermal resource. The results of this study are presented in this report.

THE GEOPRESSURED-GEOTHERMAL RESOURCE

The geopressured-geothermal resource of the Texas and Louisiana Gulf Coast area has been estimated to contain a recoverable natural gas potential of approximately 250 TCF, which is 137% of the present estimate of conventional gas reserves in the United States (Dorfman 1988). DOE has sponsored the testing of nine geopressured-geothermal wells (excluding the Hulin well) in south Louisiana. Of these, six were short-term tests of *wells of opportunity* (abandoned hydrocarbon exploration wells that were re-entered to test the geopressured-geothermal reservoirs) and three were *design wells* (wells drilled specifically for long-term flow testing of geopressured-geothermal reservoirs). Miller provides a geological review and summary of the well test results (1991). Selection of all the test prospects in south Louisiana was based on previous regional geological studies conducted at the LGS by Bebout and others (Bebout and Gutierrez 1981, Wallace 1982). Documented in these studies are formations that had the best potential for geopressured-geothermal reservoir development (figure 1). Also in the course of that research, a large number of north-south and east-west cross sections across south Louisiana were constructed. Based on these, the geopressured-geothermal trends for the Miocene, Frio, Wilcox, and Tuscaloosa were delineated (figure 2). The distribution and depths to the top of the geopressured sandstones (figure 3) showed that most of the reservoirs occurred between 12,000 and 15,000 ft, yet some were at greater depths. Other regional data provided information on the subsurface structure, regional sandstone distribution, porosity, permeability, temperature, formation pressure, and salinities.

The history of the Gulf Coast test wells has shown that the thick, geopressured-geothermal sandstone hot brine reservoirs are capable of long-term, high-yield production. Calcium carbonate scale problems, encountered initially during flow testing, have been successfully solved by using a phosphonate pill treatment method. Though current technology can be used to recover gas from brine, prevailing economic conditions make commercialized gas production by this method unfeasible. High-volume subsurface injection of brine

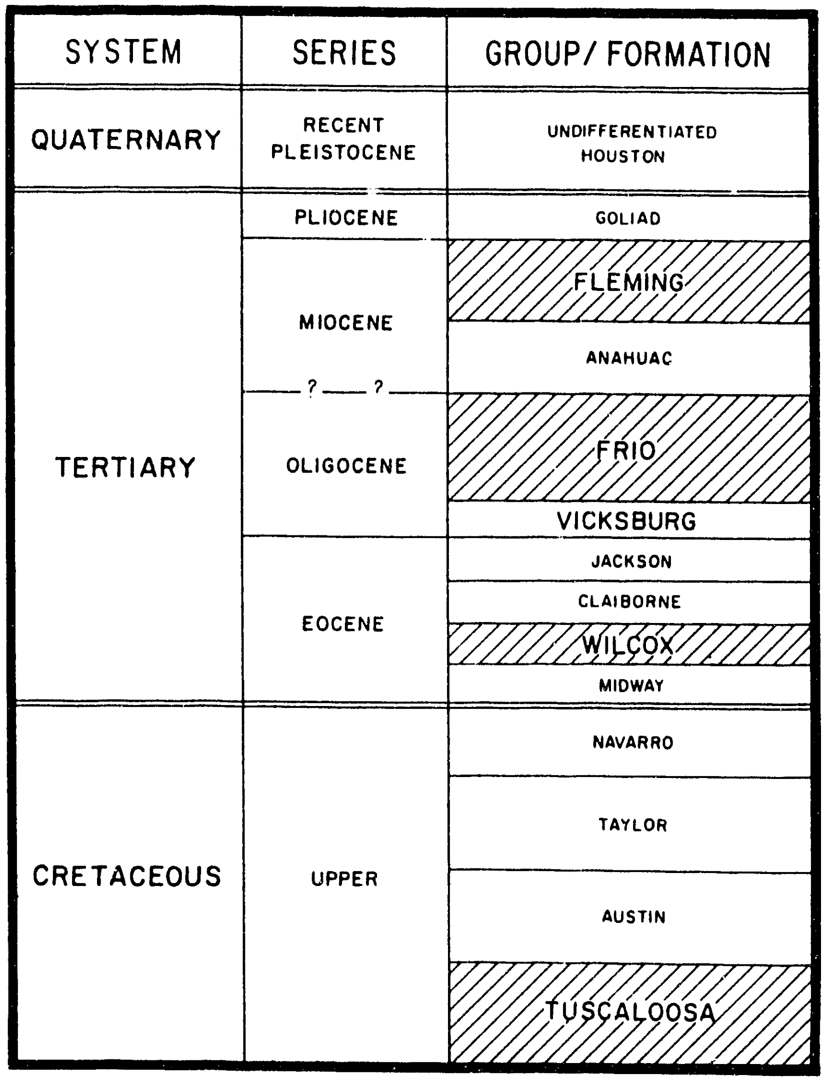


Figure 1. South Louisiana stratigraphic column showing the formations (with lined pattern) that have the greatest potential for containing thick sections of geopressured-geothermal reservoir sands.

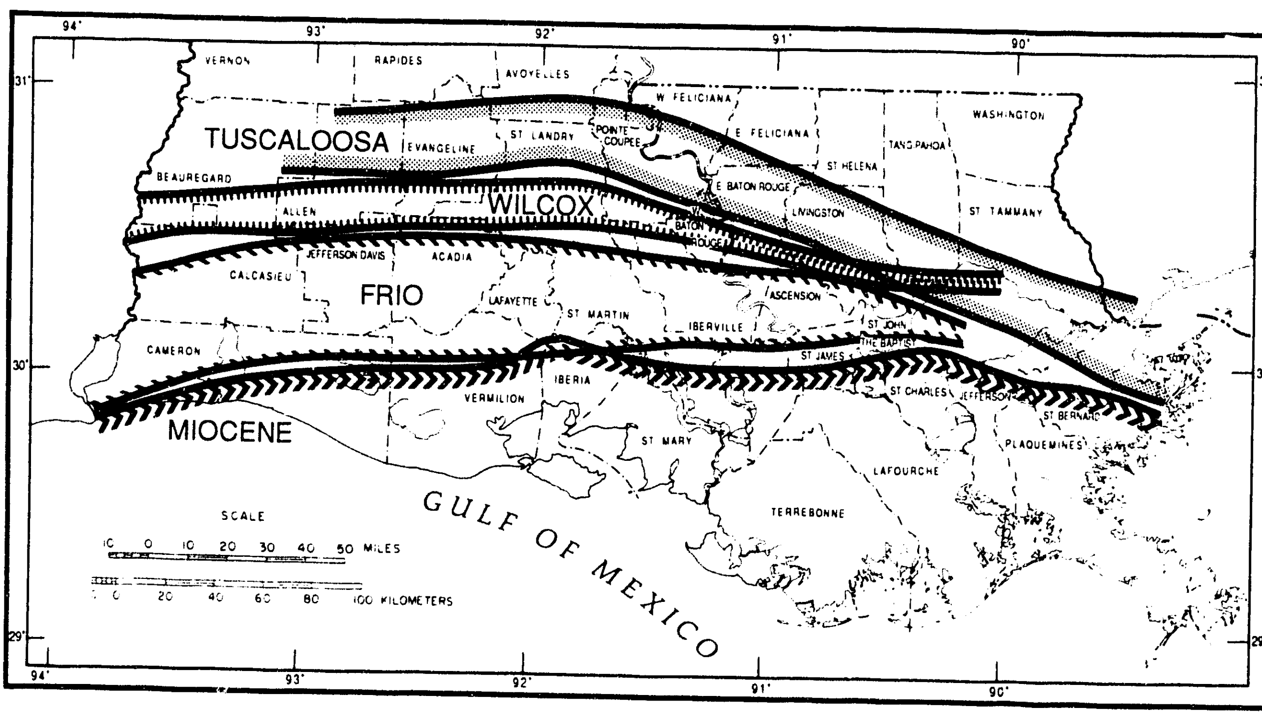


Figure 2. Geological trends of the Miocene, Frio (Oligocene), Wilcox (Eocene), and Tuscaloosa (Cretaceous) sandstone reservoirs that have the best potential for geopressured-geothermal resource development in south Louisiana.

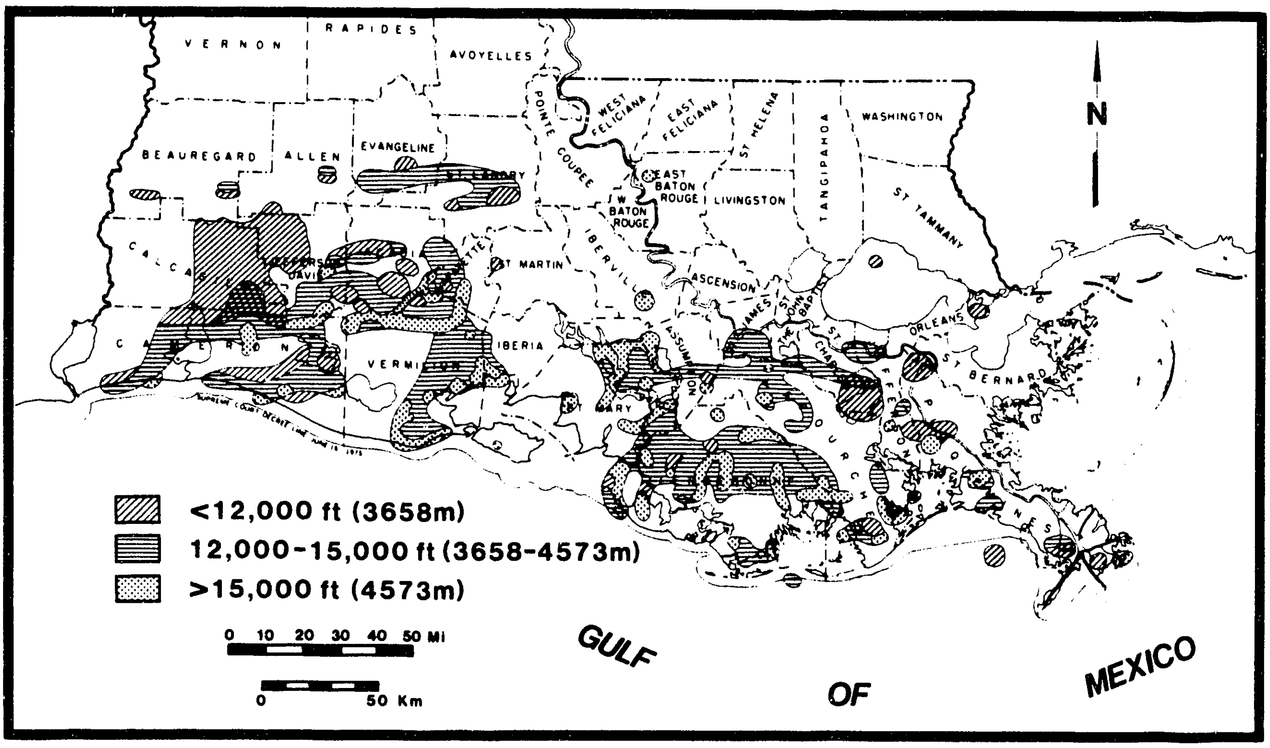


Figure 3. Distribution and depths to Tertiary geopressured-geothermal sandstones in south Louisiana.

below the base of the freshwater aquifer has been effectively accomplished. Further, none of the geopressured-geothermal development tests and operations have caused any major detrimental environmental concerns. It should be noted that all presently known information about the resource is based on individual well tests. The development of a geopressured-geothermal field with many wells may cause modification of some conclusions, especially of the environmental effects. The basic results, however, may be unaffected.

HEAVY OIL RESOURCES OF THE UNITED STATES

The U.S. Bureau of Mines conducted one of the earliest studies of heavy oil reservoirs in the United States (Dietzman et al. 1965), which documented geographic locations of those reservoirs (figure 4). Remaining heavy oil was estimated to be in excess of 150 billion barrels. In a report prepared for DOE, Rand Corporation (Nehring et al. 1983) stated that most of the heavy oil was found in shallow, high-porosity sandstone reservoirs in structural or combination (structural-stratigraphic) traps and was, therefore, amenable for recovery technologies. Most of the heavy oil occurs in the California basins, which are primarily of Pleistocene, Pliocene, and Miocene ages. In 1984, Lewin and Associates, Inc., finished a study using a proprietary data base, considered to be the most complete to date, and estimated that the United States originally had over 100 billion barrels of heavy oil in place. By 1984, approximately 12 billion barrels had been produced leaving a resource base of over 80 billion barrels for future development and production (Kuuskraa and Godec 1987a).

Of the 80 billion barrels, California had 42 billion; Alaska had 25 billion; and Wyoming had 5 billion. Smaller accumulations of one to two billion barrels for a total of six billion were estimated to be present in Arkansas, Louisiana, and Texas reservoirs. Lesser volumes of heavy oil were attributed to reservoirs in Alabama, Colorado, Kansas, Montana, New Mexico, Oklahoma, and Utah (Kuuskraa and Godec 1987b, Oil and Gas Journal 1988). One of the main findings of the Lewin and Associates study was that advances in technology were essential in order to be able to produce the full potential of heavy oil. Depending on the oil prices and technology, they estimated that up to one million barrels of heavy oil per day could be obtained

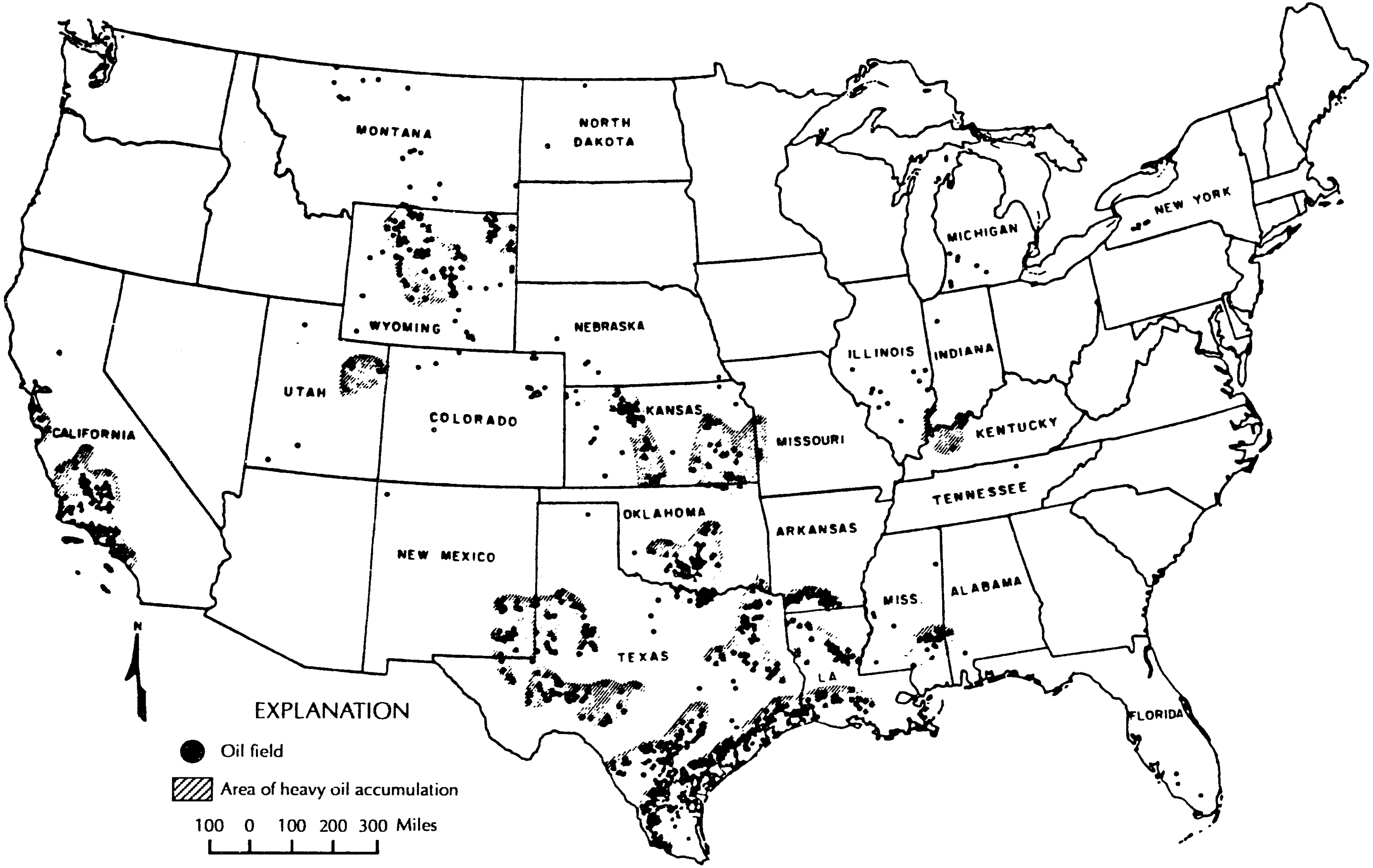


Figure 4. Geographic locations of heavy oil fields in the United States.

by the turn of the century. Future production using thermal enhanced oil recovery technology (TEOR) is more likely to be affected by the increasing environmental regulations and constraints than oil prices (Blevins 1990). Geopressured-geothermal hot brines represent a relatively environmentally clean source of high-temperature water that when pumped into target heavy oil reservoirs could reduce viscosity to a point where the oil would flow and could be easily recovered by pumping.

FIELDS WITH MEDIUM-TO-HEAVY OIL CO-LOCATED IN GEOPRESSURED-GEOTHERMAL CORRIDORS

In this report bitumens are classified as having from 0-8° API, heavy oil 8-20° API, and medium oil 20-25° API gravity. The original heavy oil resource in place in Louisiana's reservoirs is estimated to be 1.2 billion barrels (Kuuskraa and Godec 1987a), and much of this is located in north Louisiana. Very little published data on Louisiana's medium-to-heavy oil reservoirs are available. Dietzman et al. (1965) published the information quoted below on the heavy oil occurrences in north Louisiana, southwest Louisiana, south Texas, and the Texas Gulf Coast:

> North Louisiana: "Heavy oil productive formations in north Louisiana are of Tertiary (Eocene) and Cretaceous ages. Most production is obtained from sandstone reservoirs, but some limestones and chalks are also oil productive. Net thicknesses of productive zones range up to 60 feet, although about 50 percent are less than 10 feet thick. Reservoirs are found from about 150 to 6,950 feet in depth. Twenty-six of the 33 reservoirs in the area are at depths less than 3,000 feet." (Dietzman et al. 1965)

> South Texas, Gulf Coast Texas, and Southwest Louisiana: "Heavy crude oil reservoirs are concentrated along the Gulf Coast extending from the Texas-Mexico border to the middle of southern Louisiana. These accumulations are found predominately in sandstone members of the Tertiary system. The 652 reservoirs covered in this report are found at depths from about 80 feet to a maximum of 12,200 feet. Approximately 50 percent of the deposits are at depths less than 3,000 feet. Over 600 of these reservoirs have average net thicknesses of less than 100 ft. Many of the reservoirs have active water drives, but solution gas expansion is also present." (Dietzman et al. 1965)

In this report, medium-to-heavy oil reservoirs in north Louisiana have not been investigated because very little information is available about the geopressured-geothermal reservoirs in that area. The DOE research program had addressed only the geopressured-geothermal resource in south Louisiana. Table 1 provides a listing of all heavy oil occurrences in Louisiana by conservation district, parish, and field, with details about

Table 1. Louisiana oil fields with <25° API gravity oil production (compiled from DNR Report 1979).

District	Parish & Field	Producing Formation	Year Discovery		Estimated Area		Number Wells Cumulative End of Year		Number Wells During Year Completed		Number Wells During Year Abandoned		Wells Producing End of Year FLowing		Wells Producing End of Year Art. Lift	Producing Formations Oil Grav	Producing Formations Ave Por	Producing Thickness		Stru	Deepest Zone Tested	Depth of Hole
		Name.Age.Depth	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas				Oil	Gas		Name	
Monroe	CATAHOULA																					
	Big Bayou	Wil Eoc 4865	1967	-	620	-	16	-	0	-	3	-	0	-	7	20	P	11	-	N	Wilcox	6010
	Birds Creek	Spar Eoc 1935	1966	-	40	-	1	-	0	-	0	-	0	-	0	20	P	10	-	A	Sparta	1935
	California Bayou	Spar. Eoc 2584	1965	-	400	-	10	-	0	-	1	-	0	-	7	21	P	30	-	N	Wilcox	5710
	Larto Lake	Spar. Eoc 3115	1956	-	960	-	23	-	0	-	0	-	0	-	12	24	P	16	-	ML	Midway	7031
	Manifest	Spar. Eoc 1742	1942	-	280	-	8	-	9	-	0	-	0	-	0	20	P	12	-	N	Wilcox	4554
	N.Willow Lake	Spar. Eoc 2688	1964	-	240	-	6	-	0	-	0	-	0	-	1	23	P	8	-	N	Wilcox	6010
	Parker Lake*	Spar. Eoc 3316	1965	-	15[illegible]0	-	38	-	1	-	1	-	1	-	17	23	P	3	-	M	Wilcox	6615
	Sandy Lake	Spar. Eoc 1920	1964	-	440	-	11	-	0	-	0	-	-	-	7	22	P	17	-	X	Wilcox	4410
	Sandy Lake	Wil. Eoc 4298	1064	-												21	P	12	-	X		
	S. Larto Lake	Spar. Eoc 3593	1949	-	640	-	17	-	0	-	0	-	1	-	6	21	30	6	-	ML	Ft.W.Lm	10620
	S. Utility	Spar. Eoc 2441	1960	-	40	-	1	-	0	-	0	-	0	-	0	23	P	5	-	N	Wilcox	5827
	Utility	Wil. Eoc 2370	1960	-	360	-	9	-	0	-	1	-	0	-	1	21	P	12	-	N	Wilcox	5521
	CONCORDIA																					
	Hog Pen Lake	Spar. Eoc 5237	1964	-	40	-	1	-	0	-	0	-	0	-	0	14	P	5	-	X	Wilcox	8202
	Natchez Ferry	Wil. Eoc 4216	1966	-	360	-	9	-	2	-	-	0	-	1	-	5	P	20	-	X	Wilcox	6251
	N. Bee Brake	Spar. Eoc 3472	1974	-	760	-	18	-	0	-	0	-	0	-	14	21	P	4	-	N	Wilcox	6847
	Parker Lake*	Spar. Eoc 3316	1965	-	1560	-	38	-	1	-	1	-	1	-	17	23	P	3	-	N	Wilcox	6615
	Warnicott	Spar. Eoc 3224	1957	-	40	-	1	-	0	-	0	-	0	-	1	25	P	3	-	X	Wilcox	6810
	E. CARROLL																					
	Brunett Smk. Jur	Smk Jur 7080	1974	-	80	-	1	-	0	-	0	-	0	-	-	24	P	X	-	X	Wilcox	7198
	GRANT																					
	Mill Creek	Spar. EOc 1813	1954	-	120	-	4	-	0	-	0	-	0	-	0	18	P	4	-	X	Wilcox	5009
	Tullos-Urania*	Spar. Eoc 972	1956	X	9500	920	1457	5	15	0	25	0	0	4	484	21	P	4	X	A	Tokio	6538
	Tullos-Urania*	Wil. Eoc 1231	1925	X												21	P	15	X	A		
	LA SALLE																					
	Nebo-Hemphill	Ck. Eoc 1420	1940	X	8120	1300	282	1	5	0	2	0	4	0	130	19	P	15	X	AF	Paluxy	9350
	Rogers	Coc. Eoc	1957	-	880	-	29	-	0	-	0	-	0	-	15	20	P	8	-	N	Wilcox	4523
	Tullos-Urania*	Spar. Eoc 972	1956	X	9500	920	1457	5	15	0	25	0	0	4	484	21	P	4	X	A	Tokio	6538
	Tullos-Urania	Wil. Eoc 1231	1925	X												21	P	15	X			
	W. Long Slough	Spar. Eoc 2603	1969	-	400	10	-	2	-	0	-	0	-	-	5	23	P	18	-	X	Wilcox	6010
	W. Searcy	Wil. Eoc 1879	1961	-	920	-	24	-	0	-	0	-	0	-	21	21	P	15	-	N	Paluxy	4301
	W. Trout Creek	Wil. Eoc 2173	1959	-	120	-	3	-	0	-	0	-	0	-	0	21	P	5	-	M	Wilcox	3715
	White Sulphur Springs	Coc Eoc 789	1927	-	270	-	17	-	0	-	0	-	0	-	0	20	P	9	-	N	Wilcox	4416
	Tensas																					
	Holly Ridge	Tus CreU 5347	1943	-	4600	4160	112	18	24	0	1	0	0	1	43	18	P	X	18	A	Hoss	14345
	UNION																					
	Oakland	NaCreU 2240	1928	-	140	-	7	-	0	-	0	-	0	-	0	21	P	10	-	A	CreL	3001

Table 1. Louisiana oil fields with <25° API gravity oil production (compiled from DNR Report 1979), continued.

District	Parish & Field	Producing Formation	Year Discovery		Estimated Area		Number Wells Cumulative End of Year		Number Wells During Year Completed		Number Wells During Year Abandoned		Wells Producing End of Year FLowing		Wells Producing End of Year Art. Lift	Producing Formations Oil Grav	Producing Formations Ave Por	Producing Formations Producing Thickness		Producing Formations Stru	Deepest Zone Tested	Depth of Hole
		Name.Age.Depth	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas				Oil	Gas		Name	
	WINN																					
	Tullos-Urania	Spar. Eoc	1956	X	9500	920	1457	5	15	0	25	0	0	4	484	21	P	4	X	A	Tokio	6538
	Tullos-Urania	Wi. Eoc 1925	X													21	P	15	X	A		
Shreveport	BIENVILLE																					
	Ada*	Mpt.CreL 4362	1953	X	1220	13880	34	109	2	5	1	2	0	61	12	21	P	14	X	AF	Jur.	14120
	Topy Creek	Tus.CreU 3252	1955	-	480	-	12	-	0	-	3	-	0	-	2	25	P	8	-	A	Pal.	3503
	BOSSIER																					
	Bellevue*	O.CreU 1055	X	1967	3200	3200	1301	1301	63	0	19	0	0	0	807	18	P	30	X	D	Smk.	10146
	Caddo Pine Isl.	NacCreU 800	1904	1904	100480	X	16024	16024	205	76	33	0	X	X	X	20	P	25	X	AF	Ign.	11419
	Cottage Grove	Oz.CreU 1871	1954	-	1440	-	88	-	0	-	0	-	0	-	74	23	P	10	-	ML	Hoss	5581
	N. Carterville	Buc.CreU 2268	1974	-	1800	-	30	-	2	-	1	-	X	X	X	25	P	X	-	A	Smk.	11751
	Swan Lake	Pal.CreL 2666	1964	-	480	-	8	-	0	-	0	-	0	-	4	21	P	15	-	N	Pal.	2950
	CADDO																					
	Caddo Pine Isl.*	NaCreU 800	-	1976	100480	X	16305	16305	205	76	33	0	X	X	X	20	P	25	X	AF	Ign.	11419
	Walnut Bayou	PalCreL 2442	1968	-	120	640	2	4	0	0	0	0	0	0	0	10	P	7	-	X	Hoss	6816
	WEBSTER																					
	Ada*	MptCreL 4362	1953	X	1200	13880	34	109	2	5	1	2	0	61	12	21	P	14	X	AF	Jur.	14120
	Bellevue*	NaCreU 255	1921	1921	3200	3200	1301	1301	63	0	19	0	0	0	807	18	P	30	X	D	Smk	10146
	Minden	RodCreL 6462	1959	X	1400	4680	40	47	0	0	0	0	X	X	X	13	P	16	X	DS	Lou. S	11603
	Minden	Jm.CreL 6948	1958	1959												25	P	11	12	DS		
	WINN																					
	Colgrade	WilEoc 1278	1959	1977	9500	120	455	1	27	0	0	0	0	0	384	20	P	7	X	A	Wil.	1500
	Crossroads	WilEoc 1425	1954	-	1000	-	106	-	2	-	0	-	0	-	85	20	P	4	-	A	Wil.	1529
	Curry	WilEoc 1363	1957	-	280	0	22	-	0	-	0	-	0	-	14	20	P	3	-	A	Wil.	1509
	Joyce	WilEoc 1090	1949	-	1040	-	112	-	1	-	0	-	0	-	56	21	P	10	-	ML	Wil.	1926
	Salt	Spar.Eoc	1969	-	1300	-	41	-	1	-	0	-	0	-	35	21	P	X	-	A	Wil.	1592
Houma	ASSUMPTION																					
	Coteau Frene	Mio. U 12393	1967	1965	80	1600	1	8	0	0	0	0	0	6	0	25	P	14	140	AF	Mio. U	14500
	IBERVILLE																					
	Frog Lake	Mio. U 12048	1978	-	80	-	1	-	1	-	0	-	1	-	0	23	P	15	-	X	Mio. I	12436
	TERREBONNE																					
	Trinity Bayou	Mio. U 14076	1961	-	40	-	1	-	0	-	0	-	0	-	0	24	P	10	-	A	Mio. U	15265
Lafayette	IBERVILLE																					
	Maringouin	Mio. L 9175	1952	-	40	-	2	-	0	-	0	-	0	37	8	10	P	10	-	A	Mio. L	9900
	West Maringouin	Mio. U 9473		-	1969	-	200	0	2	-	1	-	0	-	0	0	P	-	X	Mio	14000	14000

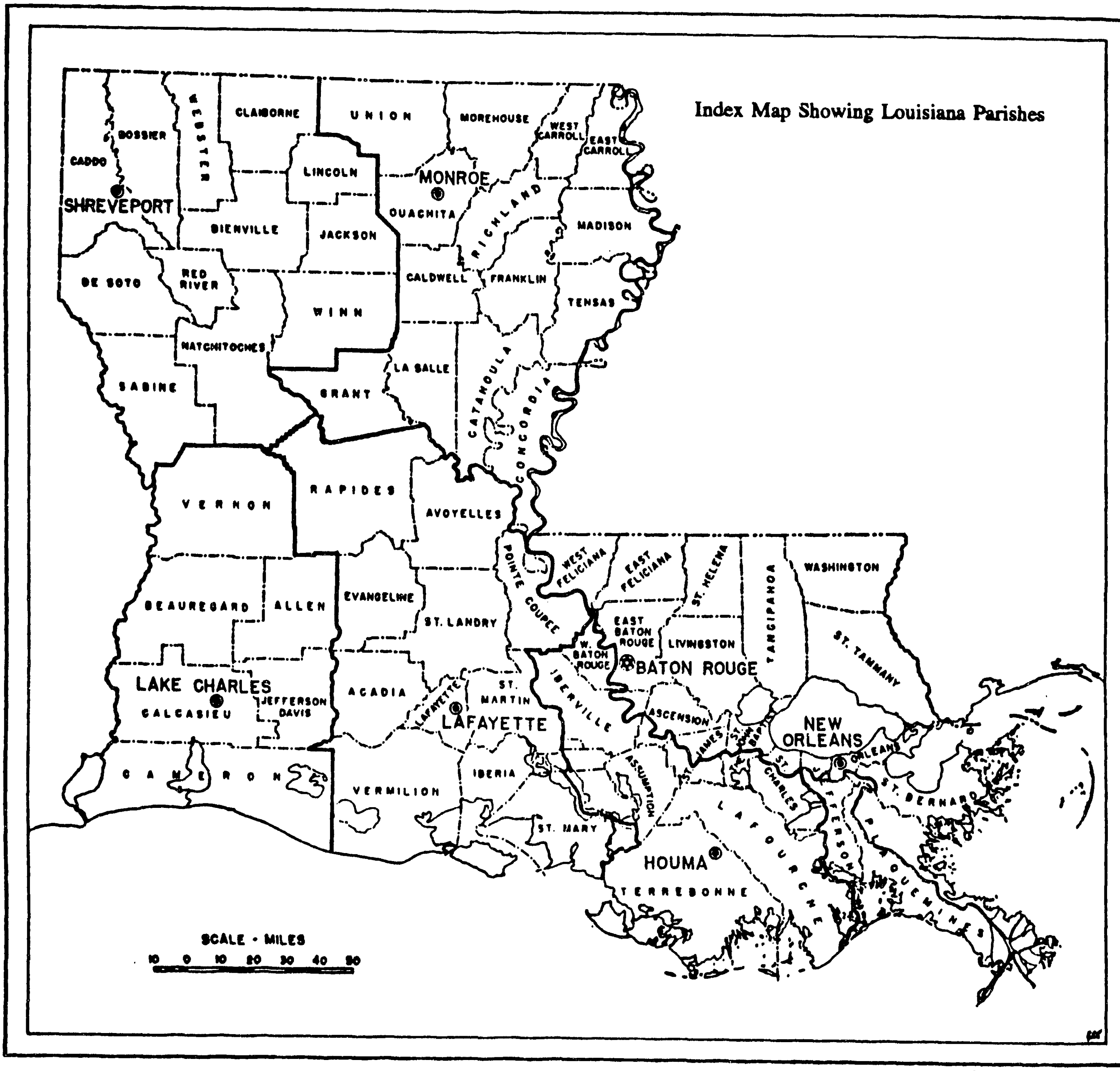
Table 1. Louisiana oil fields with <25° API gravity oil production (compiled from DNR Report 1979), continued.

District	Parish & Field	Producing Formation Name,Age,Depth	Year Discovery Oil	Year Discovery Gas	Estimated Area Oil	Estimated Area Gas	Number Wells Cumulative End of Year Oil	Number Wells Cumulative End of Year Gas	During Year Completed Oil	During Year Completed Gas	During Year Abandoned Oil	During Year Abandoned Gas	Wells Producing End of Year FLowing Oil	Wells Producing End of Year FLowing Gas	Wells Producing End of Year Art. Lift	Producing Formations Oil Grav	Producing Formations Ave Por	Producing Thickness Oil	Producing Thickness Gas	Stru	Deepest Zone Tested Name	Depth of Hole
	LAFAYETTE																					
	Lafayette	Mio L 10599		1958	-	160	-	4	-	0	-	0	0	0	0	0	P	11	-	A	Mio. L	13791
	ST. LANDRY																					
	Big Crane	Tusc. 18276	-	1978	-	640	-	1	-	1	-	0	-	0	0	0	P	-	X	X	Tusc.	19692
	Sambo	Mio. L 7755	-	1965	-	320	-	3	-	0	-	0	0	0	0	0	P	-	23	A	Mio. L	8215
	ST. MARY																					
	Franklin	Mio. U 10209	1953	1953	1280	1200	34	15	1	3	0	0	9	8	3	0	P	95	78	DS	Mio. L	17071
	VERMILLION																					
	S. Lake Arhtur	Mio. U 10570	-	1955	-	160	-	1	-	0	-	0	-	0	0	0	P	-	30	AF	Mio. L	15344
	S. Peryy	Mio. U 14717	-	1960	-	160	-	1	-	0	-	0	-	0	0	0	P	-	30	D	Mio. U	15586
Lake Charles	ACADIA																					
	Jennings	Mio. U 1006	1901	-	1520	800	861	14	4	0	2	0	8	1	71	22	P	561	-	DS	Vick.	12792
	ALLEN																					
	Harmony Church	Mio. L 5885	1955	1956	160	80	4	1	0	0	0	0	0	0	0	25	P	20	10	A	Clb.	10004
	LeBlanc	Mio. L 5407	1955	1956	40	160	2	3	0	0	0	0	0	1	0	25	P	8	18	A	Clb.	10000
	BEAUREGARD																					
	Clear Creek	Mio. L 7203	-	1956	-	56	-	480	-	5	-	0	0	0	0	0	P	-	6	AC		
	Gordon	Mio. L 5318	1944	1944	320	1000	7	14	0	1	0	0	0	1	0	24	P	24	15	AF	Wilcox	13000
	CALCASIEU																					
	Edgerly	Mio. U 2459	1912	1912	1140	400	316	7	1	0	1	0	1	0	45	22	P	84	77	DS	Vick.	9500
	Lockport	Mio. U 996	1924	1924	1600	1400	172	14	0	0	0	0	2	3	32	23	P	170	170	DS	Mio. L	11460
	Starks	Plio 570	1929	1925	480	940	85	8	1	1	0	1	1	0	19	20	P	20	20	DS	Vick	11689
	Sulphur Mines	Mio. U 2676	1926	-	820	-	174	-	6	-	2	-	6	-	16	18	P	20	-	DS	Mio. L	9774
	Vinton	Mio. L 8118	1910	1910	3160	280	765	17	10	1	6	2	14	10	139	23	P	135	135	DS	Mio. L	11002
	CAMERON																					
	Calcasieu Lake	Mio. U 10566	1958	1959	200	160	5	2	0	0	0	0	1	0	0	23	P	195	81	DS	Mio. L	18425
	Cameron Meadows	Plio 1269	1931	1931	1440	840	147	13	10	0	0	0	9	4	63	20	P	37	140	DS	Mio. L	15073
	JEFFERSON DAVI																					
	E. Fenton	Mio. L 9824	1959	1967	80	160	2	1	0	0	0	0	0	0	0	6	P	43	X	X	Mio. L	11622
	Iowa*	Mio. U 3180	1931	1931	1680	560	140	69	0	0	0	0	3	6	29	24	P	400	400	DS	Cook Mt	12742
	Iowa*	Mio. L 7050	1950	1950																		
	Welsh	Plio 1200	1902	1902	1080	1350	292	18	0	0	3	0	9	3	23	21	P	15	15	DS	Mio. L	11111
	Welsh	Mio. U 3778	1967	1967																		
	Welsh	Mio. L 5148	1967	1967																		
New Orleans	PLAQUEMINES																					

Table 1. Louisiana oil fields with <25° API gravity oil production (compiled from DNR Report 1979), continued.

		Producing Formation	Year Discovery		Estimated Area		Number Wells Cumulative End of Year		Number Wells During Year Completed		Number Wells During Year Abandoned		Wells Producing End of Year Flowing		Wells Producing End of Year Art. Lift	Producing Formations Oil Grav	Ave Por	Producing Thickness			Deepest Zone Tested	Depth of Hole
District	Parish & Field	Name,Age,Depth	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas				Oil	Gas	Stru	Name	
	Bay Denesse	Mio U 11162	1961	-	40	-	1	-	0	-	0	-	0	-	0	23	P	12	-	X	Mio. I	11918
	Lake Campo	Mio U 6646	1969	1962	200	1900	7	13	0	0	0	0	2	3	4	24	P	55	170	D	Mio U	12190
	ST. BERNARD																					
	Half Moon Lake	Mio U 4882	1963	1967	1700	320	29	2	2	0	0	0	6	0	24	23	35	104	25	D	Mio U	10300
	Stuards Bluff	Mio U 8568	-	1968	-	700	-	3	-	0	-	0	-	0	0	1	P	-	35	A	Mio U	10200
Offshore	BRETON SOUND																					
	Block 32	Mio. U 5397	1949	1949	600	800	19	11	0	0	0	0	5	6	3	25	P	45	155	AF	Mio. U	11025
	Block 45	Mio. U 6962	1967	1973	80	120	1	0	0	0	0	0	0	0	0	23	P	15	67	A	Mio. U	17312

Table 1. Louisiana oil fields with <25° API gravity oil production (compiled from DNR Report 1979), continued.



Index Map Showing Louisiana Parishes

INDEX TO TABLE 1

GENERAL

X: A definite value exists, but is unknown
O: A definite value of zero

POROSITY

P: Reservoir rock is of porous type
F: Reservoir rock is of fracture type

STRUCTURE

A:	Anticlinal
AC:	Anticlinal with accumulation due to change in character of stratum
AF:	Anticlinal with associated faulting
D:	Domal
DF:	Domal with associated faulting
DS:	Salt Dome
M:	Monoclinal
MC:	Monoclinal with accumulation due to change in character of stratum
ML:	Monoclinal-Lense
MU:	Monoclinal-Unconformity
N:	Nose
S:	Syncline
T:	Terrace
TF:	Terrace with associated faulting
TL:	Terrace Lense

RESERVOIR AND AGE NOMENCLATURE, (WITH ABBREVIATIONS)

Buckner	Buc		
Claiborne	Clb		
Cockfield	Cf	Ckf	C
Cretaceous	Cre		
Eocene	Eoc		
Hosston	Hoss		
Igneous	Ign		
James Lime	Jm		
Jurassic	Jur		
Louann Salt	LouS		
Mooringsport	Mpt		
Nacatoch	Nac		
Ozan	Oz		
Paluxy	Pxy	Pal	
Rodessa	Rod		
Smackover	Smk		
Sparta	Sp	Spa	
Tokio	Tok		
Tuscaloosa	Tus		
Vicksburg	Vick		
Wilcox	Wx	Wil	W

DESCRIPTIVE ADJUNCTS

Upper	U
Middle	M
Lower	L

age, depth, year of discovery, estimated area, number of wells producing and abandoned, oil gravity, production thickness, and deepest zone tested. The information provided in table 1 was compiled from the last published Louisiana Department of Natural Resources (DNR) Report (1979). Later information about the medium-to-heavy oil occurrences is found in the oil and gas computerized information on production and well data files called the 'PARS' system maintained at the Louisiana Office of Conservation (DNR), located in Baton Rouge, Louisiana.

The preliminary report of Louisiana co-location studies (Negus-deWys et al. 1991) contained graphs showing the frequency of heavy and medium oil test results based on API gravity. Each gravity test is recorded in the data base as a separate entry; though, it may be from the same well and/or field. The number of data points, therefore, does not reflect the exact number of fields or wells that have medium-to-heavy oil production. Appendix D contains maps of southeast and southwest Louisiana on which are plotted all the gravity tests of less than 25° API as found in the 'PARS' data base. The maps also show the geological age trends of production for the Upper, Middle, and Lower Miocene and the Upper and Middle Frio.

Based on the regional maps, parish maps were created that identify which fields with medium-to-heavy oil occurrences are located in geopressured-geothermal corridors or trends (figure 2). Most fields of interest in south Louisiana have oil gravity between 20–25° API. Thermal enhanced oil recovery using geopressured-geothermal brine would seem to be most effective in shallow reservoirs because of the brine heat loss factor. Therefore, the maps only show oil fields with reservoirs at less than 3,001 ft. Twenty-one such fields located in ten Louisiana parishes have been identified and are shown in the parish maps presented in appendix E. Fields in the Cameron, Calcasieu, Acadia, St. Martin, and Iberville parishes are located in the Frio (Oligocene) geopressured-geothermal trend. The remaining located in Iberia, Terrebonne, Lafourche, St. Mary, and Plaquemines parishes fall in the Miocene trend.

Researchers mainly tested wells in southwestern Louisiana for the DOE geopressured-geothermal research program. Because a relatively large number of medium-to-heavy oil fields are located in this area, we should, ideally, select a field in Cameron, Calcasieu, or Acadia parish to test enhanced oil recovery using hot geopressured-geothermal brine. Before the final field selection, each of the above-mentioned potential sites should be studied in greater detail, with attention to prospect geology, engineering, and reservoir production characteristics and particular reference to the source and target reservoirs. As pointed out by Seni and Walter (1991), geopressured-geothermal brine reservoirs do not require structural or stratigraphic closure to trap hydrocarbons as do oil and gas reservoirs. Such reservoirs (GP/GT) should be thick and laterally extensive within large fault blocks to contain large fluid volumes. Other factors that would need to be evaluated include brine production technology, methods for surface handling and gas separation from brine, injection technology, and the production and marketing of the oil obtained from the target reservoir.

Unresolved technical issues that need to be addressed in the process of using geopressured-geothermal brine for secondary oil recovery include 1) potential chemical reactions between the injected brine and reservoir fluids, 2) fluid temperatures, 3) brine heat loss in relation to distance and depth of target reservoir, 4) optimum injection pressure and volume rate without inducing fracturing in the target oil reservoir, and 5) the geometry and areal extent (size and thickness) of the geopressured-geothermal reservoir and of the target oil reservoir.

CONCLUSIONS

A large amount of geological, engineering, production, and other technological information on the geopressured-geothermal resource of the Gulf Coast has been gathered since the inception of the U.S. Department of Energy's geopressured-geothermal research program. The research program results are now in a stage of transition to commercialization. Of all the potential commercial applications, the concept of using geopressured-geothermal hot brines for thermal enhanced oil recovery seems to promise quick realization, industry interest, and participation, which are vital for full exploitation of this resource. Successful testing of this concept would lead to improved recovery efficiencies and the reworking of presently uneconomic and/or abandoned fields.

Use of the geopressured-geothermal brine would be a relatively environmentally clean process, conserve freshwater resources used for conventional water floods, and save combustion energy for hot water and steam production.

Suitable oil fields for testing are located in Louisiana's Frio and Miocene geopressured-geothermal corridors. Because most of the research results have been based on well tests in southwestern Louisiana, it would probably be best to choose the final test site from Cameron, Calcasieu, or Acadia parish. Before final selection, it is necessary to study the individual prospects in detail.

Medium-to-heavy oil reservoirs are generally thinner and have a much smaller areal extent than geopressured-geothermal reservoirs. Unlike hydrocarbon reservoirs, which need a structural and/or stratigraphic trapping mechanism, geopressured-geothermal sandstone reservoirs need only be thick with good porosity, permeability, and lateral extension. Such reservoirs are generally confined within large fault blocks.

Some unresolved technical issues concerning thermally enhanced oil recovery using geopressured-geothermal hot brines include 1) chemical compatibility of brines with fluids in the target reservoirs, 2) fluid temperatures, 3) brine heat loss in relation to distance and depth of target reservoirs, and 4) optimum injection pressure and rates. The depositional geometry and size of source and target reservoirs should be delineated by geological studies using well logs and geophysical information.

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APPENDIX A

Teleseisms recorded by the geopressured-
geothermal microseismic monitoring networks

DATE	TIME (UTC)	STATIONS	ORIGIN TIME	LAT.	LONG.	REGION
13-Jan-91	22:11:19	WHP,EFF,GAR,JMF	22:06:54.8	11.523 N	86.591 W	Near coast of Nicaragua
23-Jan-91	01:23:00	EFF,WHP,HJS	01:12:30.7	52.017 N	178.857 W	Rat Islands
26-Jan-91	00:38:50	EFF,JMF,WHP,HJS,WRD	00:19:03.5	3.493 N	102.633 W	Southern Sumatra
29-Jan-91	05:32:23	WHP,HJS,EFF,GAR,JMF	05:29:03.6	16.876 N	85.532 W	Caribbean Sea
03-Feb-91	04:30:56	WHP,HJS	04:26:36.8	11.803 N	87.192 W	Near coast of Nicaragua
04-Feb-91	16:15:12	EFF,GAR	16:12:01.8	15.638 N	93.287 W	Chiapas, Mexico
10-Feb-91	12:51:57	WHP	12:42:37.4	8.715 N	39.841 W	Central Mid-Atlantic Ridge
14-Feb-91	23:41:51	EFF,GAR,JMF	16:37:22.5	29.716 N	113.821 W	Gulf of California
14-Feb-91	16:41:10	EFF,GAR,JMF	23:31:21.3	22.558 S	112.816 W	Easter Island Region
01-Mar-91	17:34:47	WHP,HJS,WIS,EFF,GAR,JMF	17:30:25.9	10.795 N	84.704 W	Costa Rica
05-Mar-91	13:54:58	WHP,HJS	13:49:07.7	3.284 N	83.330 W	Off coast Central America
16-Mar-91	06:06:50	WHP,EFF,GAR	06:02:10.6	10.192 N	85.147 W	Costa Rica
01-Apr-91	05:15:00	GAR	05:03.58.1	22.307 N	107.035 W	Off coast Central Mexico
01-Apr-91	07:40:00	WHP	07:34:46.4	16.229 N	98.234 W	Guerrero, Mexico
04-Apr-91	03:28:35	WHP,HJS,GAR,JMF	03:22:58.4	6.978 N	78.155 W	South of Panama
04-Apr-91	19:04:30	EFF,GAR,JMF	19:00:00.0	37.296 N	116.313 W	Nevada Nuclear Test
05-Apr-91	04:27:18	WHP,HJS,EFF,GAR,JMF	04:19:51.4	5.967 N	77.088 W	Northern Peru
11-Apr-91	08:14:16	EFF,GAR,JMF	08:06:05.5	2.833 N	128.607 E	Halmahera
22-Apr-91	22:01:48	WHP,HJS,EFF,GAR,JMF	21:56:51.8	9.676 N	83.082 W	Costa Rica
22-Apr-91	22:13:29	WHP,HJS,EFF,GAR,JMF	22:08:31.8	9.747 N	83.641 W	Costa Rica
22-Apr-91	22:24:19	WHP,HJS,EFF,GAR,JMF	22:19:25.0	9.801 N	83.601 W	Costa Rica
22-Apr-91	22:46:45	WHP,HJS,EFF,GAR,JMF	22:41:50.6	10.050 N	83.100 W	Costa Rica
23-Apr-91	06:37:48	WHP,HJS	06:34:06.0	14.039 N	91.667 W	Guatemala
24-Apr-91	19:17:57	WHP,HJS,EFF,GAR,JMF	19:13:00.5	9.636 N	83.601 W	Costa Rica
30-Apr-91	02:22:03	WHP,HJS,EFF,GAR,JMF	02:16:34.0	6.127 N	82.676 W	South of Panama
01-May-91	07:27:23	EFF,GAR,JMF,WRD,ALP,WHP,HJS	07:18:42.5	62.535 N	151.516 W	Central Alaska
02-May-91	07:07:20	WHP,EFF,GAR,JMF	07:01:58.1	9.320 N	77.398 W	North coast of Columbia
04-May-91	03:47:59	EFF,GAR,JMF,WHP,HJS	03:42:54.9	9.492 N	82.471 W	Panama-Costa Rica border
24-May-91	20:59:45	WHP,HJS,WRD,ALP,EFF,GAR,JMF	20:50:55.3	16.483 S	70.718 W	Southern Peru

DATE	TIME (UTC)	STATIONS	ORIGIN TIME	LAT.	LONG.	REGION
03-Jun-91	05:16:38	WHP,HJS	05:05:15.1	39.980 N	74.641 W	Off coast Central Chile
10-Jun-91	17:44:07	EFF,GAR,JMF	17:35:49.3	23.750 N	45.356 W	North Atlantic Ridge
11-Jun-91	05:31:31	EFF,GAR,JMF,WHP,HJS	05:26:31.2	8.400 N	103.041 W	Off coast of Mexico
20-Jun-91	05:38:13	EFF,GAR,JMF,HJS	05:18:51.9	1.169 N	122.762 E	Minahassa Peninsula
21-Jun-91	04:54:32	WHP,HJS	04:50:55.0	13.088 N	89.471 W	El Salvador
21-Jun-91	06:31:33	EFF,GAR,JMF,WHP,HJS	06:27:37.5	13.297 N	89.793 W	El Salvador
22-Jun-91	00:34:25	WHP,HJS,EFF,GAR,JMF	00:30:27.2	23.986 N	108.491 W	Gulf of California
23-Jun-91	21:32:03	WHP,HJS,EFF,GAR,JMF	21:22:30.7	26.820 S	64.403 W	Argentina
02-Jul-91	04:42:28	WHP,HJS	04:38:21.4	12.737 N	88.230 W	Off coast Central America
02-Jul-91	05:34:12	WHP,HJS,EFF,GAR,JMF	05:14:30.2	1.124 S	99.917 E	Southern Sumatra
02-Jul-91	19:59:00	WRD,ALP,WHP,HJS	19:54:30.1	11.135 N	85.801 W	Nicaragua
02-Jul-91	20:25:20	WRD,ALP,WHP,HJS	20:20:48.3	11.171 N	85.696 W	Nicaragua
05-Jul-91	04:50:38	WHP,HJS	04:30:50.4	9.646 S	114.597 E	South of Bali Island
						Peru

APPENDIX B

List of recorded type II events

List of recorded type II events: emergent (E) and impulsive (I)
PB = Pleasant Bayou; GMc = Gladys McCall; HU = Hulin

DATE	DAY	TIME (UTC)	NETWORK	E	I	COMMENTS
01/11/91	Friday	21:29:00	PB	E		SONIC?
01/14/91	Monday	16:45:13	HU	E		SONIC? PRETTY FAST
01/16/91	Wednesday	21:09:13	HU		I	SONIC?
01/16/91	Wednesday	21:09:59	HU		I	SONIC? PART OF 21:09:13.
02/02/91	Saturday	20:32:23	PB		I	SONIC?
02/03/91	Sunday	17:09:30	HU	E	I	SONIC?
03/12/91	Tuesday	07:25:30	PB	E	I	SONIC?
03/12/91	Tuesday	07:40:35	HU	E	I	SONIC? SAME AS TX
04/13/91	Saturday	19:28:39	PB		I	SONIC?
05/10/91	Friday	20:10:27	PB	E		SONIC?
05/16/91	Thursday	19:11:53	HU		I	SONIC? BIG.
05/16/91	Thursday	19:41:25	PB	E		SONIC? BLAST ECHO?
05/18/91	Saturday	22:05:40	PB	E	I	SONIC EVENT?
05/20/91	Monday	17:16:32	PB	E		SONIC? BIG.
05/21/91	Tuesday	18:29:55	HU	E	I	SONIC?
06/01/91	Saturday	00:25:19	PB		I	SONIC? VERY BIG.
06/03/91	Monday	19:20:35	PB	E		SONIC? PRETTY SLOW.
06/17/91	Monday	16:32:14	PB	E		SONIC? BIG.
06/26/91	Sunday	18:57:15	PB	E		SONIC?
07/11/91	Thursday	06:16:00	HU	E		SONIC?
07/11/91	Thursday	15:46:55	GMc		I	SONIC?
07/16/91	Tuesday	15:00:29	HU	E		SONIC? PRETTY FAST.
07/25/91	Thursday	19:25:56	PB	E		SONIC?
07/30/91	Tuesday	19:17:25	PB	E		SONIC?
07/31/91	Wednesday	15:50:23	HU	E		SONIC? CHECK TX, RR
07/31/91	Wednesday	15:55:55	GMc	E		SONIC? CHECK HU, TX
07/31/91	Wednesday	16:08:45	PB	E		SONIC? CHECK RR, HU
08/02/91	Friday	19:12:11	PB		I	SONIC? SLOW.
08/03/91	Saturday	18:11:28	PB	E	I	SONIC?
08/04/91	Sunday	15:15:00	PB	E	I	Several sonic events.
08/11/91	Saturday	12:16:56	HU		I	VERY BIG. EXPLOSION?
08/14/91	Wednesday	15:31:15	HU		I	SONIC & Other sonic events.
08/21/91	Wednesday	09:01:17	PB	E	I	SONIC & Other sonic events.
08/23/91	Friday	16:10:25	PB		I	SONIC? PRETTY BIG.
08/26/91	Monday	23:27:00	PB	E		SONIC? VERY SLOW.
09/09/91	Friday	02:56:20	HU	E		SONIC? PRETTY FAST.
09/25/91	Wednesday	21:25:24	PB		I	SONIC? SLOW.
10/02/91	Wednesday	00:02:52	PB		I	SONIC, SLOW, IMPULSIVE.
10/02/91	Wednesday	04:02:25	HU		I	FAST. POSSIBLE EVENT?
10/05/91	Saturday	01:02:00	HU	E		SONIC?
10/18/91	Friday	00:46:24	HU	E	I	SONIC? VERY FAST.
10/19/91	Saturday	21:19:10	GMc	E		SONIC? SLOW.
10/24/91	Thursday	20:07:55	HU	E		SONIC?
11/07/91	Thursday	01:54:33	HU		I	FAST, IMPULSIVE.
12/03/91	Tuesday	01:37:24	PB		I	SONIC? PRETTY BIG.
12/03/91	Tuesday	16:44:26	GMc		I	SONIC? CHECK HU
12/03/91	Tuesday	16:46:38	HU		I	FAST SONIC? FELT?
12/03/91	Tuesday	20:47:15	PB	E		SONIC? LOW FREQUENCY.
12/08/91	Sunday	07:02:12	GMc	E		SONIC? CHECK HU
12/08/91	Sunday	07:05:53	HU	E		SONIC?
12/15/91	Sunday	12:10:16	HU		I	PLANT EXPLOSION

APPENDIX C

Bench mark data sheets for Hulin site, April 1991

BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

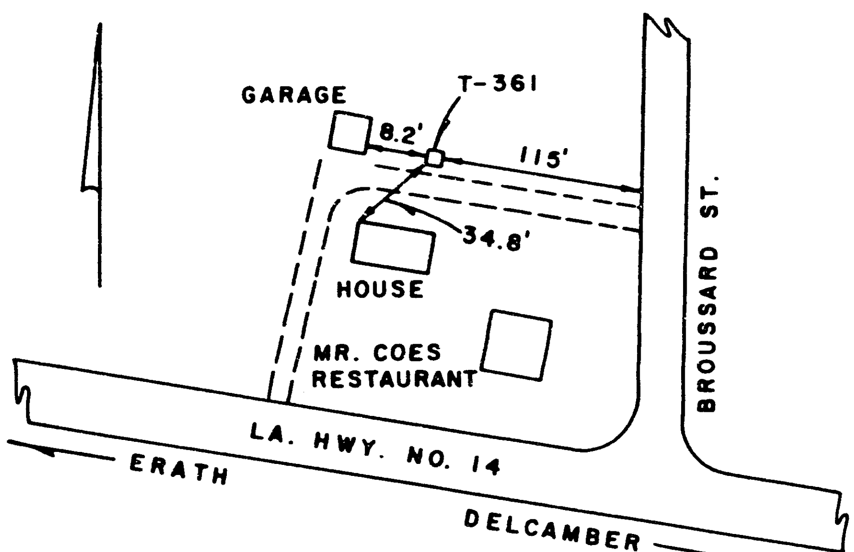
BENCH MARK NGS T-361 DATUM: NGVD 1929

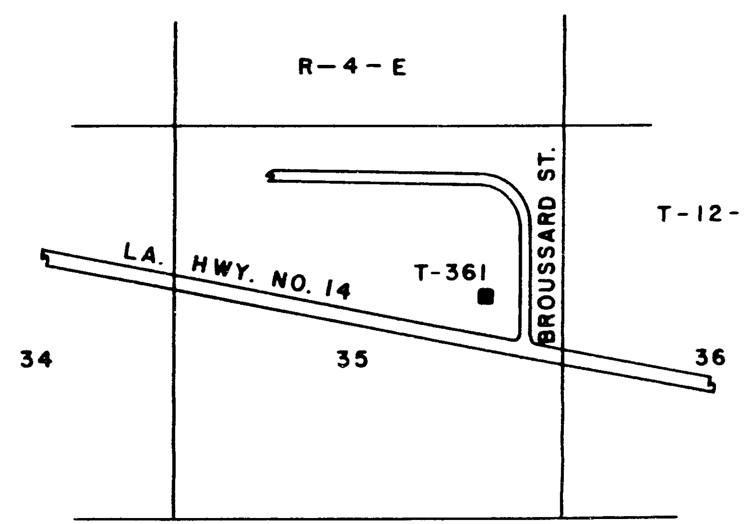
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.271	1.607
April 1991	5.271	1.607

DESCRIPTION:

The mark is located on the east edge of Erath, Louisiana. The station is located 150'+ northwest of the intersection of Hwy. No. 14 and Broussard Street, in the back yard of Mrs. Coes house.

SKETCH:





BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

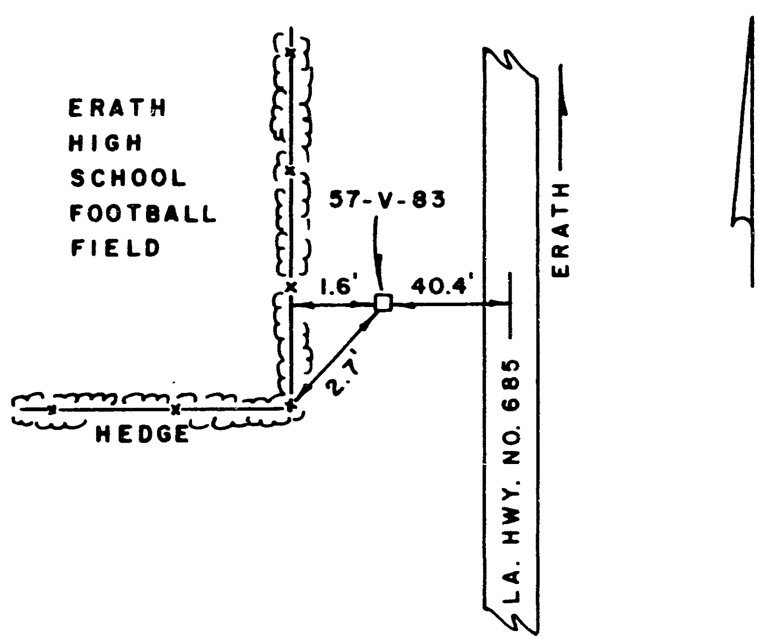
BENCH MARK NGS 57-V-83 DATUM: NGVD 1929

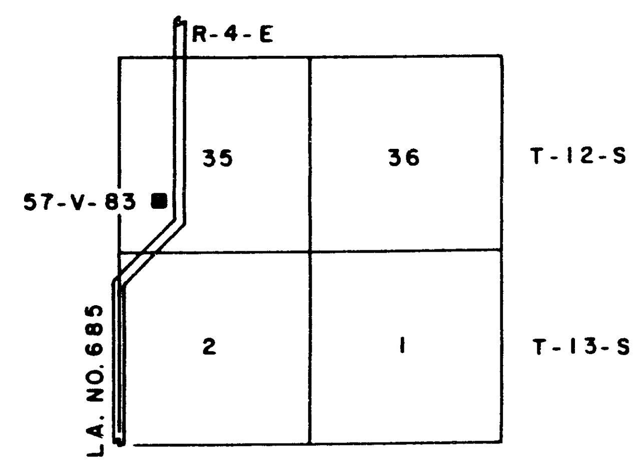
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.723	1.744
April 1991	5.768	1.758

DESCRIPTION:

The mark is located 0.58 mile south along LA Hwy. No. 685 from the intersection with LA Hwy. No. 14 in Erath, Louisiana. The station is a concrete monument with cap projecting 0.3' above ground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

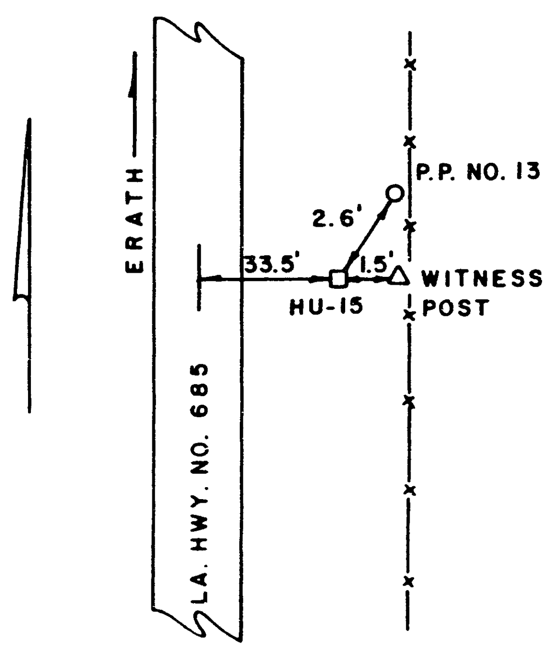
VERMILION PARISH, LOUISIANA

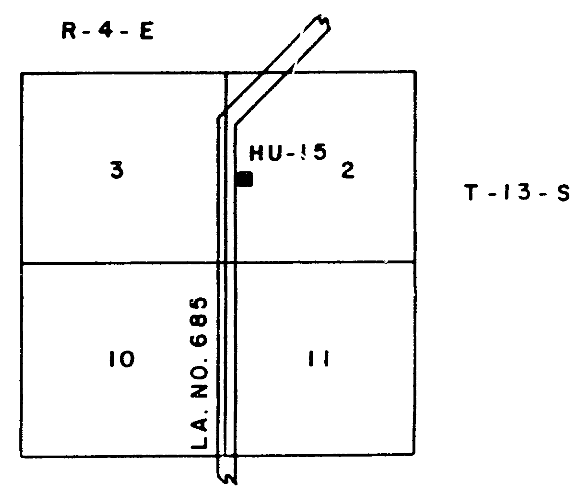
BENCH MARK HU-15	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	4.534	1.382
April 1991	4.532	1.381

DESCRIPTION:

The mark is located 1.11 miles south along LA Hwy. No. 685 from the intersection with LA Hwy. No. 14 in Erath, Louisiana. The station is a disk on top of a 5/8" rod and set 0.4' below ground.

SKETCH:





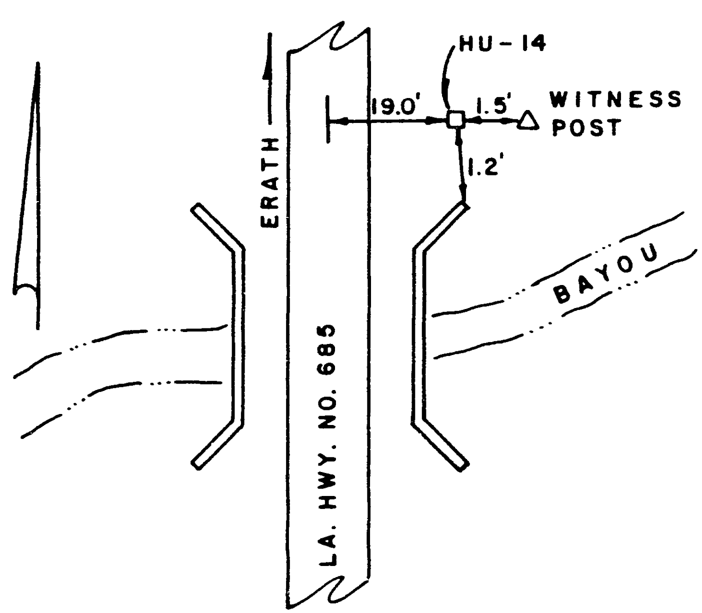
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE – GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

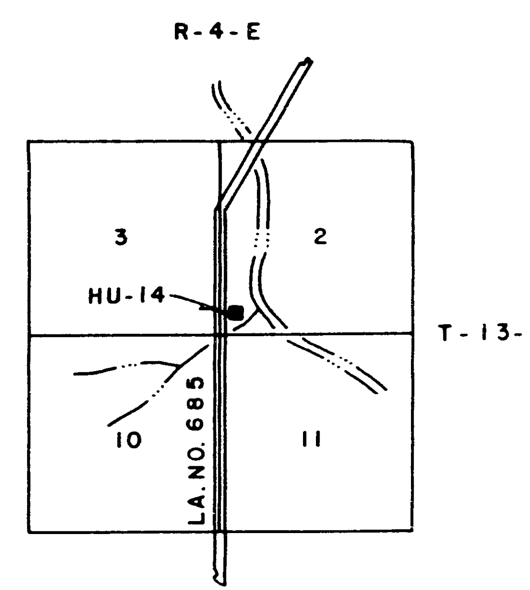
BENCH MARK HU-14	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.445	1.660
April 1991	5.433	1.656

DESCRIPTION:

The mark is located 1.79 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The station is a cap set on a 5/8" rod and is 0.3' below ground.

SKETCH:





BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE – GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

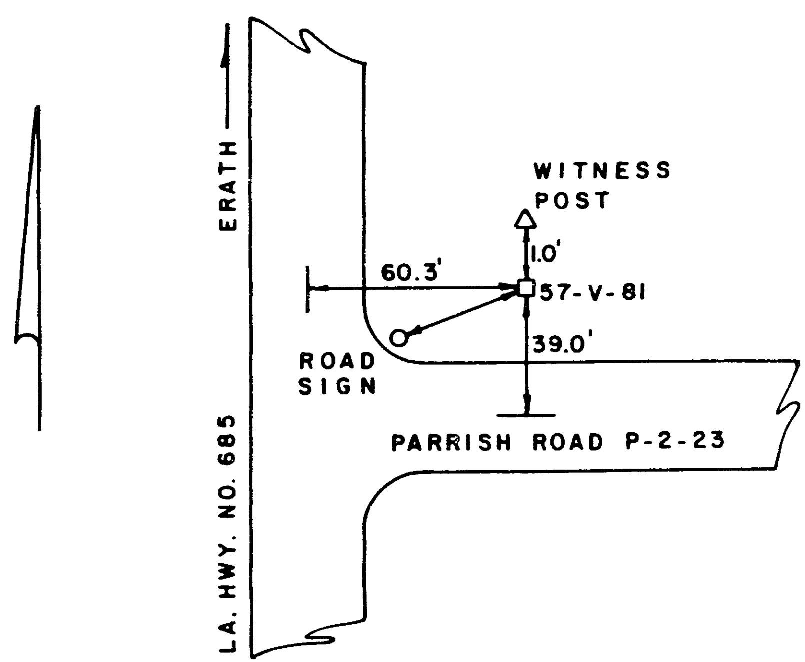
BENCH MARK 57-V-81 DATUM: NGVD 1929

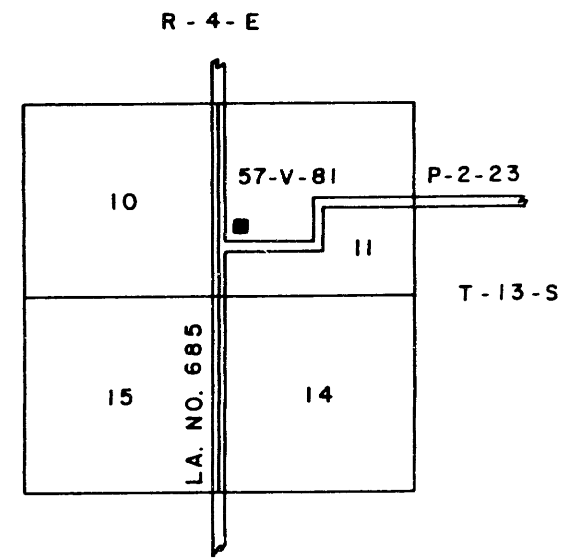
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	8.542	2.604
April 1991	8.518	2.596

DESCRIPTION:

The mark is located 2.51 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The station is a concrete monument flush with the ground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

VERMILION PARISH, LOUISIANA

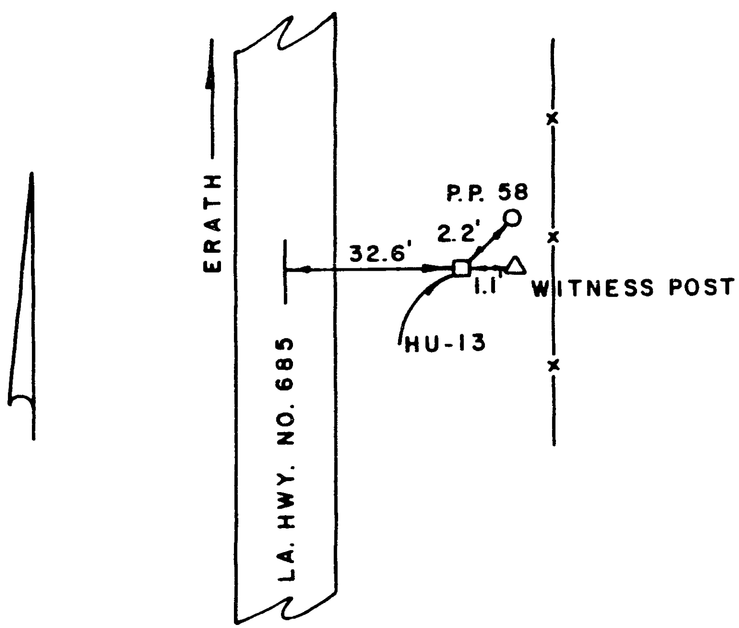
BENCH MARK HU-13 DATUM: NGVD 1929

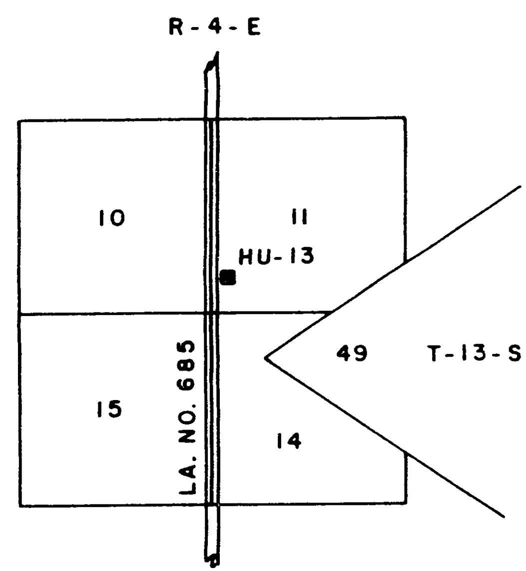
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	8.114	2.473
April 1991	8.085	2.464

DESCRIPTION:

The mark is located 2.68 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The station is a cap set on a 5/8" rod and is flush with the ground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

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GEOPRESSURE - GEOTHERMAL TEST WELL

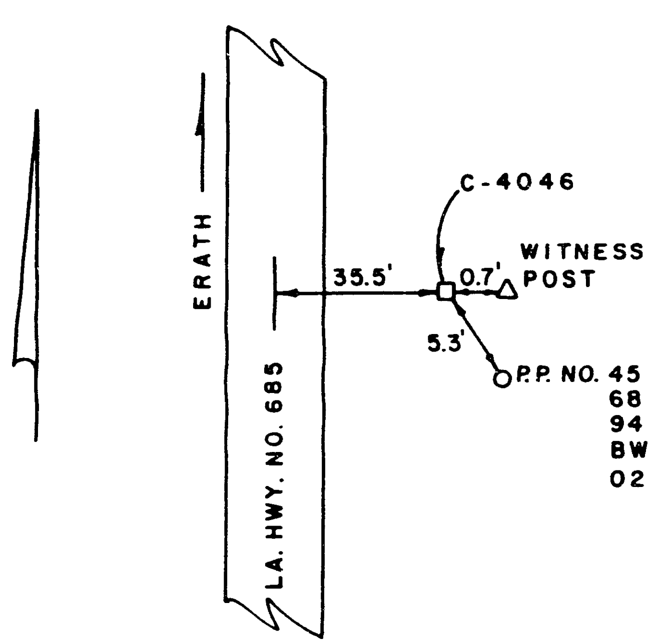
VERMILION PARISH, LOUISIANA

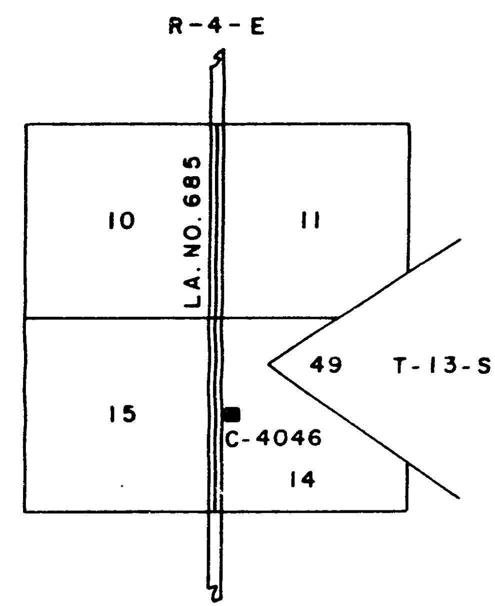
BENCH MARK C-4046	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	9.038	2.755
April 1991	9.003	2.744

DESCRIPTION:

The mark is located 3.35 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The station is a 5/8" rod and is 0.1' below ground.

SKETCH:





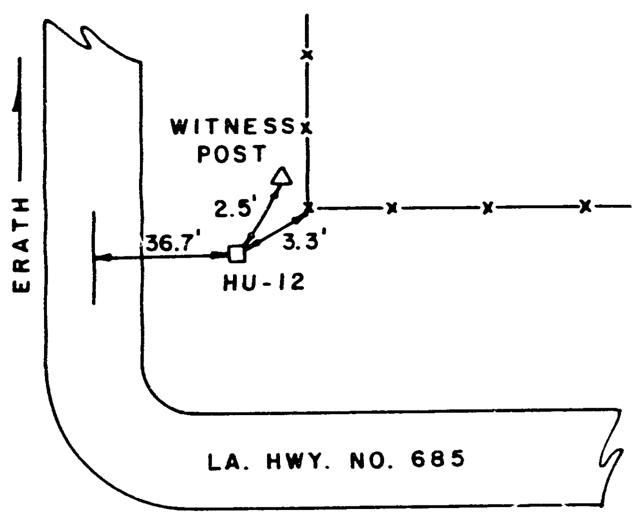
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

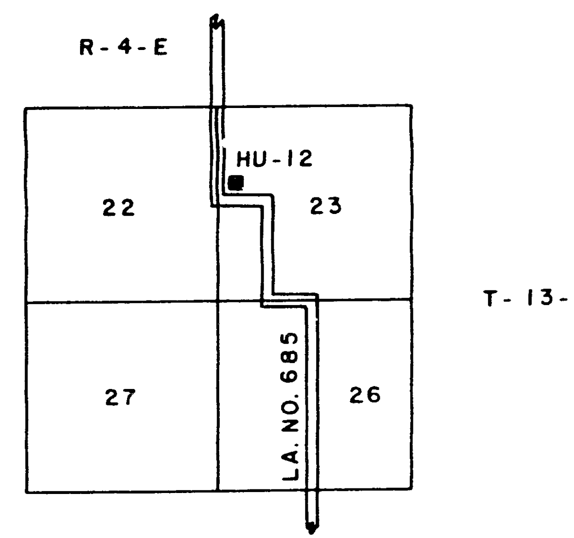
BENCH MARK HU-12	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	6.515	1.986
April 1991	6.466	1.971

DESCRIPTION:

The mark is located 4.26 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The station is a disk on a 5/8" rod set flush with the ground.

SKETCH:





BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
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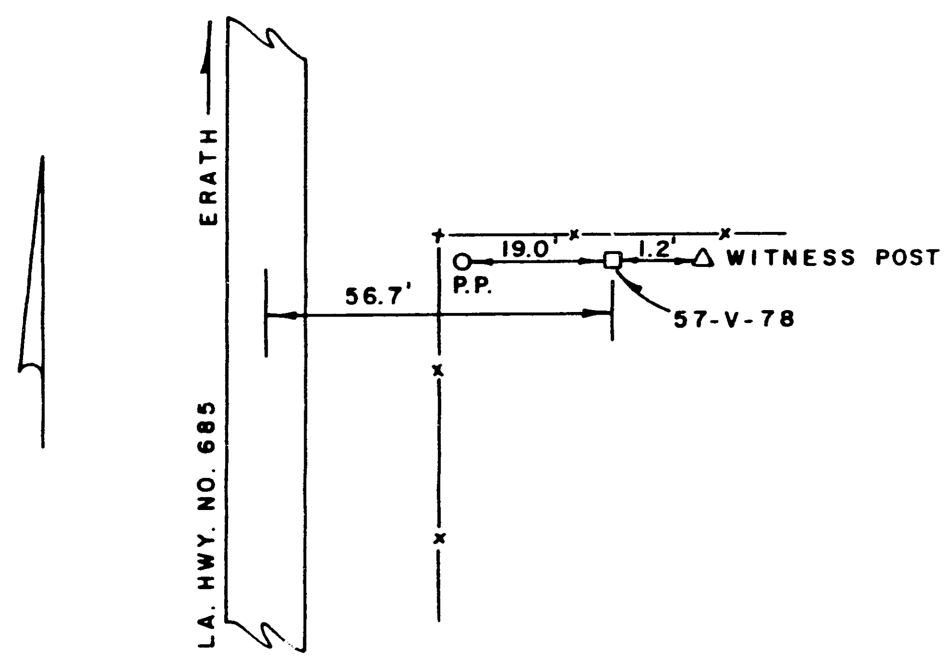
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

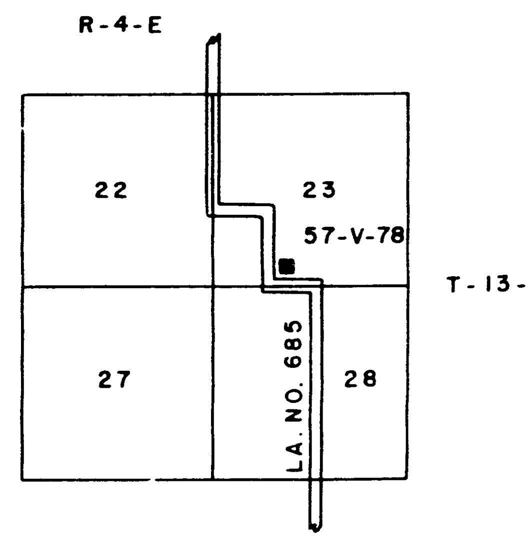
BENCH MARK 57-V-78	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	9.228	2.813
April 1991	9.202	2.805

DESCRIPTION:

The mark is located 4.74 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The mark is a cap on a 5/8" rod set 0.3' underground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

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GEOPRESSURE - GEOTHERMAL TEST WELL

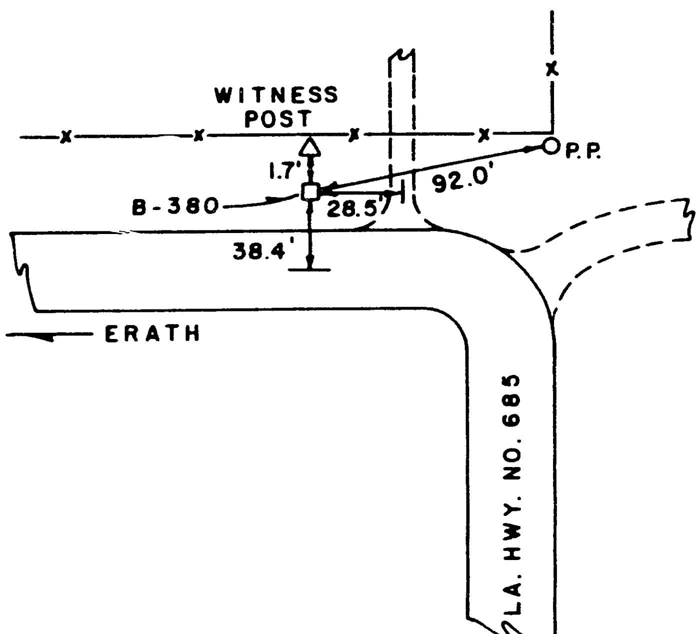
VERMILION PARISH, LOUISIANA

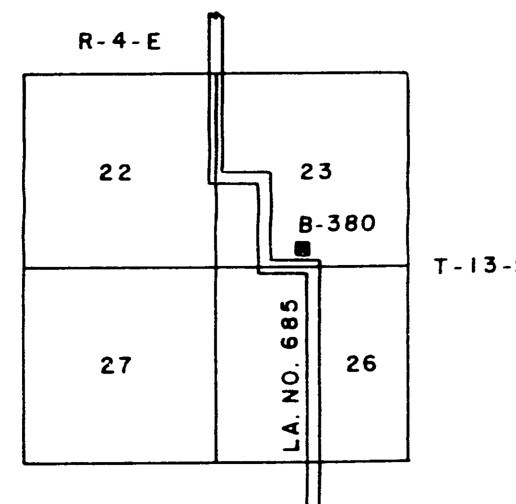
BENCH MARK B-380	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	6.394	1.949
April 1991	6.348	1.935

DESCRIPTION:

The mark is located 5.14 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, Louisiana. The station is a NGS rod set 0.4' underground.

SKETCH:





BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

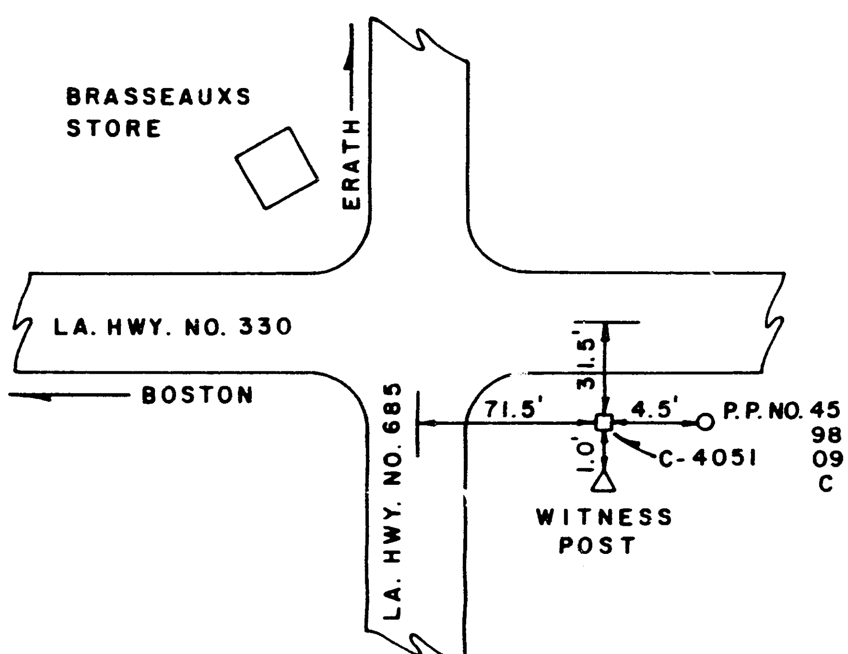
BENCH MARK C-4051 DATUM: NGVD 1929

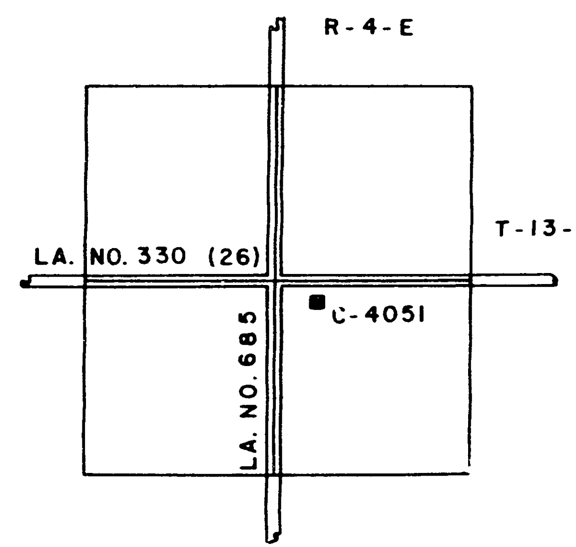
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	6.359	1.938
April 1991	6.317	1.925

DESCRIPTION:

The mark is located 5.70 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 14 in Erath, and at the intersection of LA Hwy. No. 330. The station is a concrete monument flush with the ground.

SKETCH:





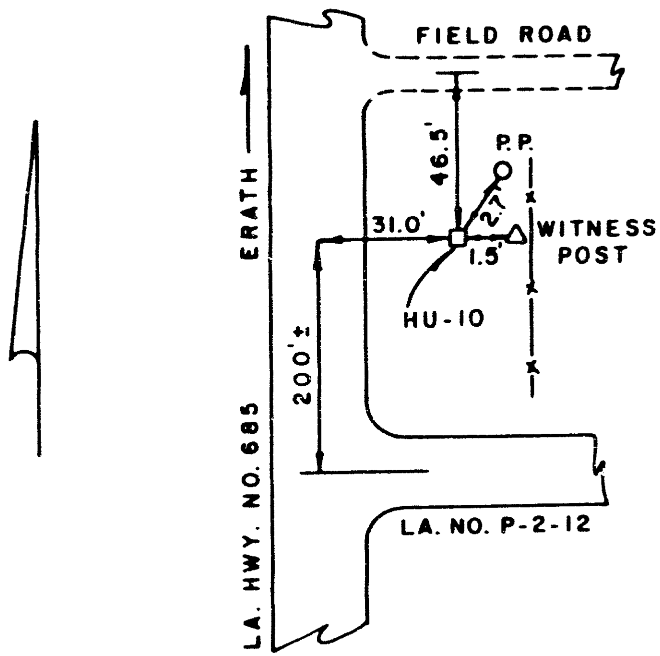
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

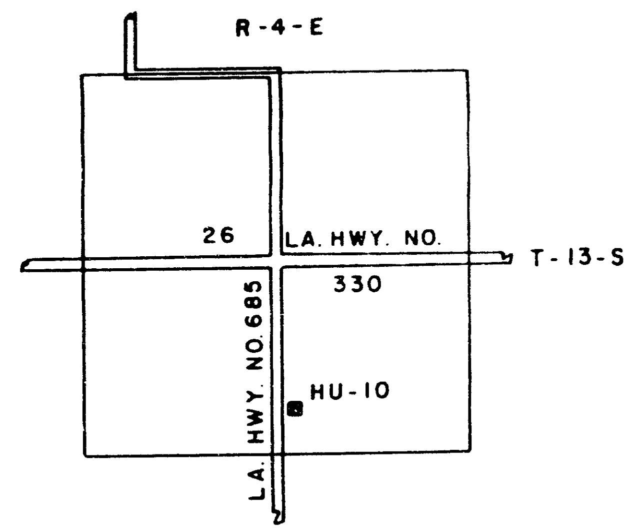
BENCH MARK HU-10	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.628	1.715
April 1991	5.581	1.701

DESCRIPTION:

The mark is located 0.43 mile south along LA Hwy. No. 685 from intersection of LA Hwy. No. 330. The station is a cap set on 5/8" rod and is 0.4' below ground.

SKETCH:





BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
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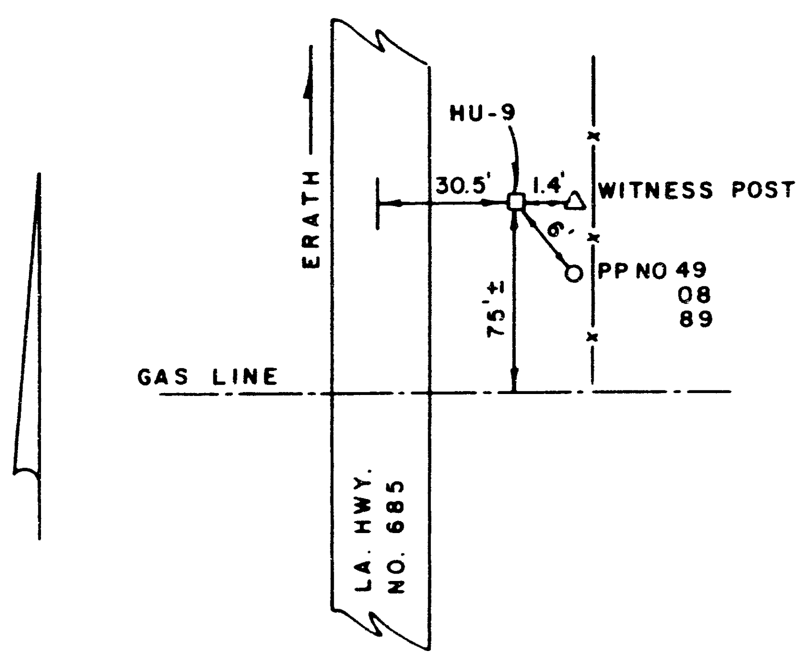
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

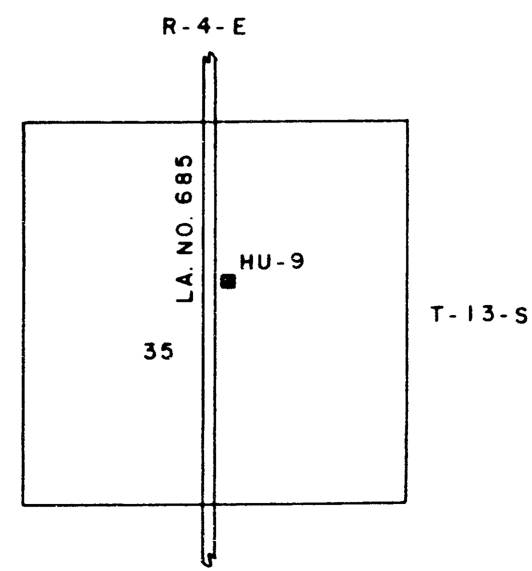
BENCH MARK HU-9	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	4.901	1.494
April 1991	4.852	1.479

DESCRIPTION:

The mark is located 0.84 mile south along LA Hwy. No. 685 from intersection of LA Hwy. No. 330. The station is a cap set on a 5/8" rod and is 0.4' below ground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

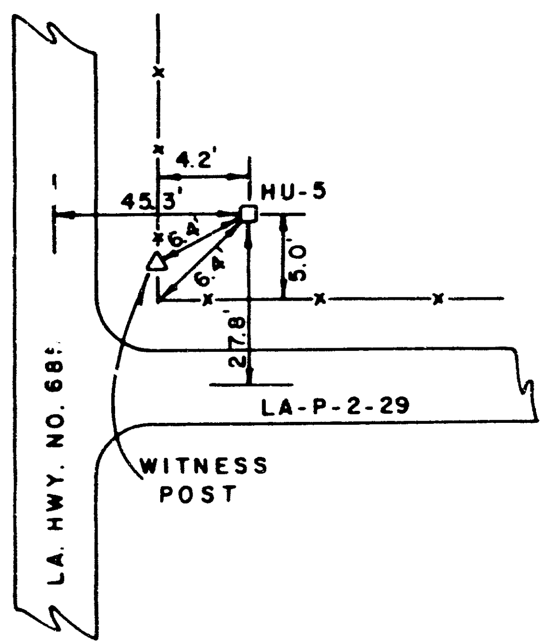
VERMILION PARISH, LOUISIANA

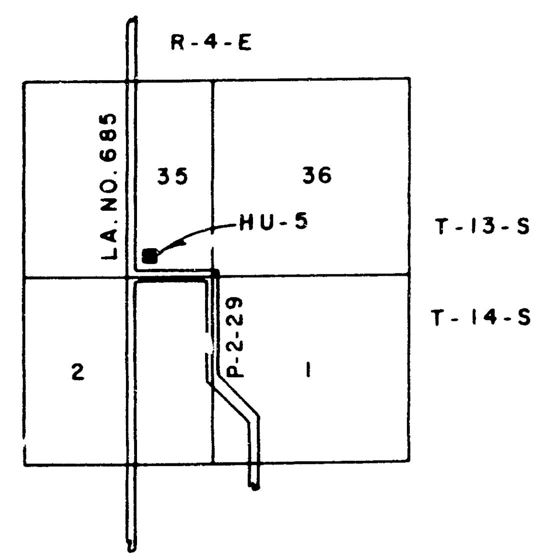
BENCH MARK HU-5	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	1.687	0.514
April 1991	1.636	0.499

DESCRIPTION:

The mark is located 1.65 mile south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 330 at the intersection of Parish Rd. P-2-29. The station is a cap on a 5/8" rod set 0.5' underground.

SKETCH:





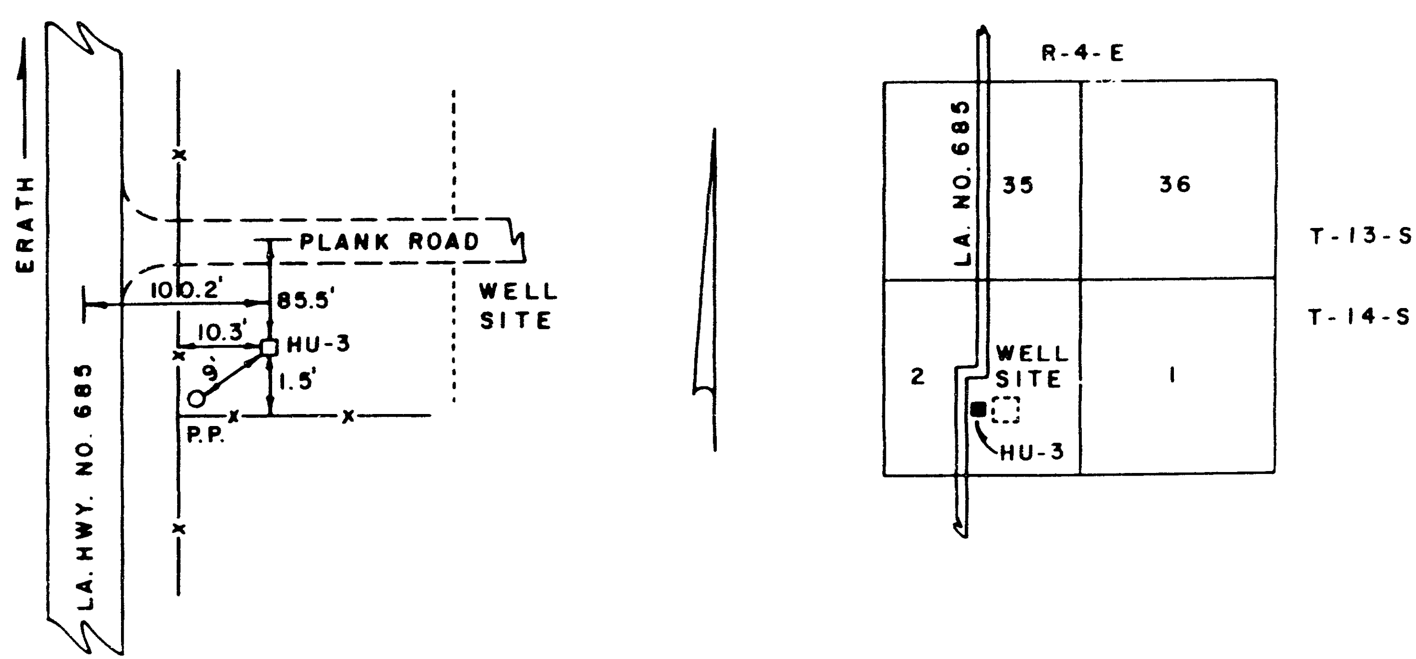
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

BENCH MARK HU-3	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	3.347	1.020
April 1991	3.301	1.006

DESCRIPTION:

The mark is located 2.13 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 330 and at the entrance to the Willis Hulin Well Site. The station is a cap on a 5/8" rod set 0.5' underground.

SKETCH:



BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

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GEOPRESSURE - GEOTHERMAL TEST WELL

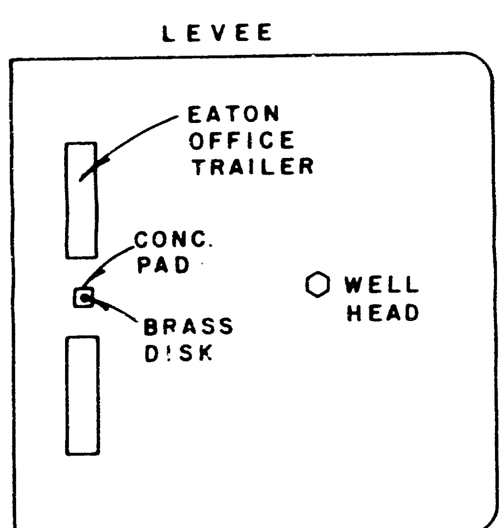
VERMILION PARISH, LOUISIANA

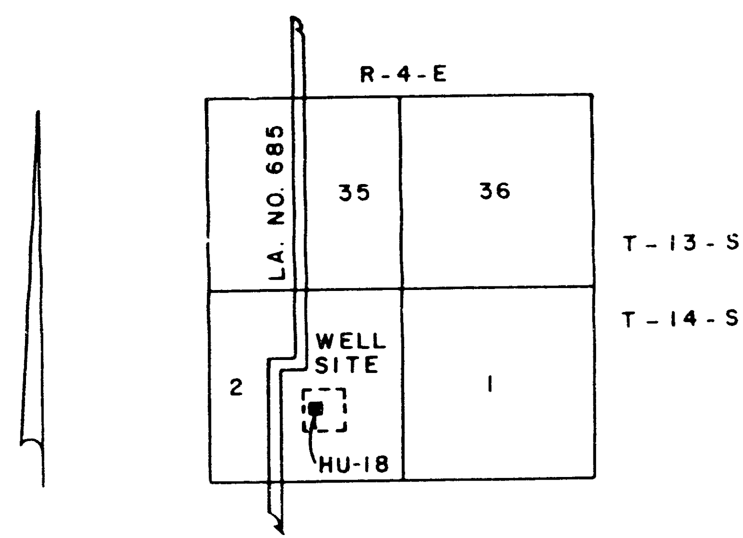
BENCH MARK HU-18	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
April 1991	3.945	1.202

DESCRIPTION:

The mark is located at the Willis Hulin Well Site and is a disk set in a concrete pad at the south end of the Eaton office trailer.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

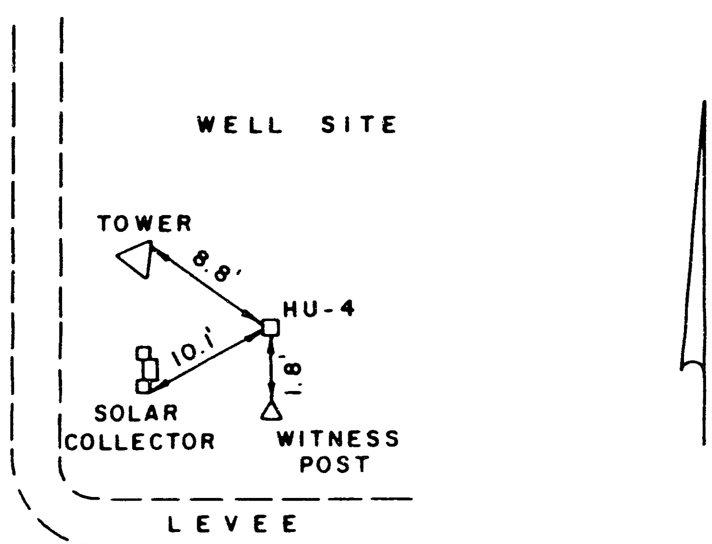
VERMILION PARISH, LOUISIANA

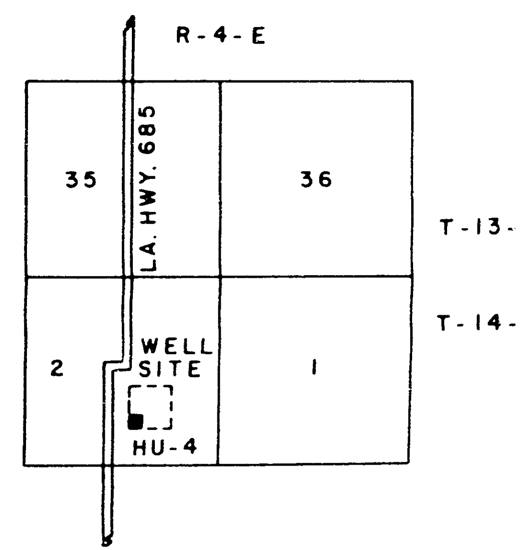
BENCH MARK HU-4	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.309	0.704
April 1991	2.261	0.689

DESCRIPTION:

The mark is located 2.13 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 330, and the southwest corner of the Willis Hulin Well Site. The station is a cap set on a 5/8" rod set 0.5' below ground.

SKETCH:





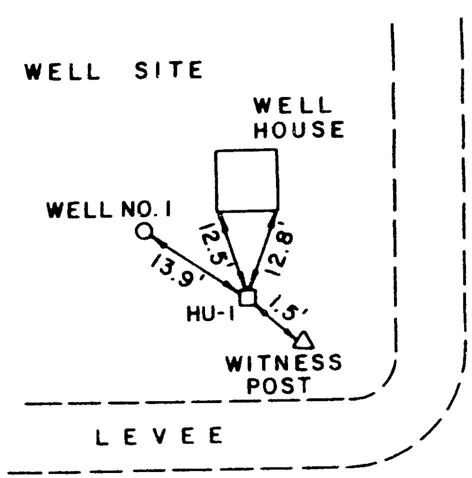
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

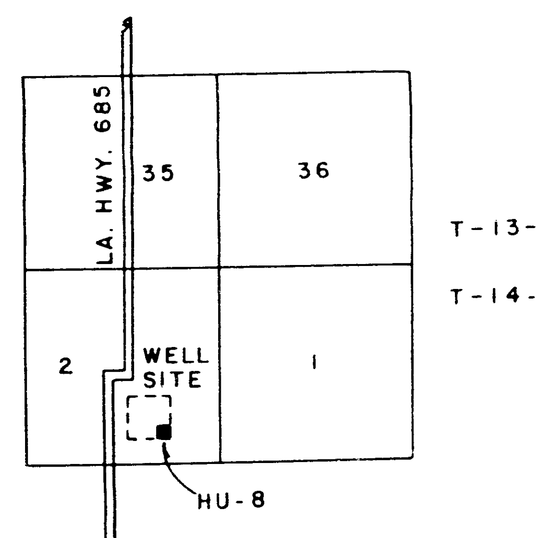
BENCH MARK HU-1	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.055	0.626
April 1991	2.006	0.611

DESCRIPTION:

The mark is located 2.13 miles south along LA Hwy. No. 685 from the intersectionof LA Hwy. No. 330 and in the southeast corner of the Willis Hulin Well Site. The station is a cap on a 5/8" rod set 0.5' underground.

SKETCH:





BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

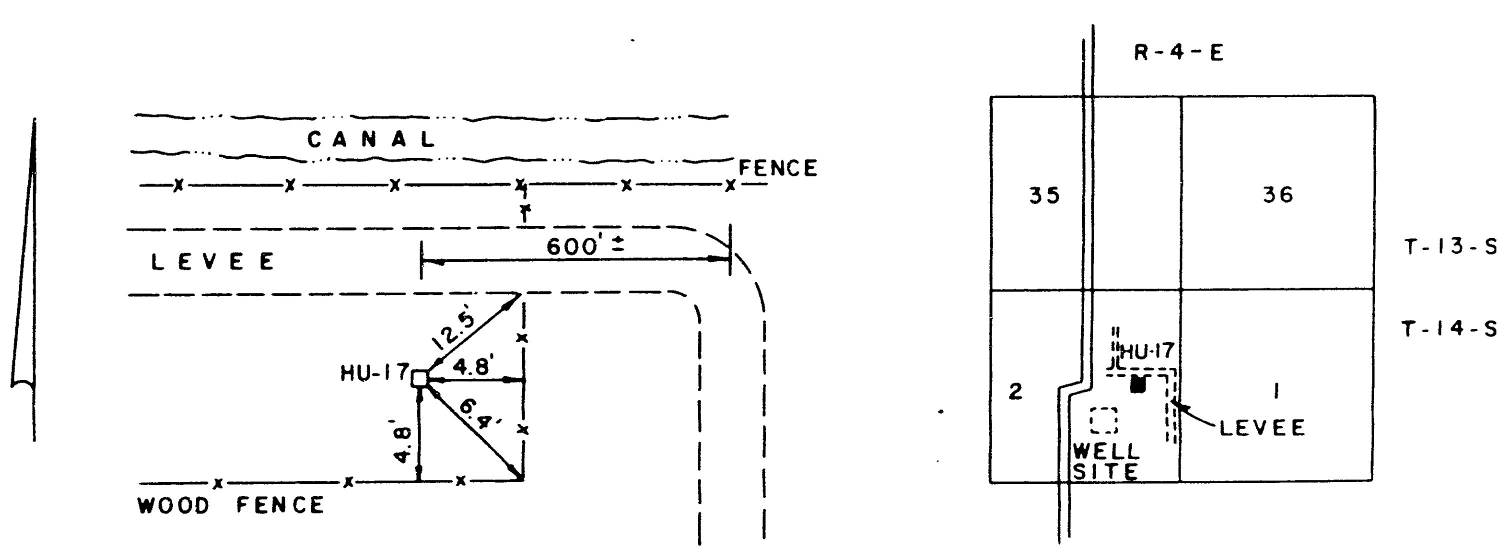
BENCH MARK HU-17 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.584	0.788
April 1991	2.533	0.772

DESCRIPTION:

The mark is located 900' northeast of the Willis Hulin Well Site. 600'± west of the corner of the levee and on the south toe. The station is a cap on a 5/8" rod and is 0.5' below ground.

SKETCH:



BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

VERMILION PARISH, LOUISIANA

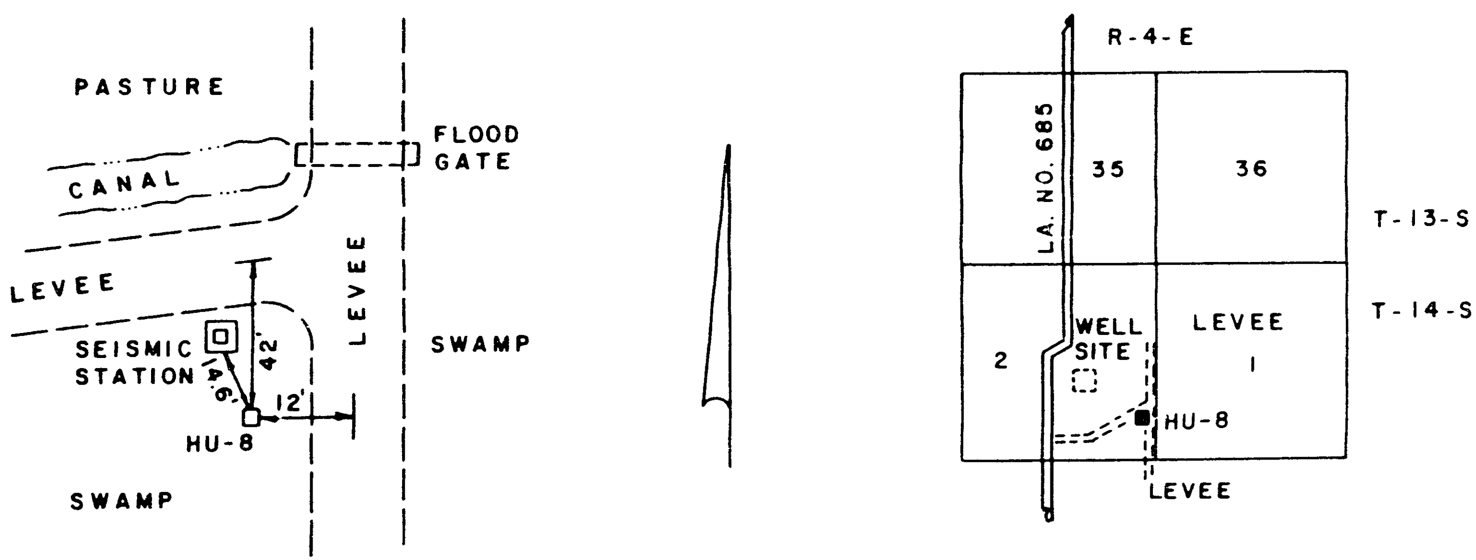
BENCH MARK HU-8 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.545	0.776
April 1991	NOT RECOVERED	

DESCRIPTION:

The mark is located 2.200 miles southeast of the Willis Hulin Well Site at the corner of the levees. The station is a cap on a 5/8" rod and is 0.4' below ground.

SKETCH:



BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

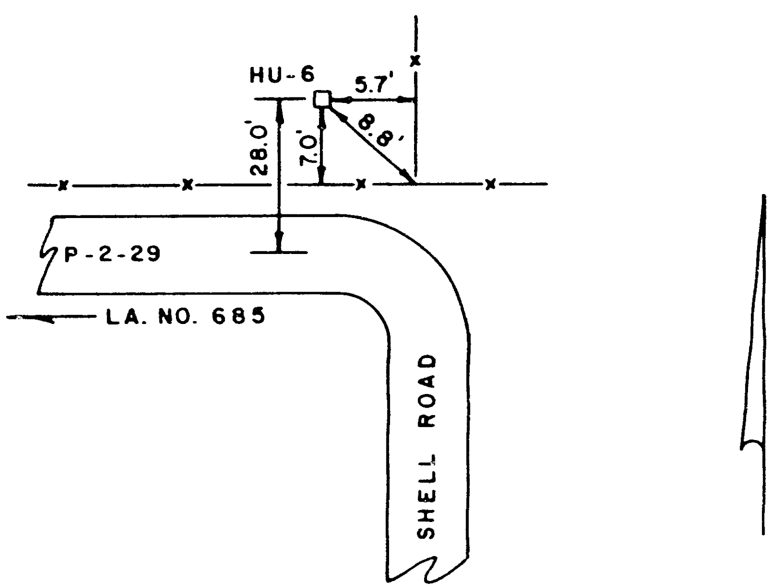
BENCH MARK HU-6 DATUM: NGVD 1929

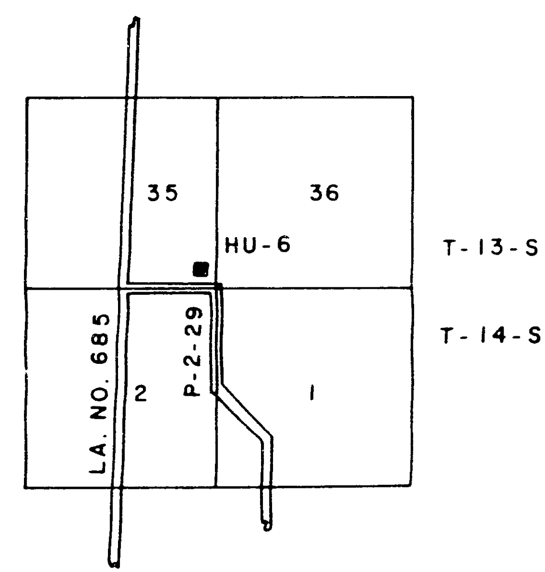
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	3.899	1.188
April 1991	3.846	1.172

DESCRIPTION:

The mark is located 0.65 mile south along LA Hwy. No. 685. Then 0.49 mile east along Parish Rd. P-2-29. The station is a disk on a 5/8" rod set 0.5' underground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

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GEOPRESSURE - GEOTHERMAL TEST WELL

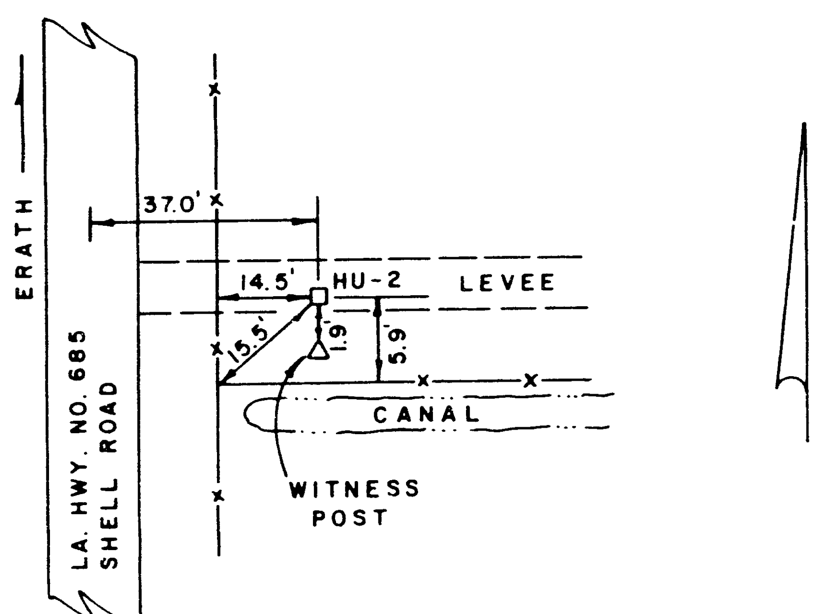
VERMILION PARISH, LOUISIANA

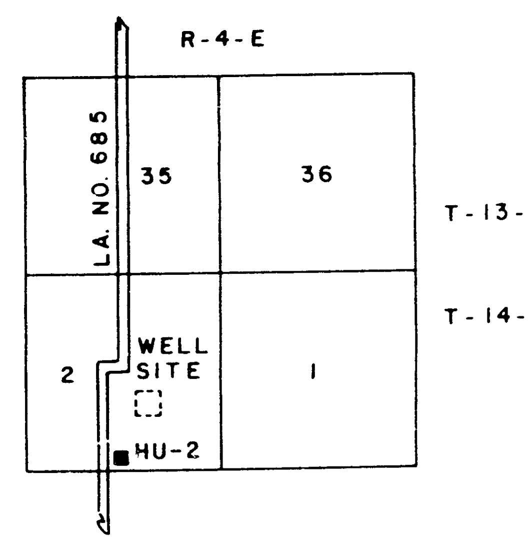
BENCH MARK HU-2	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	4.442	1.354
April 1991	4.404	1.342

DESCRIPTION:

The mark is located 2.52 miles south along LA Hwy. No. 685 from the intersection of LA Hwy. No. 330, and 0.39 mile south of the entrance road to the Willis Hulin Well Site. The station is a cap on a 5/8" rod 0.5' underground.

SKETCH:





BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

VERMILION PARISH, LOUISIANA

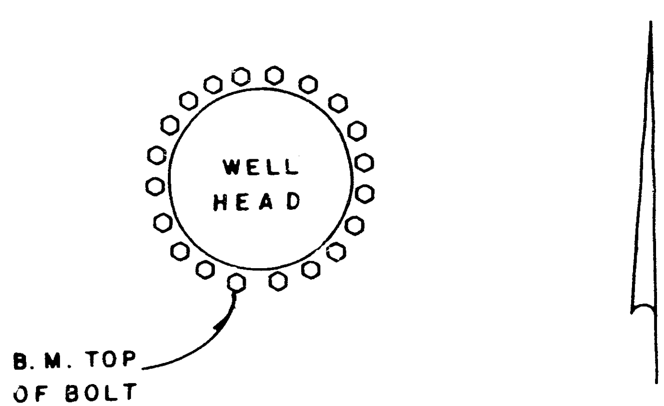
BENCH MARK Well Head DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.114	1.559
April 1991	5.049	1.539

DESCRIPTION:

The mark is the top of the western most of the two most southern bolts on the well head. The ring of bolts are approximately at ground level.

SKETCH:



APPENDIX D

Regional maps showing locations of wells recorded as having <25° API oil production in the Louisiana Office of Conservation 'PARS' computer data base

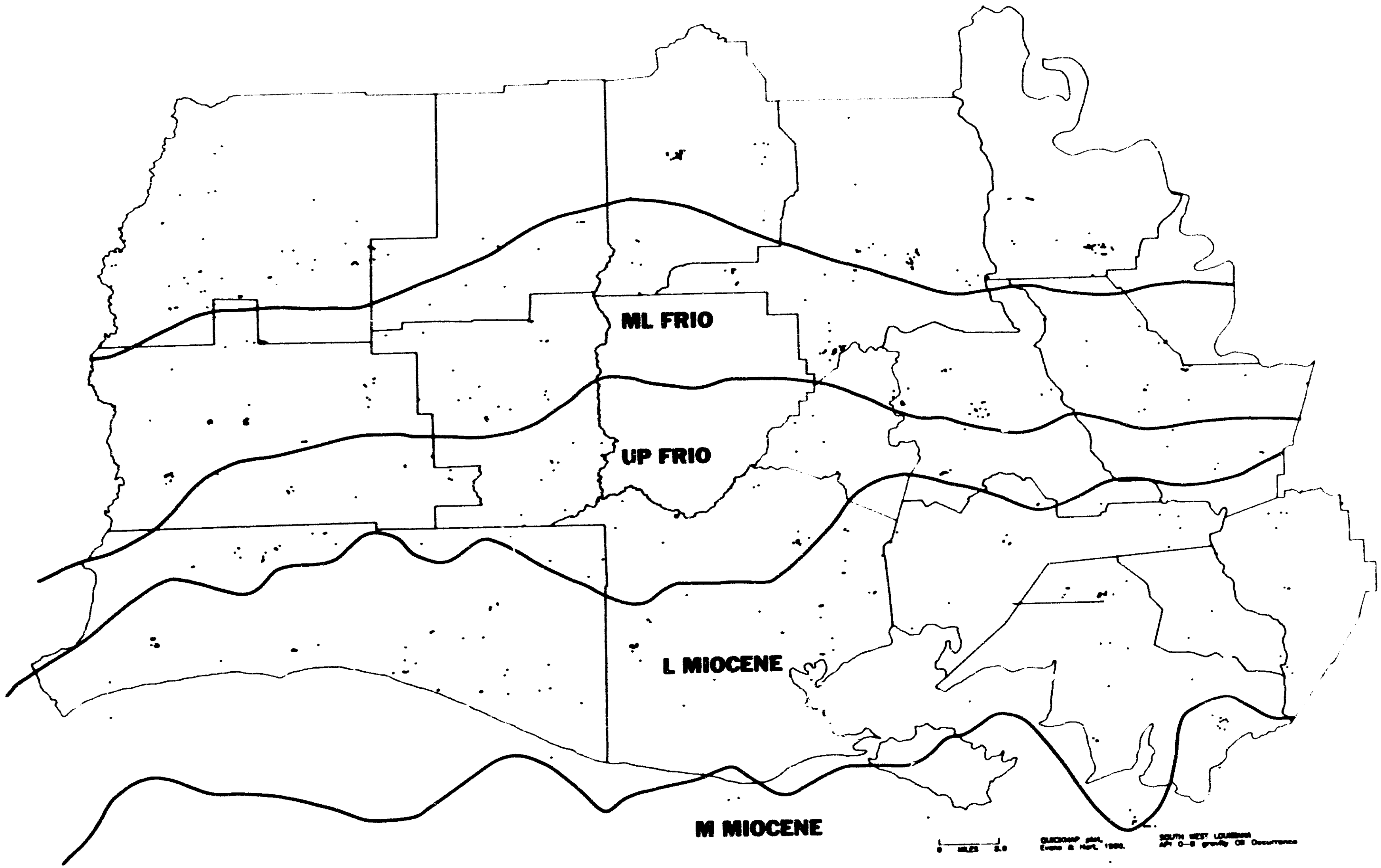


Figure D-1a. Map of southwest Louisiana showing locations of recorded 0–8° API gravity oil occurrences and geological age trends.

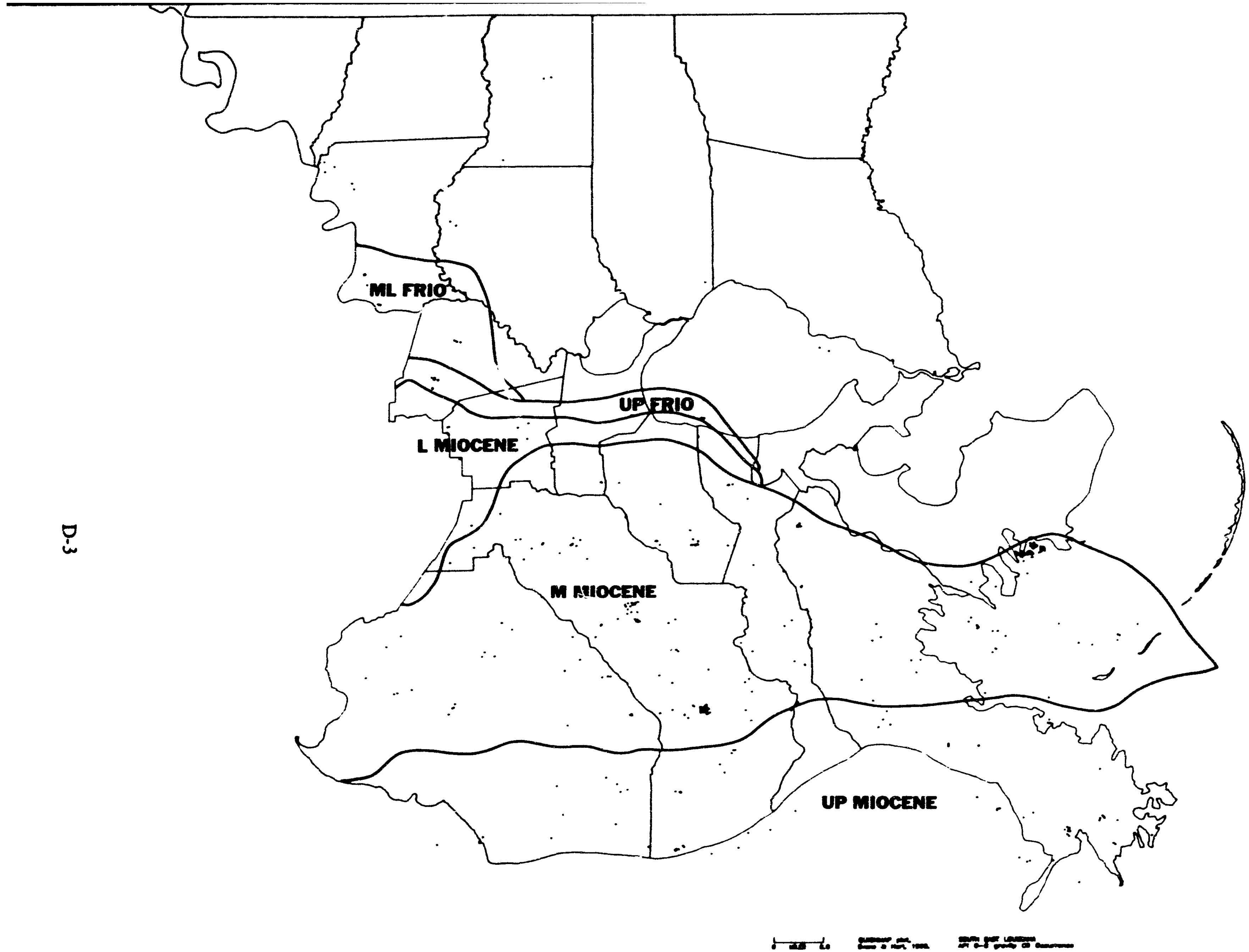


Figure D-1b. Map of southeast Louisiana showing locations of recorded 0–8° API gravity oil occurrences and geological age trends.

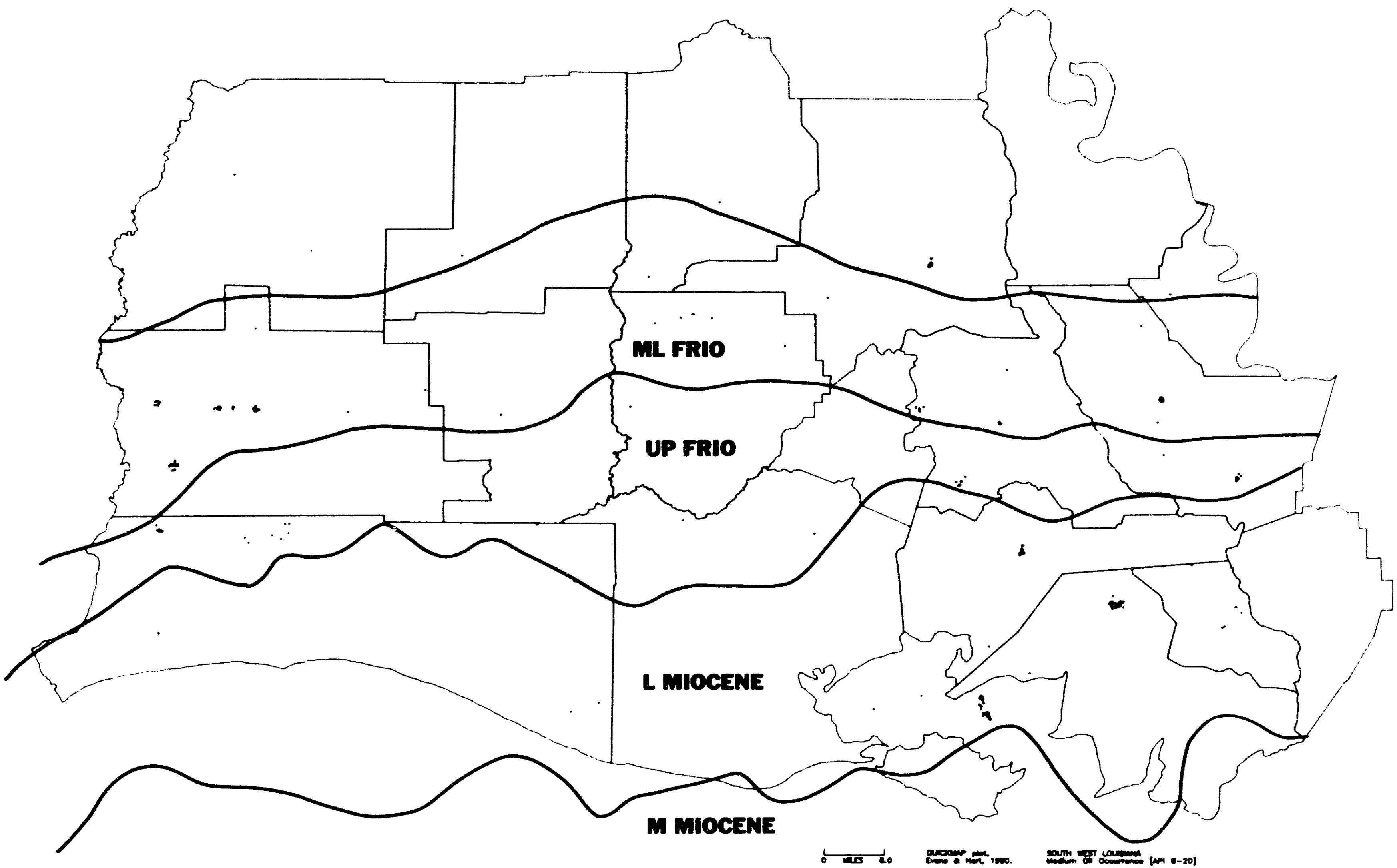


Figure D-2a. Map of southwest Louisiana showing locations of recorded 8–20° API gravity oil occurrences and geological age trends.

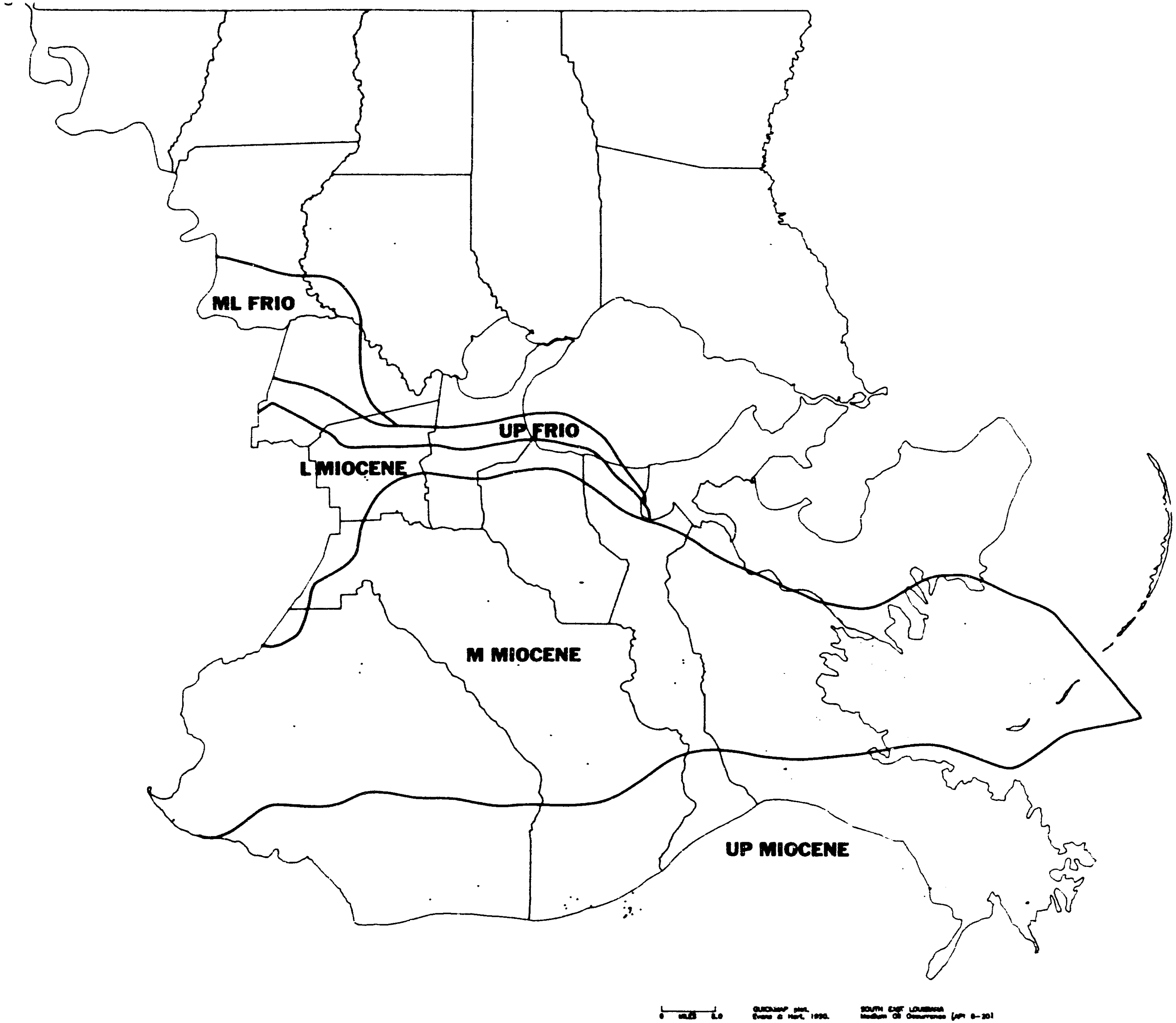


Figure D-2b. Map of southeast Louisiana showing locations of recorded 8–20° API gravity oil occurrences and geological age trends.

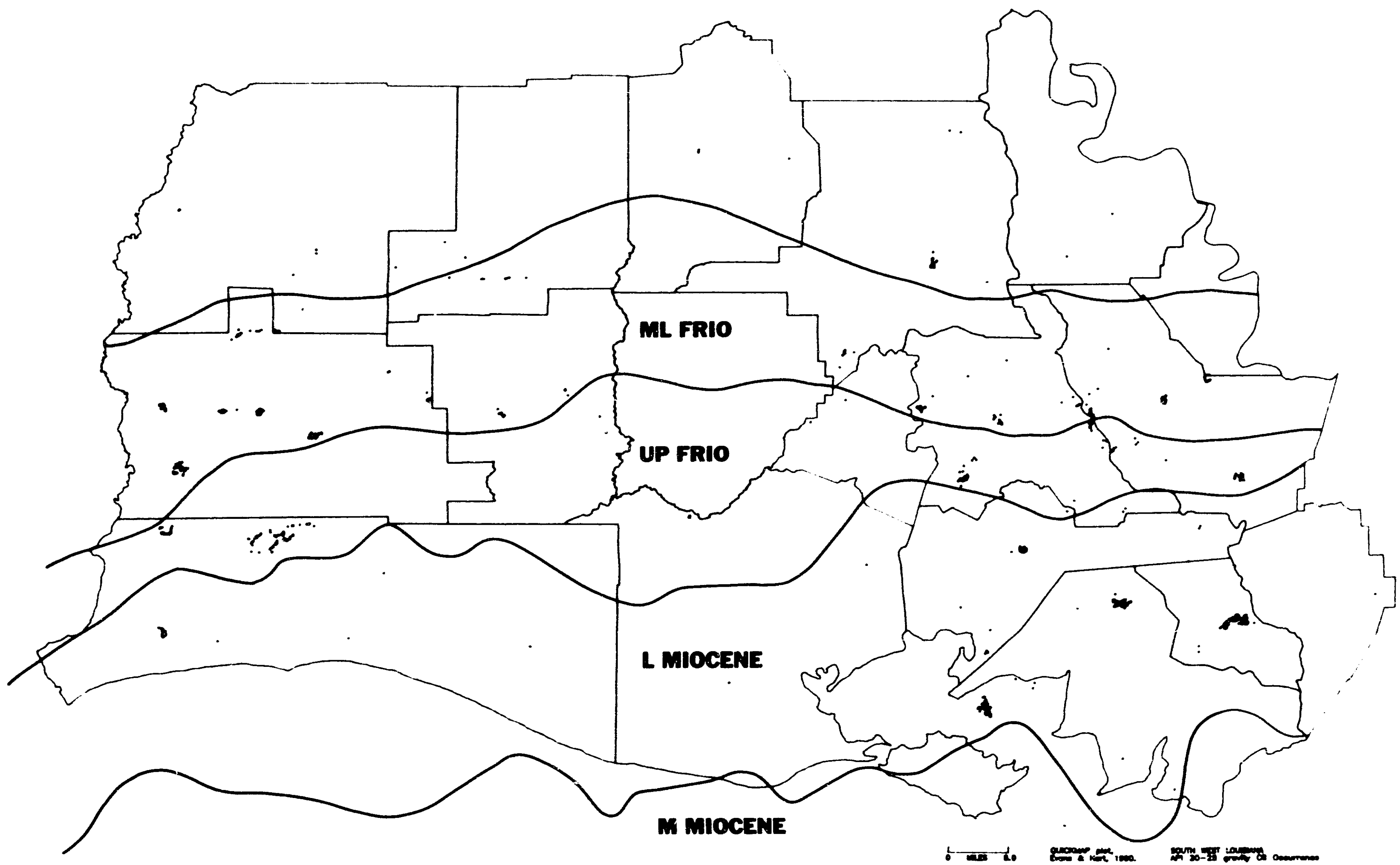


Figure D-3a. Map of southwest Louisiana showing locations of recorded 20–25° API gravity oil occurrences and geological age trends.

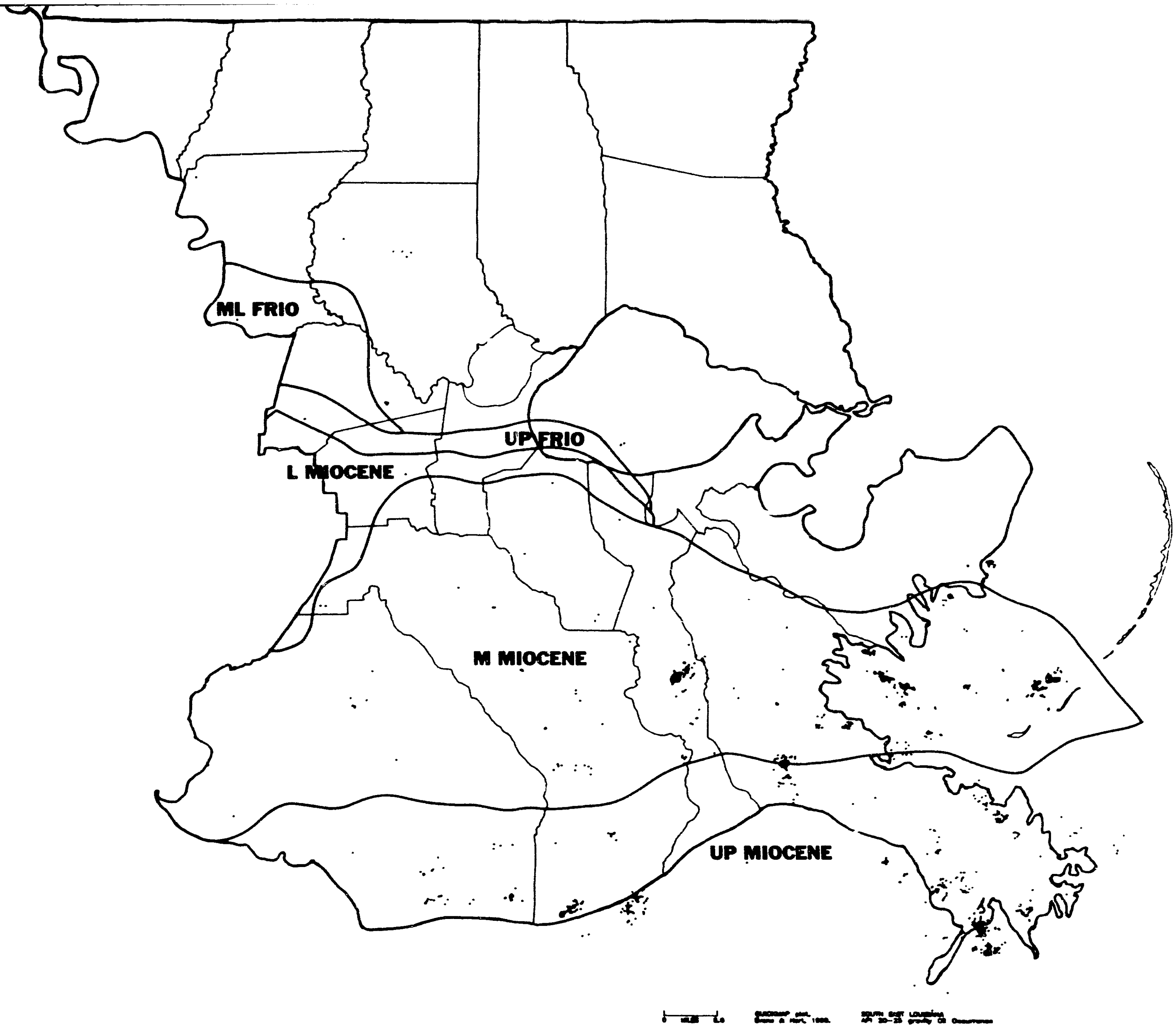


Figure D-3b. Map of southeast Louisiana showing locations of recorded 20–25° API gravity oil occurrences and geological age trends.

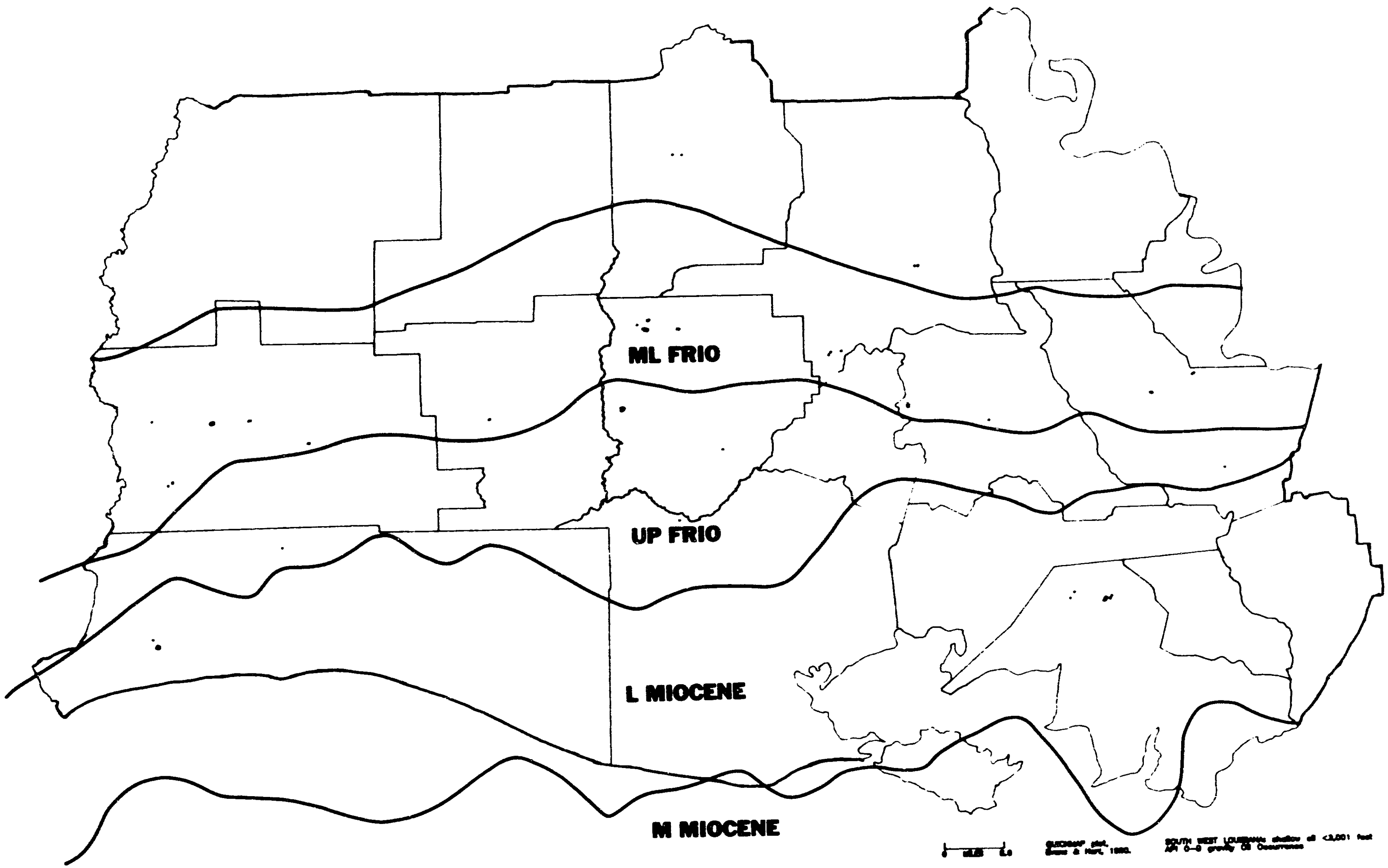


Figure D-4a. Map of southwest Louisiana showing locations of recorded occurrences of 0–8° API gravity oil at shallow depths (<3,001 ft) and geological age trends.

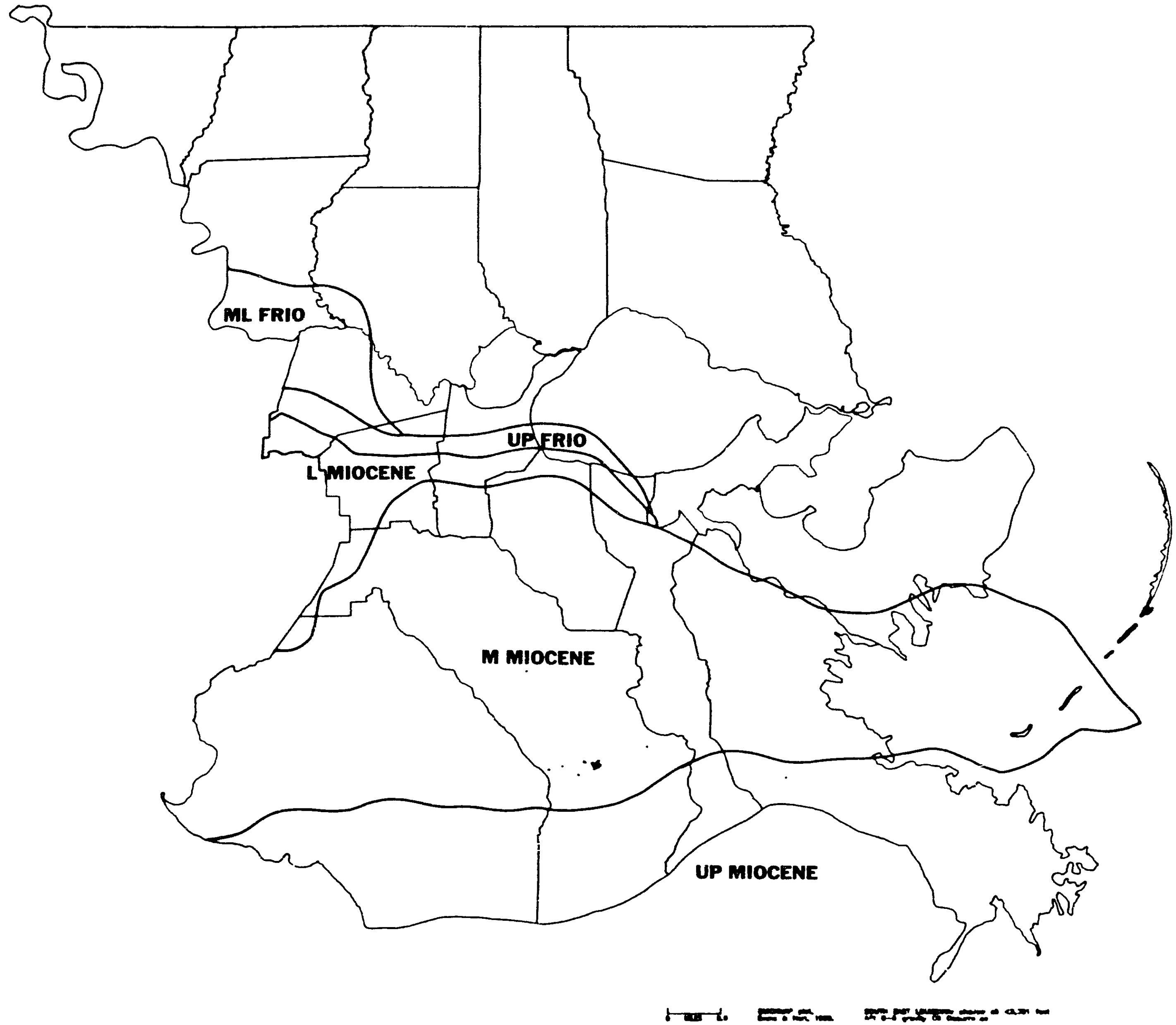


Figure D-4b. Map of southeast Louisiana showing locations of recorded occurrences of 0–8° API gravity oil and shallow depths (<3,001 ft) and geological age trends.

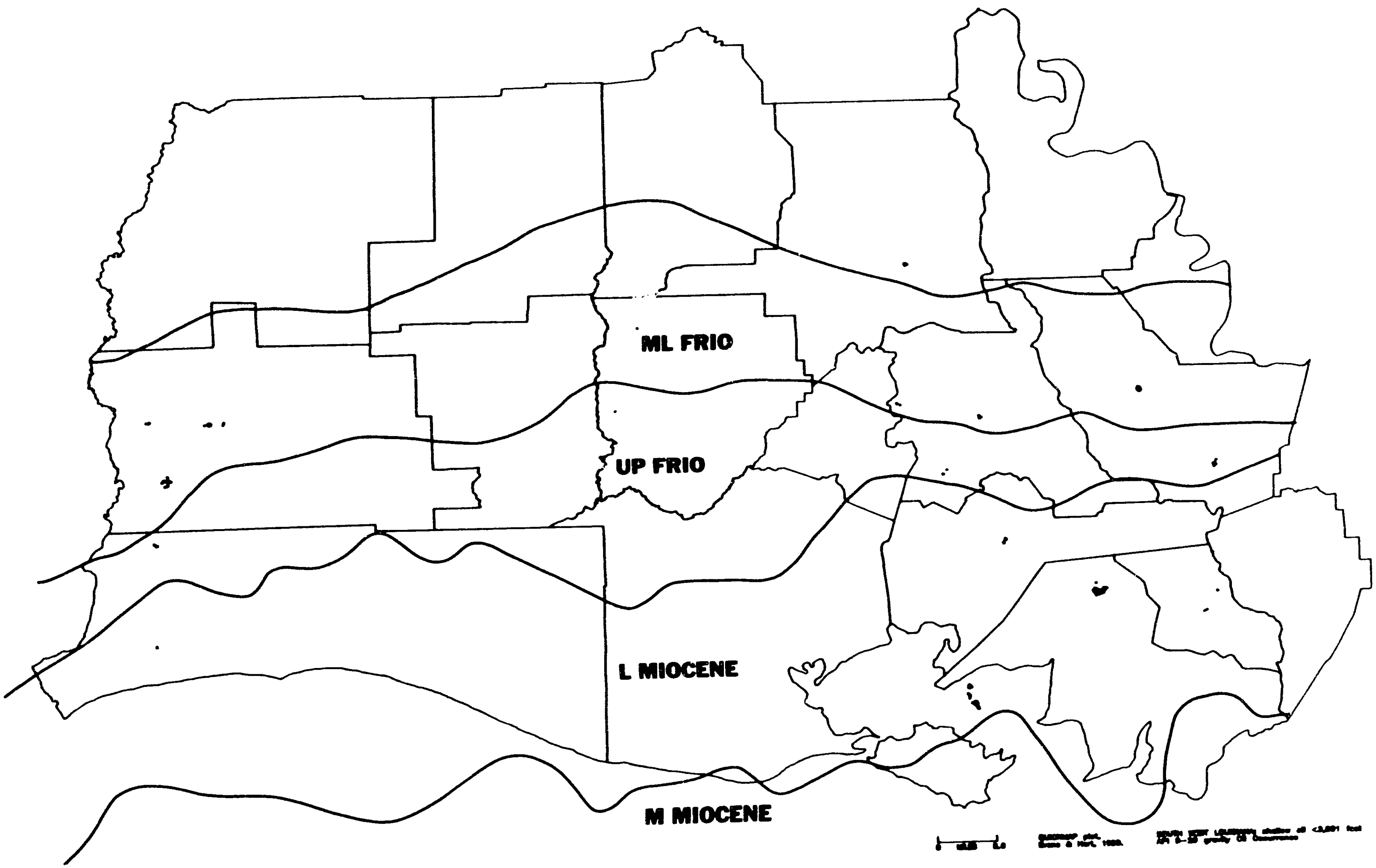


Figure D-5a. Map of southwest Louisiana showing locations of recorded occurrences of 8–20° API gravity oil at shallow depth (<3,001 ft) and geological age trends.

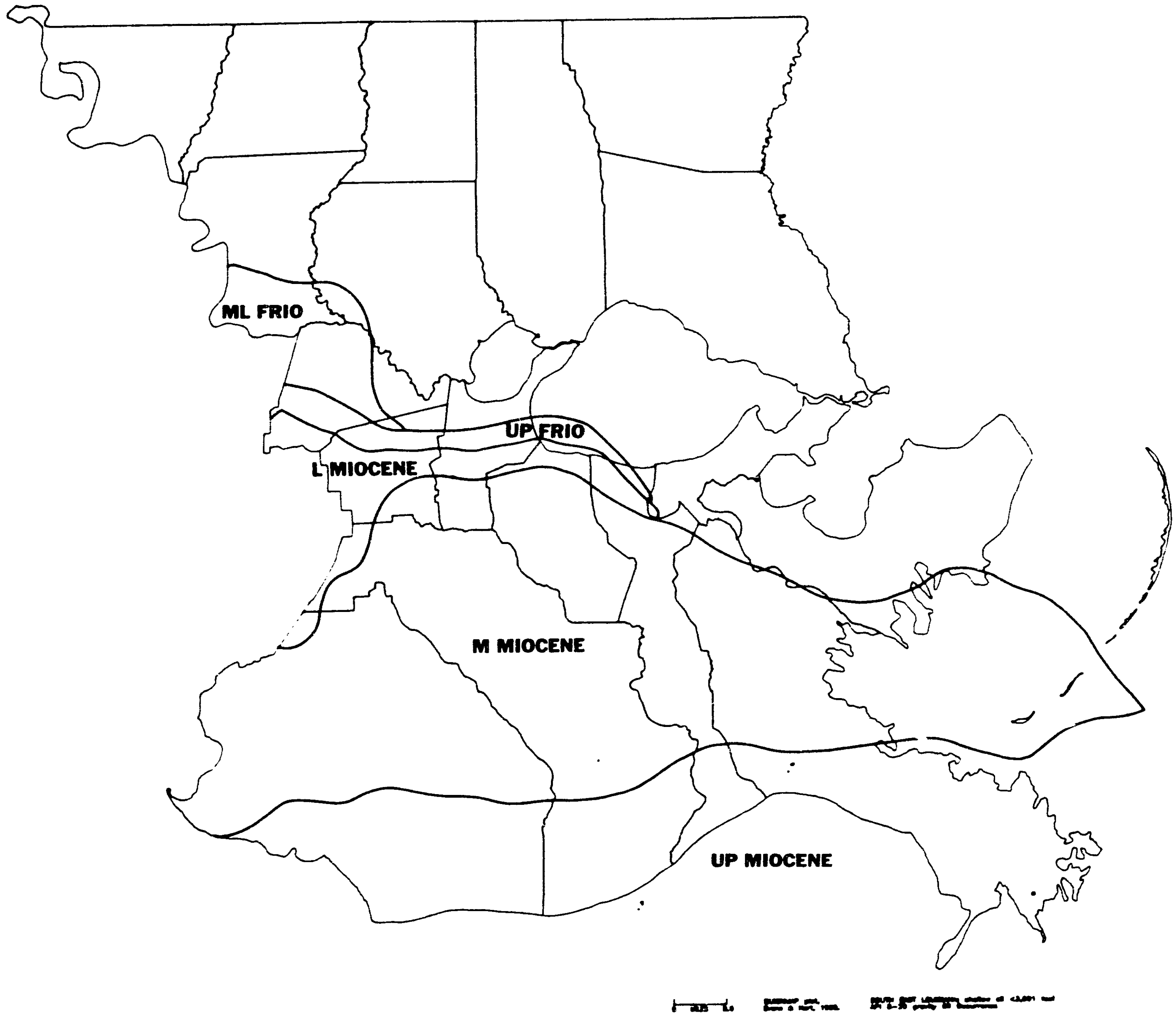


Figure D-5b. Map of southeast Louisiana showing locations of recorded occurrences of 8–20° API gravity oil at shallow depth (<3,001 ft) and geological age trends.

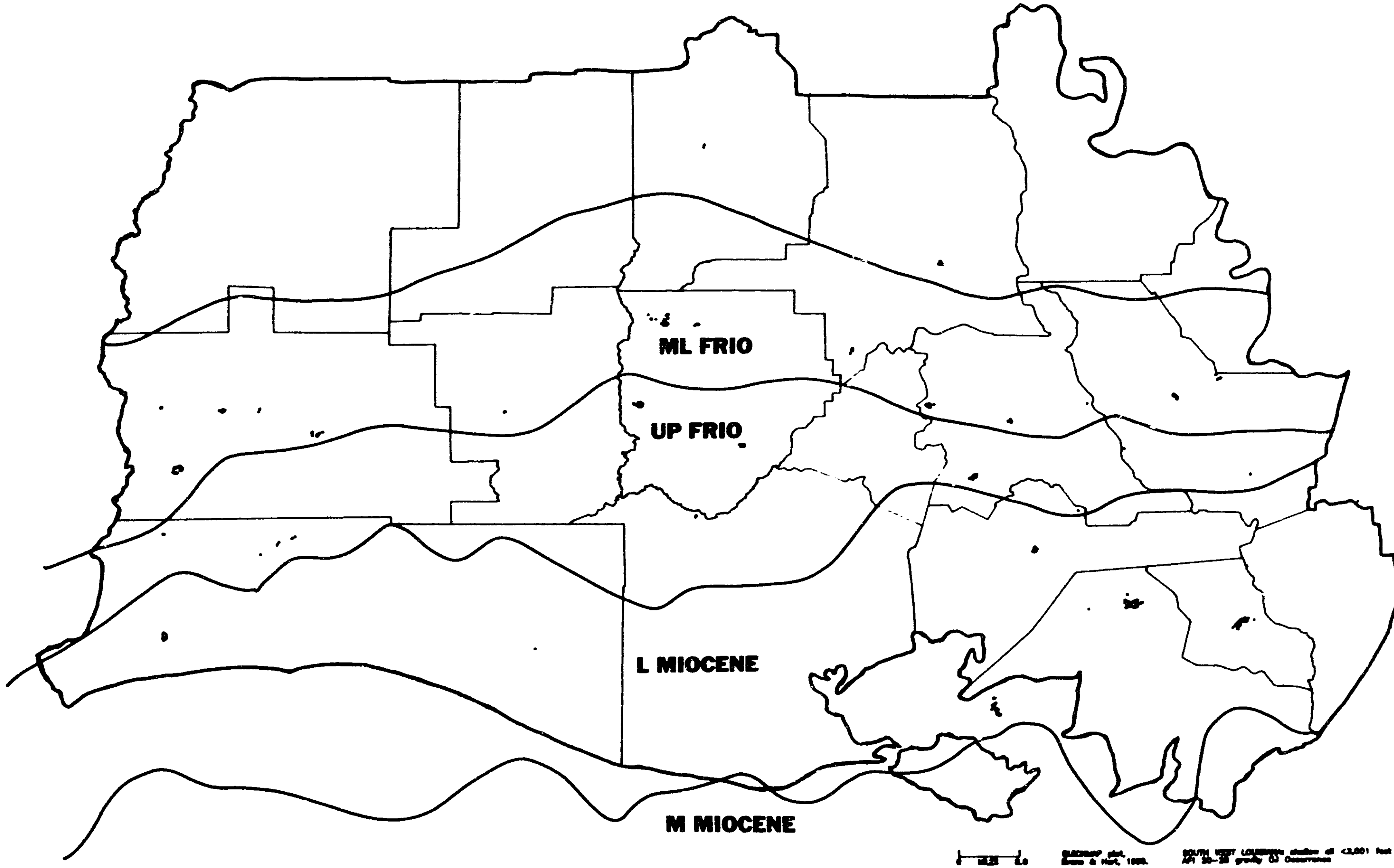


Figure D-6a. Map of southwest Louisiana showing locations of recorded occurrences of 20–25° API gravity oil at shallow depth (<3,001 ft) and geological age trends.

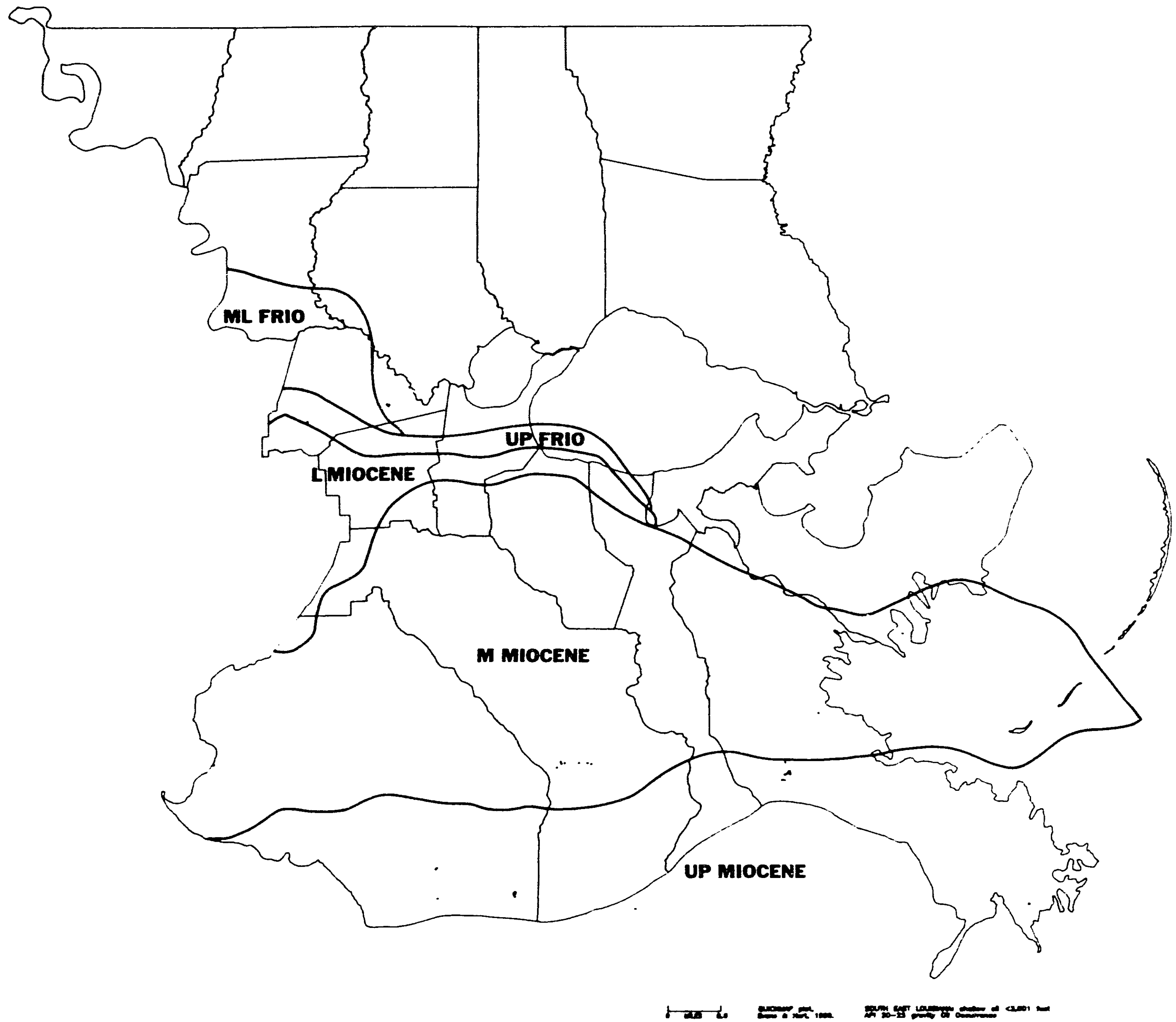


Figure D-6b. Map of southeast Louisiana showing locations of recorded occurrences of 20–25° API gravity oil at shallow depth (<3,001 ft) and geological age trends.

APPENDIX E

Parish maps identifying oil fields
with recorded <25° API gravity production
at less than 3,001 ft depth located in the
Miocene and Frio (Oligocene)
Geopressured-geothermal trend.

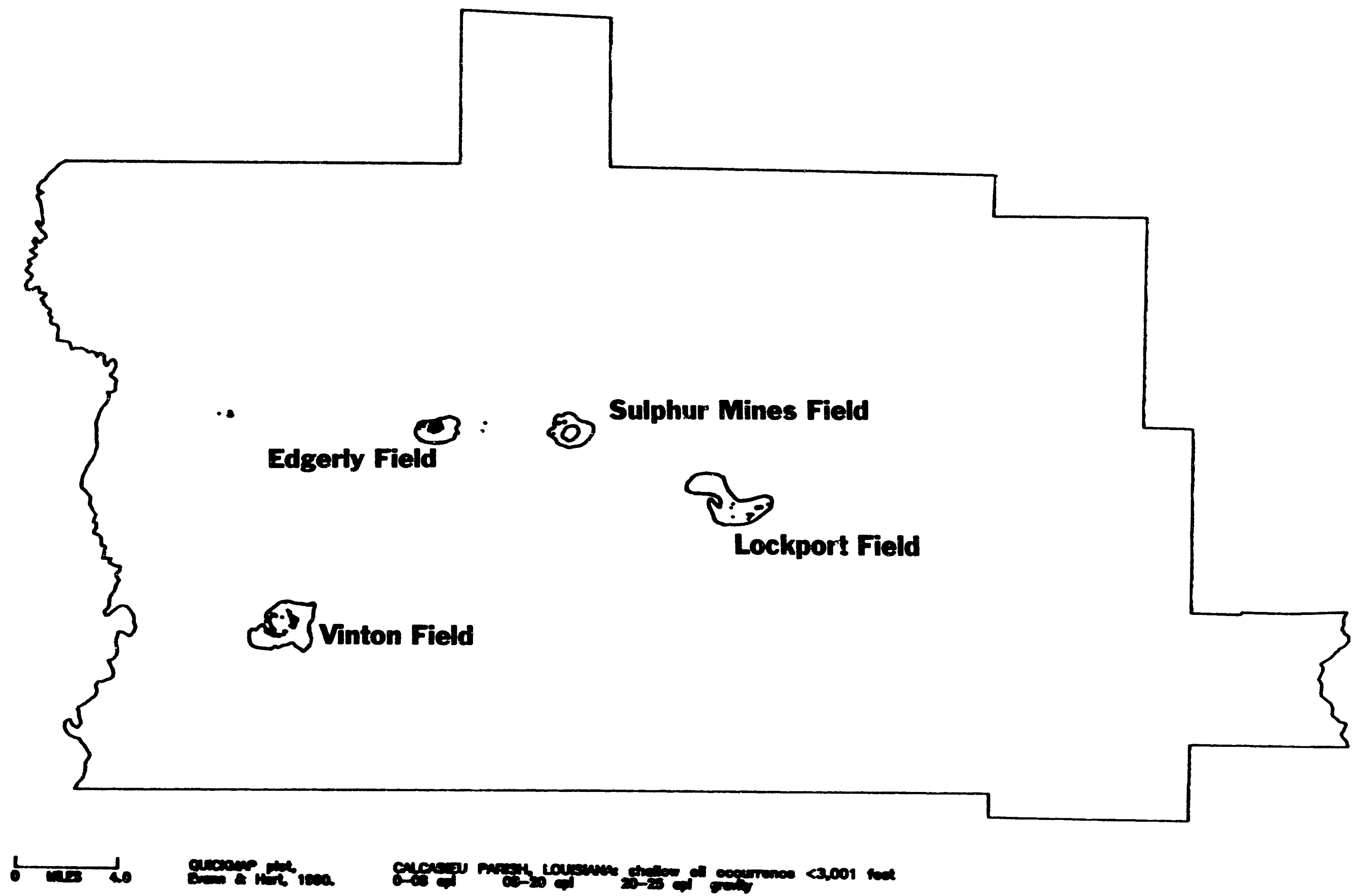


Figure E-1. Map of Calcasieu Parish, Louisiana, showing oil fields with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Frio geopressured-geothermal trend.

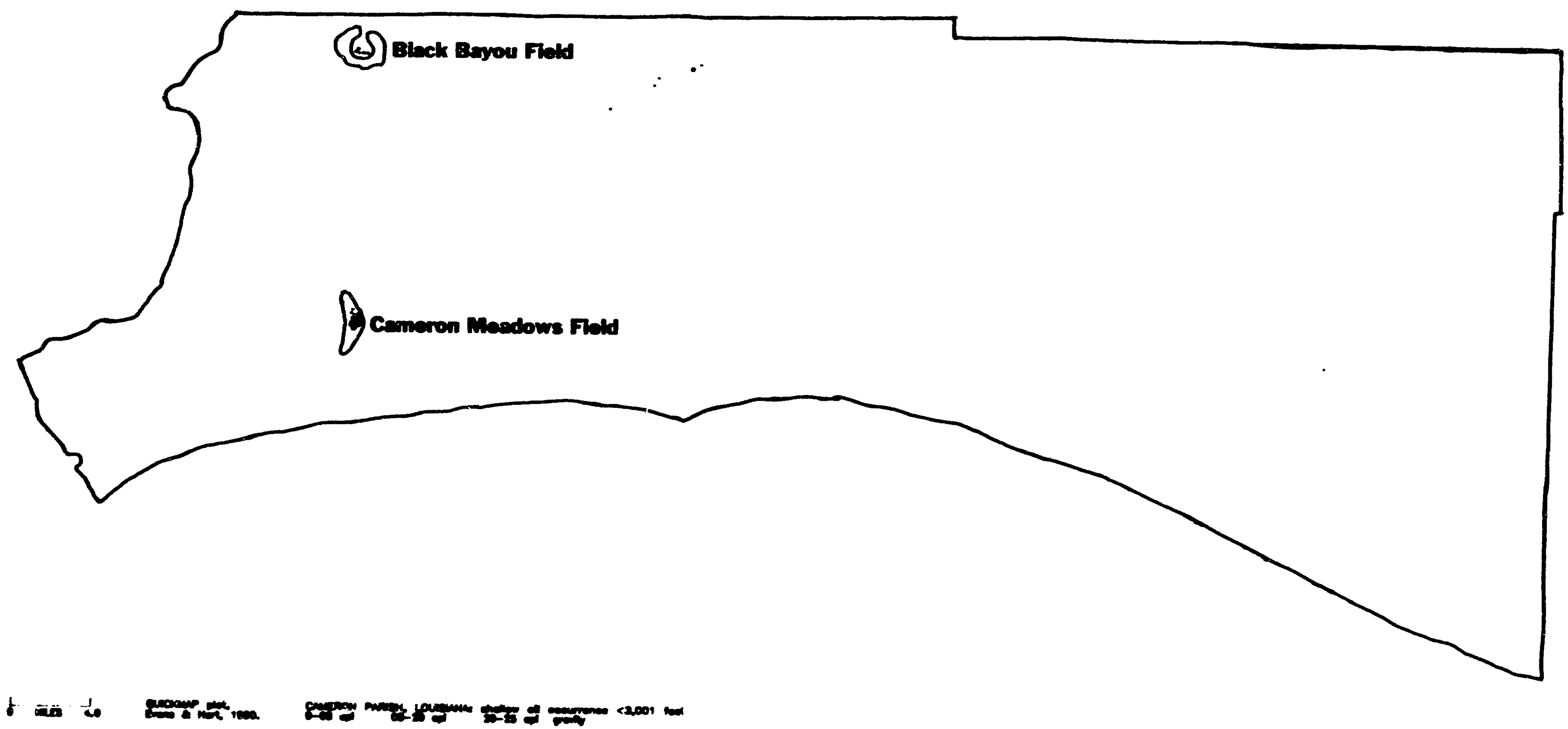


Figure E-2. Map of Cameron Parish, Louisiana, showing oil fields with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Frio/Miocene geopressured-geothermal trend.

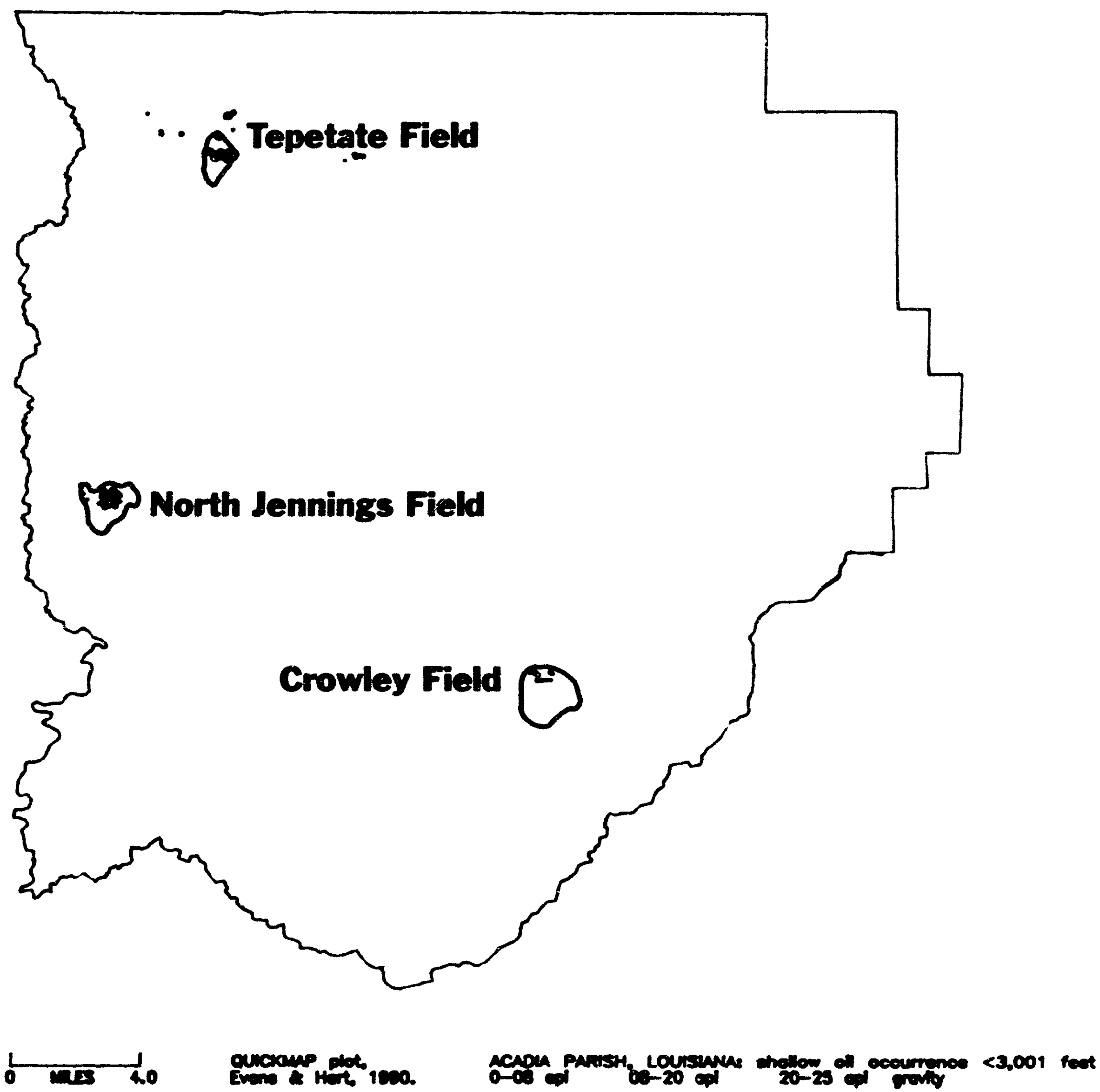


Figure E-3. Map of Acadia Parish, Louisiana, showing oil fields with $<25°$ API gravity oil at shallow depths ($<3,001$ ft) and located in the Frio geopressured-geothermal trend.

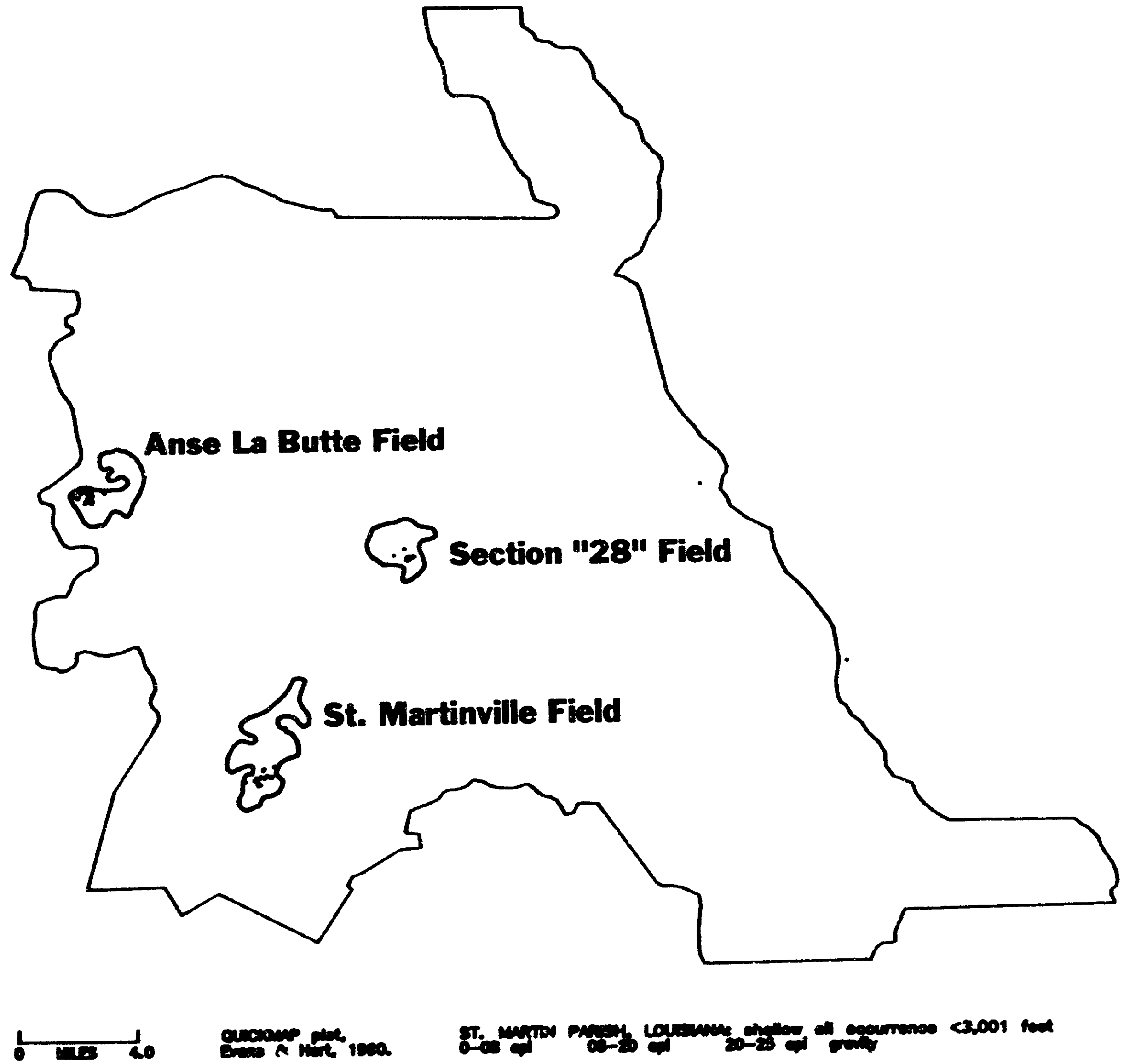


Figure E-4. Map of St. Martin Parish, Louisiana, showing oil fields with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Frio geopressured-geothermal trend.

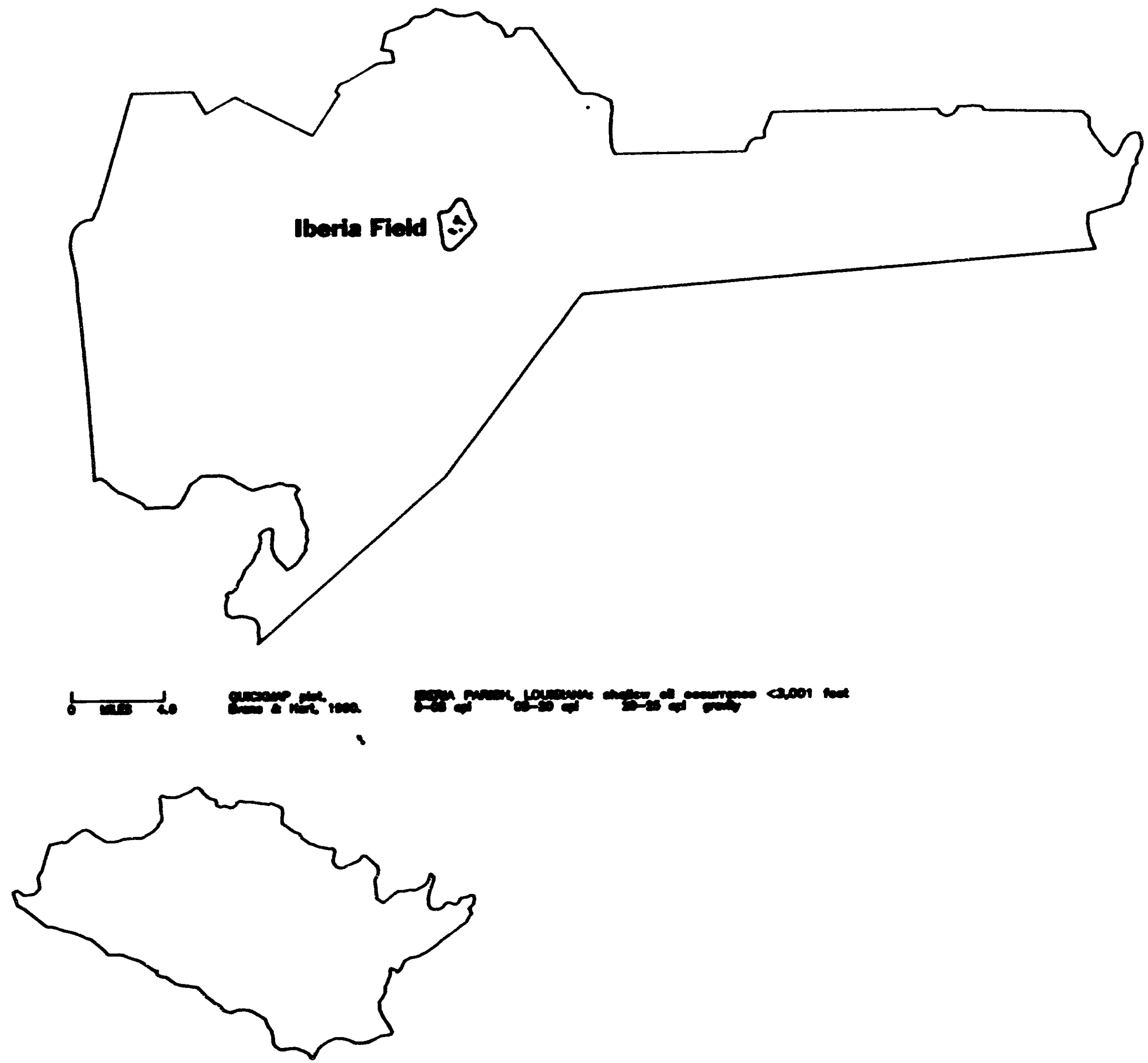


Figure E-5. Map of Iberia Parish, Louisiana, showing the Iberia oil field with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Miocene geopressured-geothermal trend.

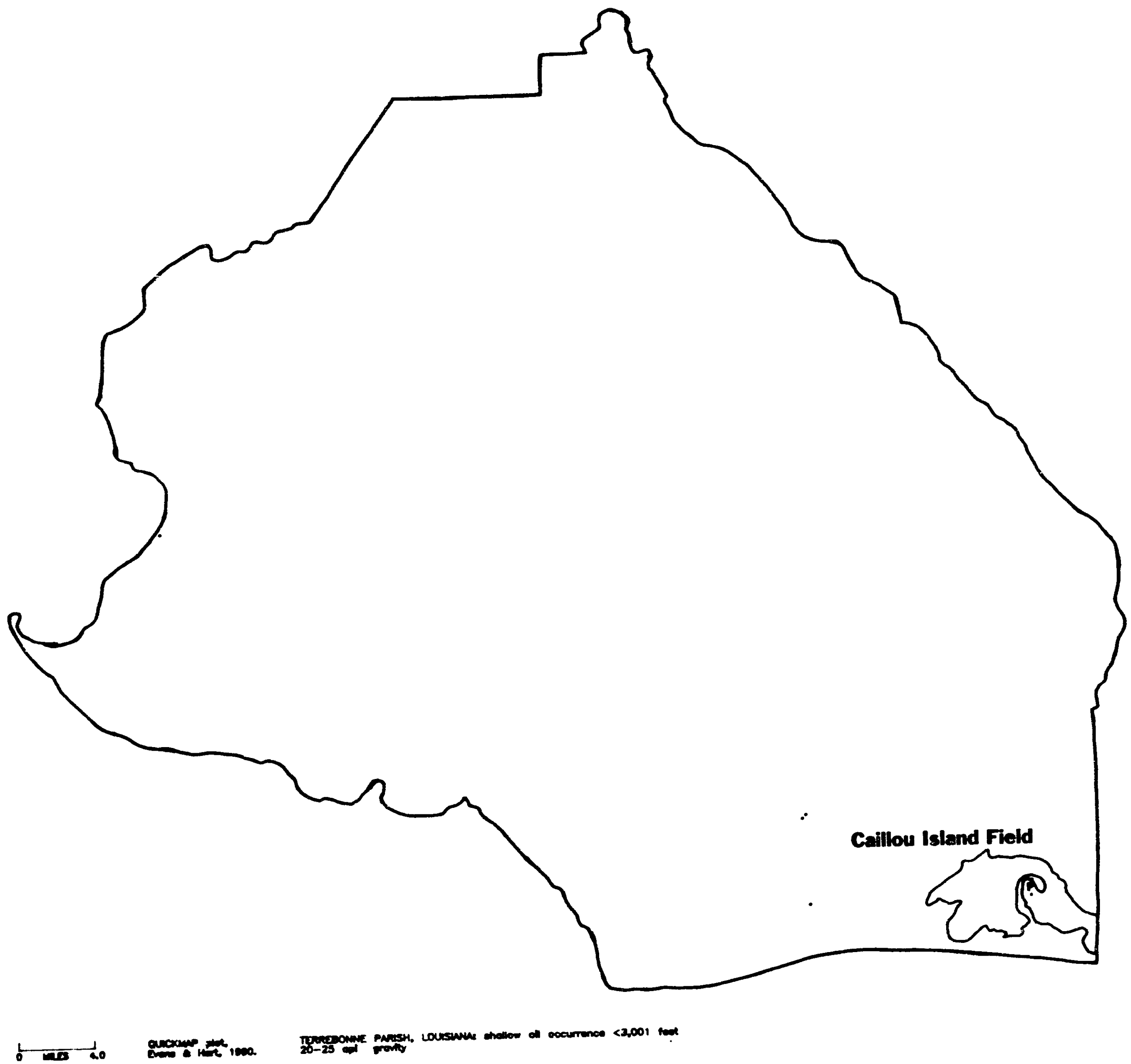


Figure E-6. Map of Terrebonne Parish, Louisiana, showing the Caillou Island oil field with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Miocene geopressured-geothermal trend.

Figure E-7. Map of Lafourche Parish, Louisiana, showing the Golden Meadow field with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Miocene geopressured-geothermal trend.

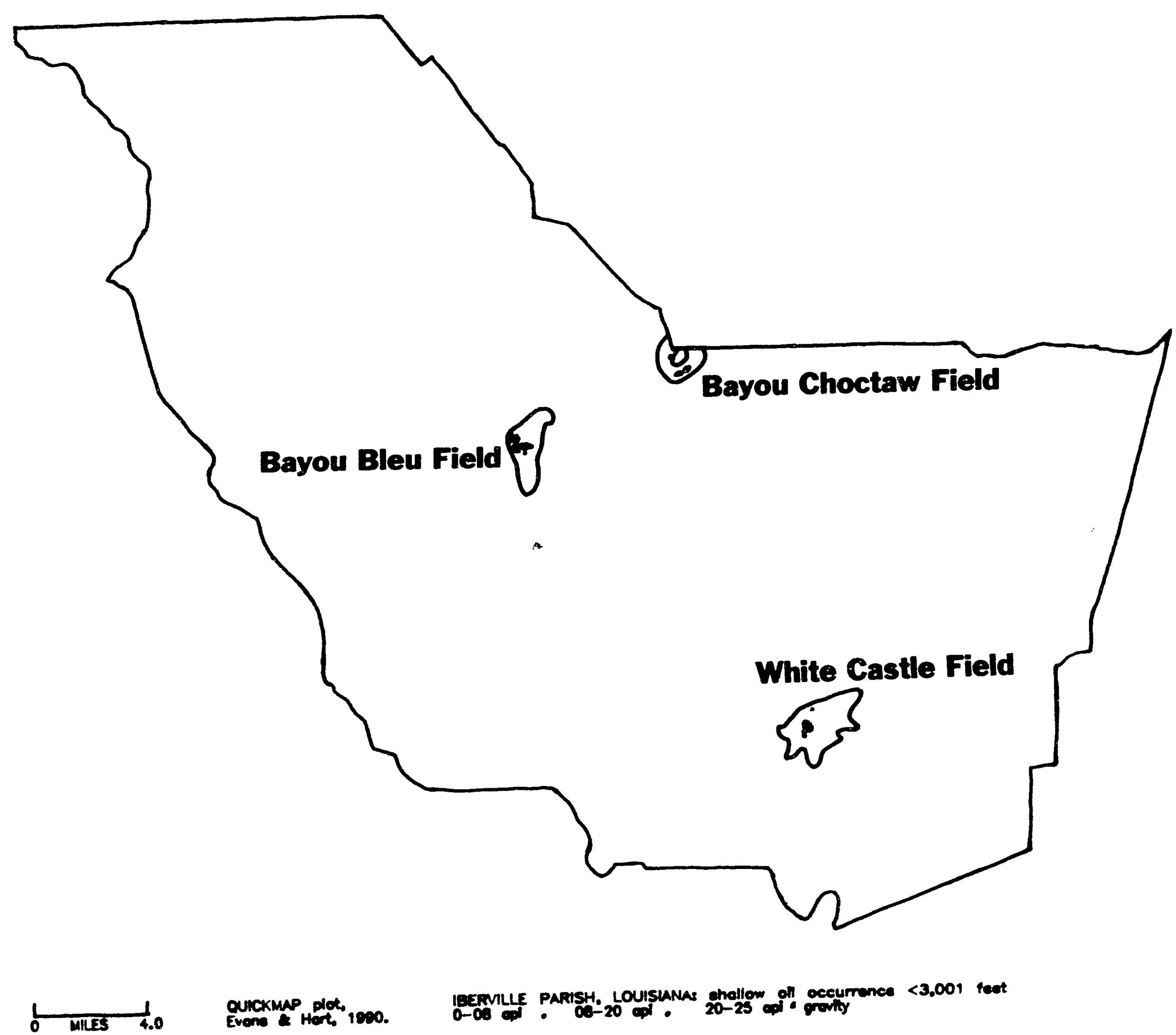


Figure E-8. Map of Iberville Parish, Louisiana, showing oil fields with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Miocene geopressured-geothermal trend.

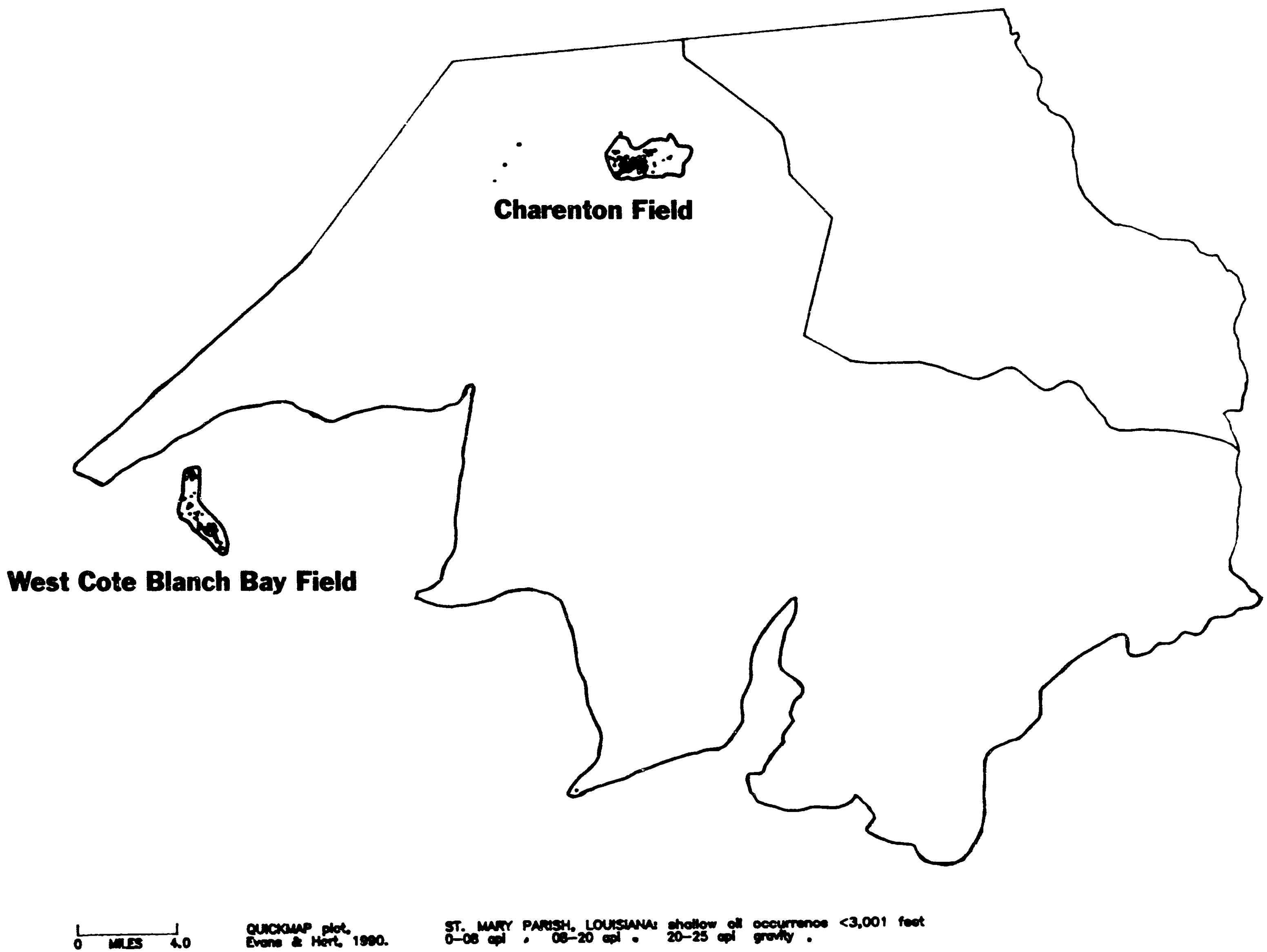


Figure E-9. Map of St. Mary Parish and immediate offshore Louisiana showing oil fields with $<25°$ API gravity oil at shallow depths ($<3{,}001$ ft) and located in the Miocene geopressured-geothermal trend.

Figure E-10. Map of Plaquemines Parish, Louisiana, showing oil fields with <25° API gravity oil at shallow depths (<3,001 ft) and located in the Miocene geopressured-geothermal trend.

END

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12/1/92