DOE/NV/10425-T6

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TECHNICAL SUPPORT
FOR
GEOPRESSURED-GEOTHERMAL WELL ACTIVITIES
IN LOUISIANA

ANNUAL REPORT
for the period
1 December 1988 to 31 December 1990

C.G. Groat
Program Coordinator

July 1991

Work Performed under Contract
DE-FC07-85NV10425

Louisiana Geological Survey
Louisiana State University
Box G, University Station
Baton Rouge, Louisiana 70893-4107

DISCLAIMER

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PREFACE

This report describes environmental activities carried out by Louisiana State University (LSU) under U.S. Department of Energy Contract DE-FC07-85NV10425 for the period 1 December 1988 through 31 December 1990. Other aspects of the LSU technical support program completed under prior contracts were covered in final form in reports preceding this one. During the contract period, the Louisiana Geological Survey monitored microseismic activity, and land surface subsidence at three designed geopressured-geothermal test well sites in Louisiana and Texas. Geologic studies around well sites also continued. In addition, preliminary co-location studies of heavy oil occurrences together with geopressured-geothermal fluids in Louisiana were initiated. Don Stevenson supervised microearthquake monitoring activities, subsidence studies and assisted in contract coordination, which was handled by C. G. Groat. Geologic studies and preliminary co-location work was carried out by Chacko John. This report is a progress report in the sense that it discusses program components, provides data, and presents preliminary interpretations. A detailed report on co-location of medium-to-heavy oil with geopressured brine resources in south Louisiana will be provided in the next annual report. The environmental monitoring, geologic, and co-location tasks as described in our contract continues and will be the subject of subsequent annual reports.

MICROEARTHQUAKE MONITORING

by
Donald Stevenson

ABSTRACT

Continuous recording microearthquake monitoring networks have been established around U.S. Department of Energy (DOE) geopressured-geothermal design wells in southwestern Louisiana and southeastern Texas since summer 1980 to assess the effects well development may have had on subsidence and growth-fault activation. This monitoring has shown several unusual characteristics of Gulf Coast seismic activity. The observed activity is classified into two dominant types, one with identifiable body phases (type I) and the other with only surface-wave signatures (type II). During this reporting period no type I or body-wave events were reported. A total of 230 type II or surface-wave events were recorded.

Origins of the type II events are still not positively understood; however, little or no evidence is available to connect them with geopressured-geothermal well activity. We continue to suspect sonic booms from military aircraft or some other human-induced source.

INTRODUCTION

Under DOE sponsorship the Louisiana Geological Survey (LGS) and Louisiana State University (LSU) have conducted baseline microearthquake studies around the geopressured-geothermal design wells in Louisiana and Texas to assess effects of well development on subsidence and growth-fault activation. The monitoring program was designed to establish the nature of local seismic activity before production and to determine whether well activities induce changes in the rates of local fault movement. This section describes the results obtained from microearthquake monitoring during the 24-month period beginning 1 December 1988 and ending 31 December 1990.

During this reporting period three separate monitoring networks were in operation: Gladys McCall, Louisiana; Hulin, Louisiana; and Pleasant Bayou, Texas. The Gladys McCall network has been in operation since summer 1980. The Hulin and Pleasant Bayou networks went on line in October 1985 and operate today collecting seismic data before and during testing.

THE LOUISIANA AND TEXAS MICROEARTHQUAKE MONITORING NETWORKS

The seismic networks that have been deployed by LGS/LSU are shown in figure 1. Each network has consisted of from four to six short-period vertical component seismometers. To reduce the adverse effect of surface cultural noise on the data, seismometers are installed in boreholes up to 30 m (110 ft) deep. The seismic signals detected at each field site within a network are sent to the central recording facility at the LGS/LSU seismological laboratory in Baton Rouge via phone lines (figure 2). Data received from the field are recorded in two formats. First, the phone lines are fed directly into a 14-track programmable analog tape recorder together with a time code. The tapes allow us to digitize and save any signal of interest for further analyses and computer storage. Second, the phone signals are selectively demultiplexed into individual station signals and continuously recorded on visual drum recorders for daily analysis. From the paper drum record,

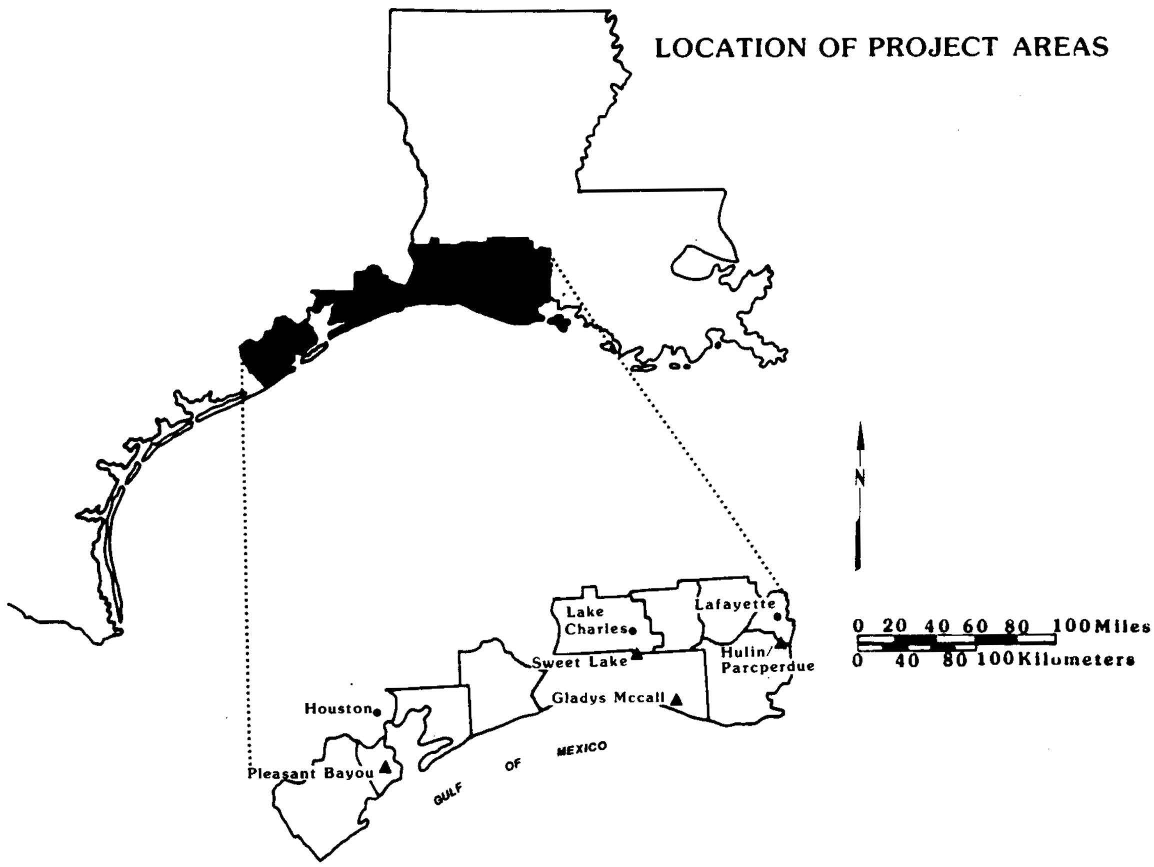

Figure 1. Microearthquake network locations: Louisiana and Texas.

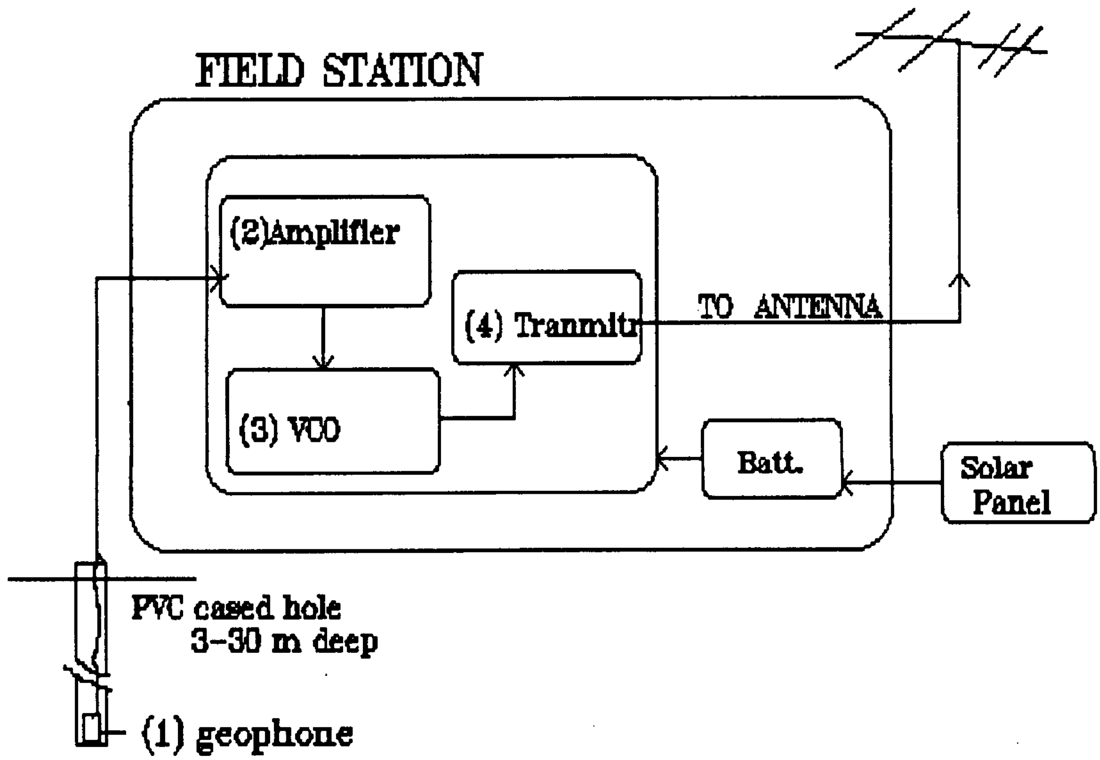

Figure 2. Schematic of typical field station set up.

we pick events for more detailed analysis and tape playback. Records are scanned daily to detect possible natural seismic activity. All events thought to be local microearthquakes are processed to obtain hypocenter locations and relative magnitudes. The hypocenter is determined by using the HYPOELIPSE (Lahr 1986) computer algorithm. Magnitudes are calculated on the basis of event duration. Because a magnitude scale has not been developed for the Gulf Coast, the absolute values of computed magnitudes may not be valid. However, they do serve as good indicators of the relative size of events.

Magnitudes calculated for microearthquakes recorded at all the networks indicate that events have been small, less than 1.5. The exception to this is the magnitude 3.8 earthquake that occurred on 16 October 1983 to the northwest of the plugged and abandoned Sweet Lake prospect. A detailed discussion of the Lake Charles earthquake is published in the Bulletin of the Seismological Society of America (Stevenson and Agnew 1988).

Gladys McCall

This five-station network has been in place since late summer 1980 and has been operating continuously for the past eight years. Figure 3 shows network station locations surrounding the prospect within a diameter of approximately 10 km. Table 1 is a list of station coordinates. We anticipate monitoring at the Gladys McCall prospect to be completed at the end of the 1991 contract year. No testing has taken place for over three years and only a short test, less than one month of relatively low volume testing, has been proposed for 1991.

Hulin

This four-station network was put together from equipment within the old Parcperdue array. The Hulin station coordinates are listed in table 1. The Hulin network has been operational since December 1988. Figure 4 shows network station locations surrounding the Hulin prospect in roughly a 1 to 7 km radius.

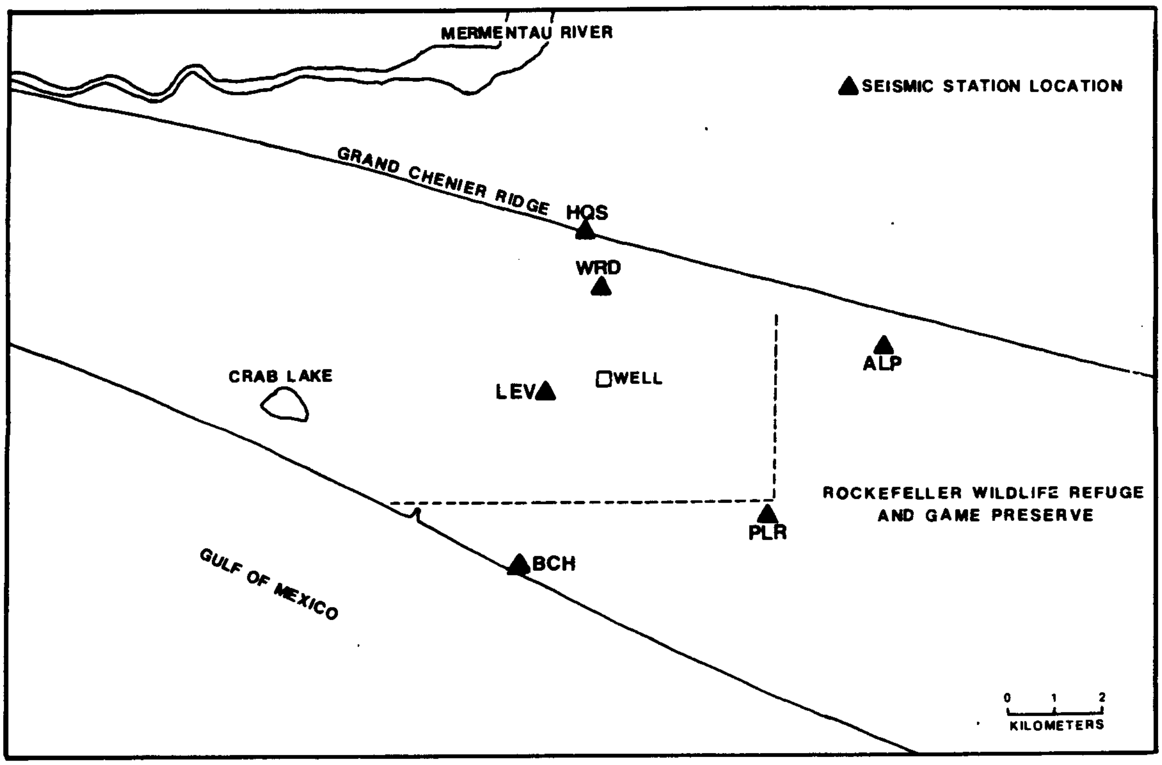

Figure 3. Locations of Gladys McCall microearthquake recording stations.

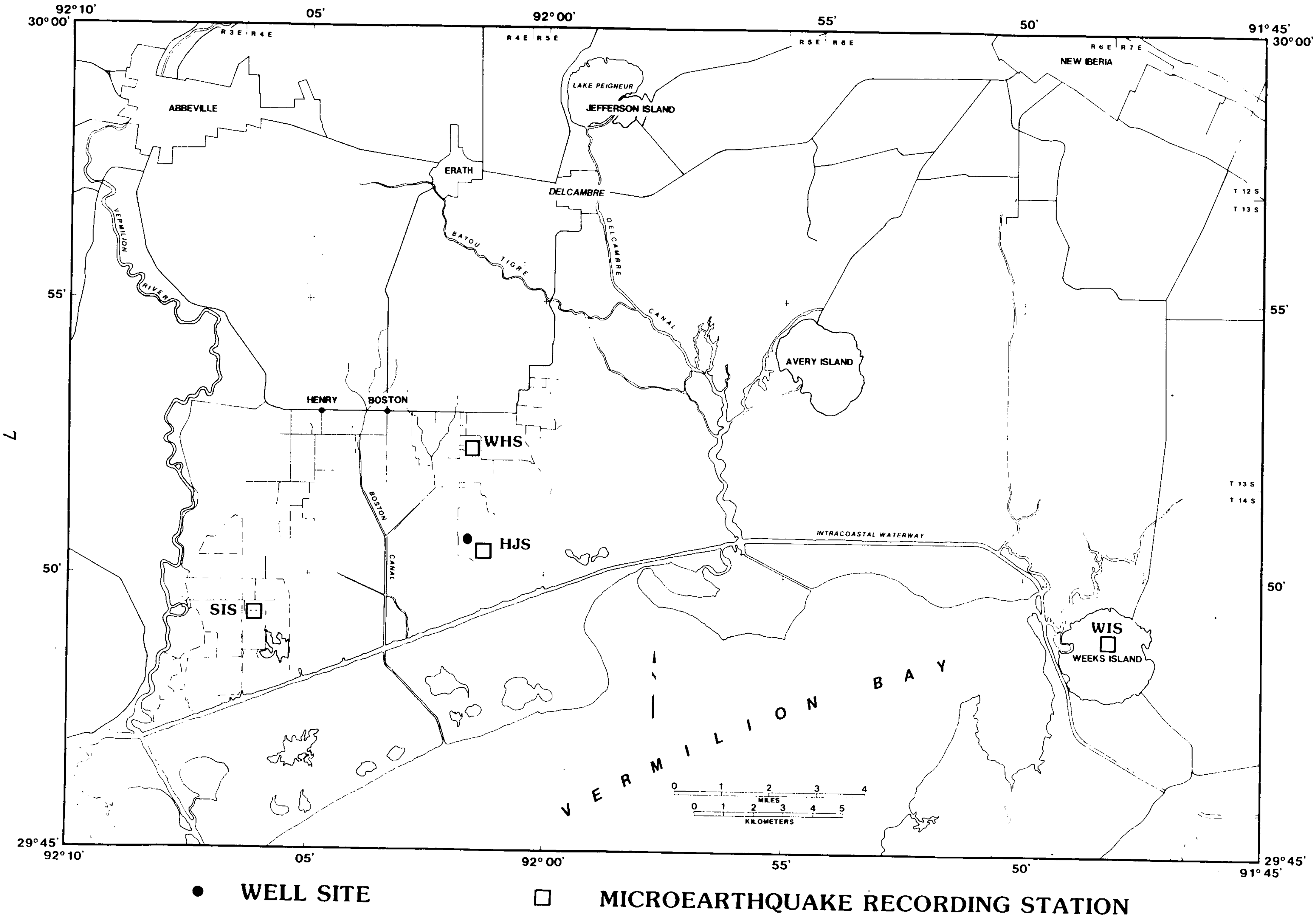

Figure 4. Locations of Hulin microearthquake recording stations

Table 1. Coordinates for Hulin, Gladys McCall, and Pleasant Bayou seismic monitoring networks.

Station Name	North Latitude	West Longitude
Hulin		
HJS	29 50'55.6"	92 01'20.2"
WHS	29 52'20.9"	92 01'40.5"
SIS	29 49'16.7"	92 06'08.9"
WIS	29 48'23.4"	91 48'23.2"
Gladys McCall		
BCH	29 40'38.0"	92 53'19.0"
PLR	29 41'14.0"	92 50'00.0"
ALP	29 43'13.0"	92 28'32.0"
WRD	29 43'52.4"	92 52'19.4"
HQS	29 44'31.0"	92 52'27.0"
Pleasant Bayou		
DLF	29 10'29.4"	95 16'53.4"
EFF	29 15'53.4"	95 16'10.2"
GAR	29 20'13.8"	95 18'21.6"
JMF	29 20'00.0"	95 12'06.0"

Pleasant Bayou

This four-station network has been operating since October 1985 collecting data before and during testing (figure 5). Station coordinates are listed in table 1. Monitoring and data collection continue.

DATA ANALYSIS

The present microearthquake recording networks, associated with the Louisiana and Texas geopressured-geothermal wells, are the first continuous seismic monitoring stations established in the Gulf Coast region. The lack of historical background data has hampered the interpretation and identification of recorded seismic signals since monitoring began. However, ten years of Gulf Coast seismic monitoring experience has enabled us to identify many previously unidentified signals and signals initially thought to be microearthquakes induced by wells. In previous reports, a vast majority of signals initially attributed to seismic activity around Louisiana and Texas test wells were found to derive from thunderstorms passing over or close to the seismic recording networks (Louisiana Geological Survey 1985, 1987, 1988). Each passing year of data collection has allowed us to identify more previously unidentified signals. Only through understanding the origins of the unidentified signals can we separate the potential well-induced activity from other unrelated or spurious signals.

Types of Signals

As stated above, various signal sources have been identified during this study, and as more data are collected, increasing numbers are identified and catalogued. Geophysical exploration blasting continues to account for much of the activity, as does cultural noise such as the movement of vehicles along nearby roads (figure 6). Distant teleseisms from throughout the world are also recorded by all networks. We currently have over 100 cataloged and digitized teleseisms from all over the world. Two other types of signals continue to be recorded by the three networks: type I, or body-wave events, and type II, or surface-wave events

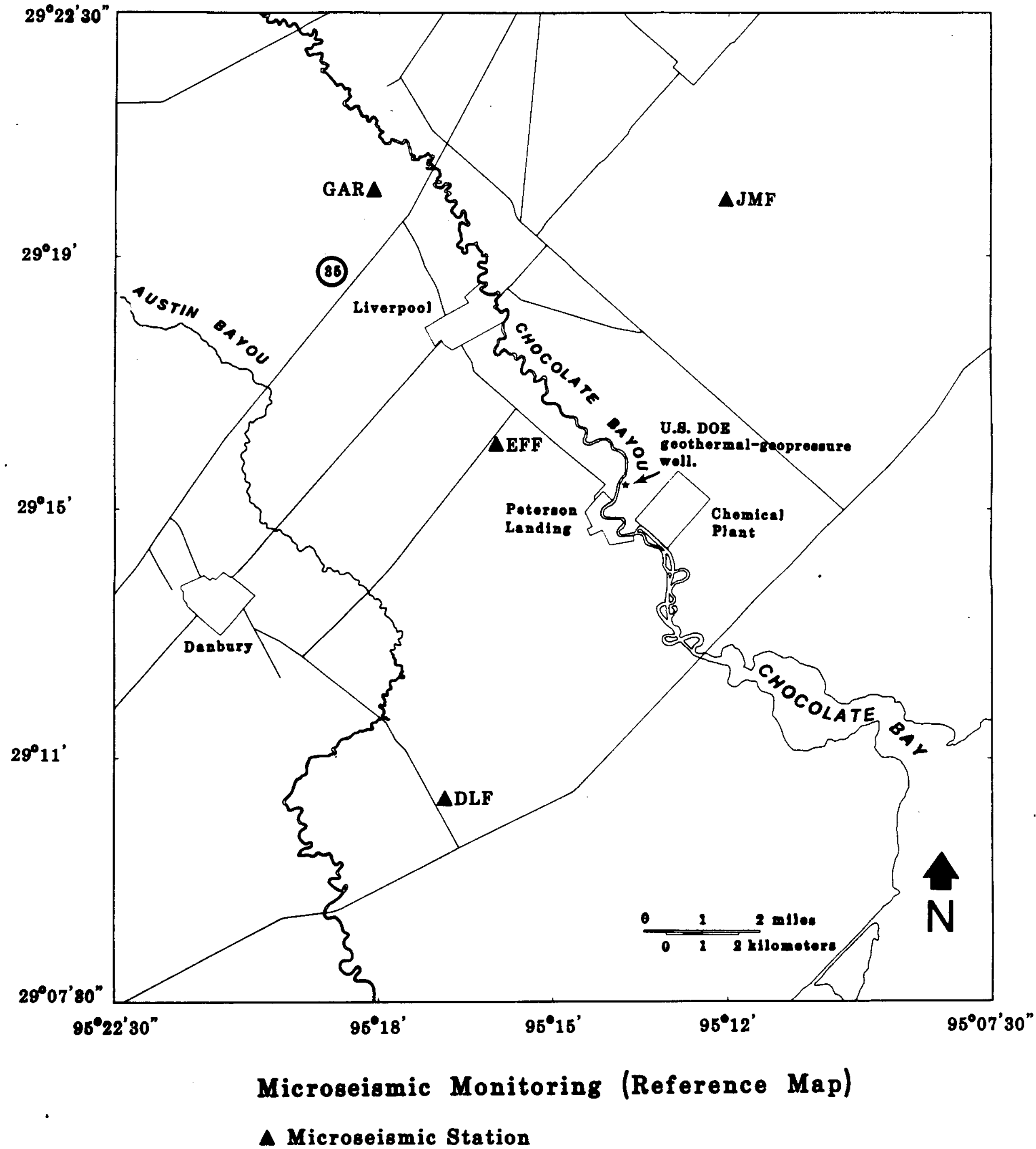

Figure 5. Locations of Pleasant Bayou microearthquake recording stations.

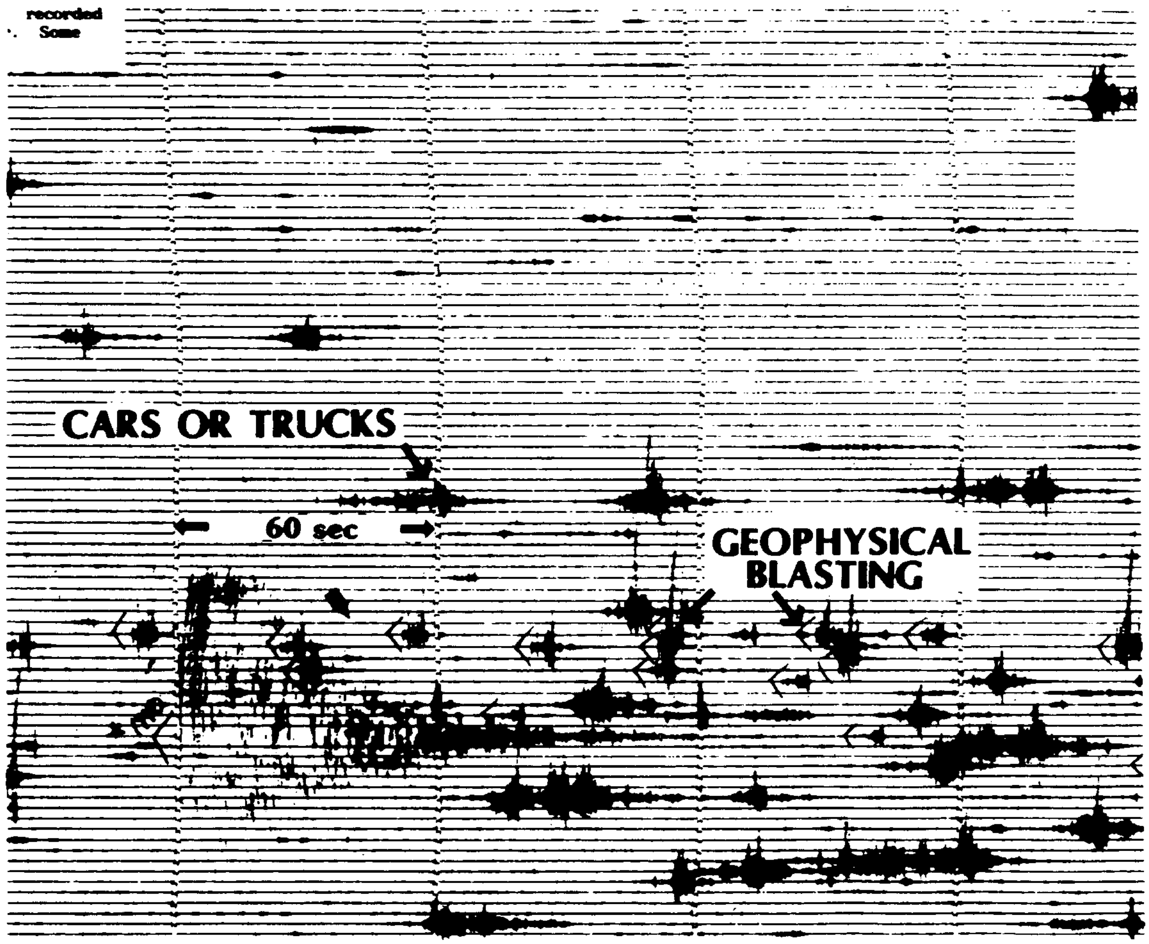

Figure 6. Sample record from a Louisiana microearthquake recording station; the large signal is type I from a Lake Charles, Louisiana, earthquake of 16 October 1983.

(figure 6). Type I events are classified as microearthquakes and typically are characterized by a P-wave arrival (primary compressional/dilatational, 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.

Type II events are signals consisting entirely of surface (Rayleigh) waves. They are characterized either by an impulsive or emergent first arrival. The apparent velocity with which these events traverse the networks is essentially sonic (0.35 to 0.76 km/s, or 1,150 to 2,495 ft/s). It was noted early in this study that the type II events were similar to fundamental mode Rayleigh waves reported for a portion of the Gulf Coast in Texas (Ebinero et al. 1983). Because the sediment velocities in southern Louisiana are similar to those in coastal Texas, the initial conclusion was that the type II events might be attributable to leaking energy from microearthquakes within a near-surface, low-velocity layer (Teledyne Geotech 1984). However, acoustical transmissions through the air (thunder or sonic booms) also occupy the frequency and velocity range of the type II events.

Type I Events

No local type I events have been noted during this reporting period. The only site with significant brine production during this reporting period was Pleasant Bayou, Texas, where production has been ongoing intermittently since 6 June 1988. We continue to review data daily for evidence of well-induced and co-production microearthquake activity. All such suspected microearthquakes are reported in our quarterly progress reports.

Type II Events

The origins and causes of many type II events have been virtually unknown since the beginning of the microearthquake monitoring program. They have been recorded by all monitoring networks, and single events have occasionally appeared across two different networks. As stated above, they were originally thought to be a form of microearthquake activity occasionally attributed to geopressured-geothermal well production (Teledyne Geotech 1983, 1984; Woodward-Clyde 1984). In our 1983-1984 and 1984-1986 annual reports, we demonstrated that most of the 1,000+ documented type II events (Teledyne Geotech 1983, 1984; Woodward-Clyde 1984) were due to thunderstorms passing across the microearthquake monitoring networks as opposed to some underground source. However, after all suspected events associated with thunderstorm activity are removed from consideration, a relatively small group of unidentified emergent and impulsive type II signals remains. As more data are collected and analyzed, it is becoming more apparent that these remaining events are probably not microearthquakes.

In our last annual report, we presented figures showing plots of type II events (impulsive and emergent) versus time of day and day of week for both impulsive and emergent events (Louisiana Geological Survey 1987). Figures 7 and 8 show the same data together with data collected over the present reporting period. The additional two years of data indicate that both emergent and impulsive events occur on all days of the week. However, the majority continue to occur on weekdays rather than weekends. Additionally, most of the recorded activity, both impulsive and emergent, takes place during morning (10 to 15 hours UCT), afternoon (15 to 22 hours UCT), and evening (22 to 02 hours UCT) hours; very few events are reported during late night hours (02 to 10 hours UCT). Results obtained during this reporting period continue to support our contention that type II events are probably not attributable to underground earth movement, but are due to some human-induced source. We continue to feel that all type II events are of sonic origin.

DISCUSSION

Through the course of this reporting period, a total of 48 impulsive and 182 emergent type II events have been cataloged (Appendix I). Some have been picked up on stations of more than one network. We continue to feel that these events are not of earth origin. Appendix II lists world-wide teleseisms that were recorded by the geopressured-geothermal microearthquake monitoring networks. A total of 83 have been cataloged and archived.

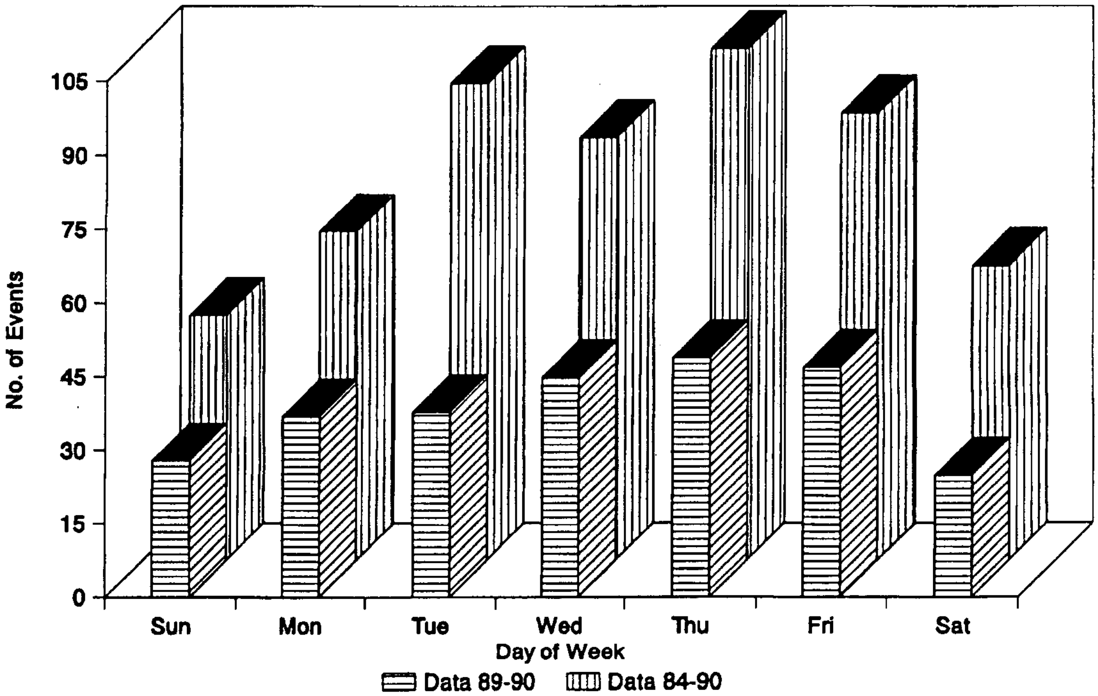

Figure 7. Number of type II events (impulsive & emergent) with respect to day of the week.

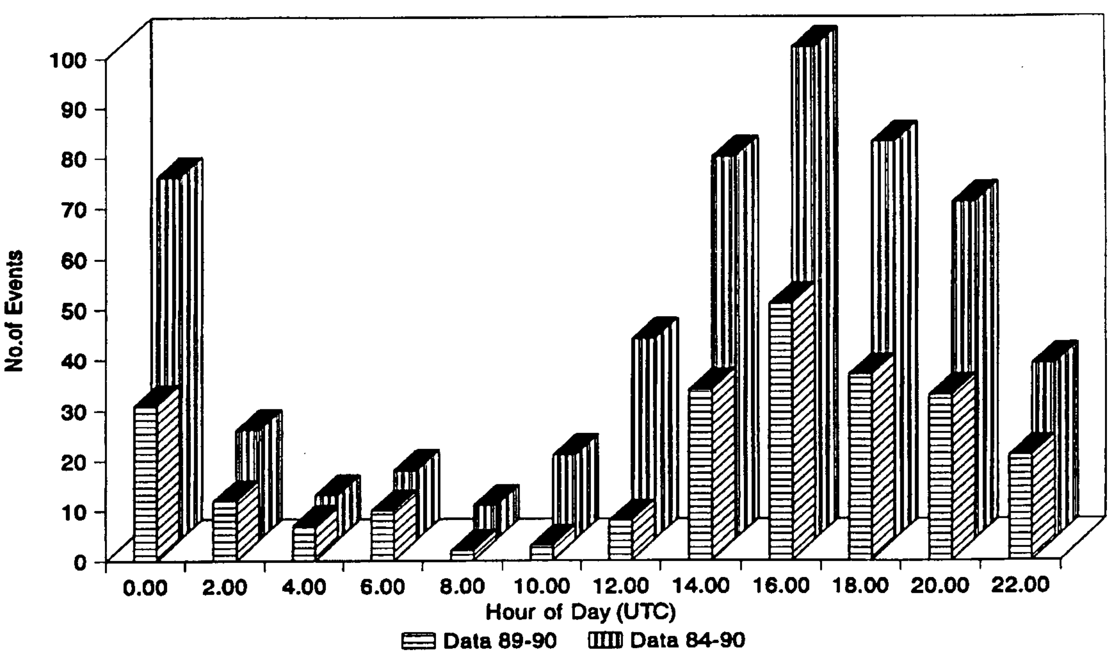

Figure 8. Number of type II events (impulsive & emergent) with respect to hour of the day.

CONCLUSIONS

Nine years of microearthquake monitoring data at DOE geopressured-geothermal prospects in Louisiana and Texas have shown many different and curious signal characteristics. Two main signal types have been reported from all networks. These include the type I, or body-wave events, which more closely resemble microearthquakes reported from other areas of the world and type II, or Rayleigh wave events, which display characteristics more closely related to sonic waves.

Type II events are further classified into groups of emergent and impulsive signals. Both examples of type II events have been recorded by all networks. Emergent type II events mainly indicate regional characteristics, while impulsive type II events appear to be local to the network recording them. It is our opinion that no type II events are related to geopressured-geothermal well activity. All type II events are presently suspected to be of natural and human-induced atmospheric origin rather than earth origin. Reasons for these inferences include the fact that time of occurrence is limited to mostly day and early evening hours on weekdays, and the marked similarity to sonic-boom wave forms and frequency content reported by other researchers.

Included in the type I group are local and teleseismic events. Teleseismic type I events have been recorded by all networks. No evidence of local type I microearthquake activity has been noted for this reporting period at any of the DOE geopressured-geothermal microearthquake monitoring networks. Records continue to be analyzed daily for evidence of possible well-induced microearthquake activity.

Data has shown that Gulf Coast geopressured-geothermal wells development does not cause induced microearthquake activity that is a single production and disposal well site. However, this may not apply to fields of production and disposal wells. Our data apply only to a single pair of production and disposal wells within a given area.

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APPENDIX I

APPENDIX I

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

DATE	DAY	TIME (UTC)	STATIONS RECORDI	E	IM	PB	GM	PP	HU	COMMENTS
01/04/89	Wednesday	01:39:10	ALP,PLR,WRD	E			GM			
01/04/89	Wednesday	20:12:32	PLR	E			GM			
01/04/89	Wednesday	20:19:30	EFF,GAR,JMF		I	PB				Sonic?
01/05/89	Thursday	01:05:32	PLR	E			GM			
01/05/89	Thursday	16:58:30	EFF,GAR,JMF	E		PB				
01/06/89	Friday	16:05:41	PLR,WRD,ALP	E			GM			
01/06/89	Friday	16:05:41	PLR,ALP,WRD	E			GM			Sonic?
01/06/89	Friday	16:05:41	PLR,WRD,ALP	E			GM			
01/09/89	Monday	20:28:35	EFF,GAR,JMF	E	I	PB				
01/10/89	Tuesday	16:12:10	EFF,GAR,JMF	E		PB				Sonic?
01/12/89	Thursday	20:20:10	PLR,WRD,ALP	E	I		GM			
01/12/89	Thursday	20:19:10	PLR,WRD,ALP	E			GM			
01/12/89	Thursday	20:08:00	PLR,ALP,WRD	E			GM			
01/15/89	Sunday	21:40:05	ALP,WRD		I		GM			
01/15/89	Sunday	17:38:55	ALP,WRD	E			GM			
01/16/89	Monday	18:47:00	ALP,WRD	E			GM			
01/17/89	Tuesday	19:51:15	ALP,WRD	E			GM			
01/20/89	Friday	20:28:22	EFF,GAR,JMF	E		PB				
01/20/89	Friday	17:04:08	EFF,GAR,JMF	E		PB				
01/25/89	Wednesday	16:00:45	ALP,WRD		I		GM			
01/25/89	Wednesday	20:44:33	ALP,WRD	E			GM			
01/25/89	Wednesday	20:36:35	EFF,JMF,GAR	E		PB				Very slow moving
01/25/89	Wednesday	15:58:55	ALP,WRD		I		GM			
01/26/89	Thursday	00:37:45	EFF,JMF,GAR	E		PB				Very slow moving
01/26/89	Thursday	20:46:58	ALP,WRD,PLR	E			GM			
01/26/89	Thursday	00:49:10	ALP,WRD	E			GM			
01/27/89	Friday	16:12:20	ALP,WRD,PLR	E			GM			
01/27/89	Friday	16:14:00	ALP,WRD,PLR	E			GM			
01/28/89	Saturday	14:38:10	ALP,PLR,WRD	E	I		GM			
01/29/89	Sunday	14:43:00	EFF,GAR,JMF	E		PB				
02/01/89	Wednesday	15:54:00	EFF,GAR,JMF	E		PB				
02/02/89	Thursday	20:14:00	EFF,GAR,JMF		I	PB				Sonic?
02/07/89	Tuesday	20:48:35	EFF,GAR,JMF	E		PB				Very slow moving
02/09/89	Thursday	17:29:10	EFF,GAR,JMF	E		PB				Sonic...Slow
02/09/89	Thursday	17:32:00	EFF,GAR,JMF	E		PB				
02/12/89	Sunday	22:05:05	WRD,ALP	E			GM			
02/18/89	Saturday	00:00:00	EFF,GAR,JMF		I	PB				Several Blasts
02/19/89	Sunday	00:00:00	EFF,GAR,JMF		I	PB				Several Blasts
02/21/89	Tuesday	20:06:50	EFF,GAR,JMF		I	PB				
02/24/89	Friday	16:27:40	WHP,HJS	E	I				HU	
02/27/89	Monday	20:27:00	WHP,HJS	E					HU	Sonic?
02/28/89	Tuesday	20:12:55	WRD,ALP,PLR		I		GM			
02/28/89	Tuesday	20:15:07	WHP,HJS	E					HU	
02/28/89	Tuesday	13:11:22	EFF,GAR,JMF		I	PB				
02/28/89	Tuesday	20:16:37	WHP,HJS		I				HU	
03/03/89	Friday	16:05:21	WRD,ALP,PLR	E			GM			Sonic?
03/03/89	Friday	16:04:20	WRD,ALP,PLR	E			GM			Sonic?
03/06/89	Monday	23:06:00	EFF,GAR,JMF	E		PB				
03/06/89	Monday	23:05:15	WHP,HJS	E					HU	
03/07/89	Tuesday	23:20:50	WHP,HJS	E					HU	sonic?
03/07/89	Tuesday	17:26:53	EFF,GAR,JMF	E		PB				Very slow, sonic?
03/07/89	Tuesday	17:25:17	EFF,GAR,JMF	E		PB				Very slow, sonic?

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

DATE	DAY	TIME (UTC)	STATIONS RECORDI	E	IM	PB	GM	PP	HU	COMMENTS
03/09/89	Thursday	18:56:38	WHP,HJS	E					HU	sonic?
03/09/89	Thursday	18:55:15	WHP,HJS	E					HU	Sonic?
03/11/89	Saturday	15:57:50	WHP,HJS		I				HU	Sonic?
03/13/89	Monday	01:36:00	WRD,ALP,PLR	E			GM			Sonic?
03/13/89	Monday	01:18:00	EFF,GAR,JMF	E		PB				
03/13/89	Monday	01:39:36	WHP,HJS		I				HU	teleseismic
03/16/89	Thursday	23:20:57	WHP,HJS		I				HU	Blast?
03/16/89	Thursday	23:21:00	WHP,HJS	E					HU	Blast?
03/18/89	Saturday	16:03:08	WHP,HJS	E					HU	Sonic?
03/18/89	Saturday	16:02:45	WHP,HJS	E					HU	Sonic?
03/18/89	Saturday	16:01:20	WHP,HJS	E					HU	Sonic?
03/19/89	Sunday	21:30:26	EFF,GAR,JMF		I	PB				
03/19/89	Sunday	16:47:49	EFF,GAR,JMF	E		PB				
03/19/89	Sunday	16:47:23	WHP,HJS		I				HU	
03/20/89	Monday	21:11:00	EFF,GAR,JMF	E		PB				
03/29/89	Wednesday	20:09:50	WRD	E			GM			Thunder?
03/29/89	Wednesday	20:10:18	WRD	E			GM			Thunder?
03/29/89	Wednesday	20:20:24	WHP,HJS	E					HU	Thunder? I at WHP
03/29/89	Wednesday	20:13:30	WHP,HJS	E					HU	Thunder?
03/29/89	Wednesday	20:21:18	WHP,HJS	E					HU	Thunder?
03/31/89	Friday	00:59:02	EFF,GAR,JMF	E		PB				Sonic?
03/31/89	Friday	00:45:22	ALP,WRD	E			GM			
03/31/89	Friday	00:44:17	ALP,WRD	E			GM			
04/02/89	Sunday	10:40:32	EFF,GAR,JMF		I	PB				Teleseism
04/03/89	Monday	05:23:16	WHP,HJS,SIS	E					HU	Sonic?
04/15/89	Saturday	17:40:25	WHP,HJS,SIS	E					HU	
04/19/89	Wednesday	15:03:00	WHP,HJS,SIS	E					HU	Sonic?
04/19/89	Wednesday	15:21:21	WHP,HJS,SIS	E					HU	
04/20/89	Thursday	20:15:40	WHP,HJS,SIS	E					HU	
04/20/89	Thursday	22:53:06	WHP,HJS,SIS	E					HU	
04/20/89	Thursday	20:00:52	WHP,SIS	E					HU	
04/21/89	Friday	19:44:23	WHP,HJS,SIS	E					HU	
04/21/89	Friday	00:06:20	WHP,HJS,SIS	E					HU	
04/21/89	Friday	19:44:54	ALP		I		GM			Blasts?
04/21/89	Friday	19:48:09	WHP,HJS,SIS	E					HU	
04/21/89	Friday	19:53:50	WHP,HJS,SIS	E					HU	
04/22/89	Saturday	19:20:43	WRD,ALP	E			GM			
04/22/89	Saturday	15:08:00	WHP,HJS,SIS	E					HU	
04/23/89	Sunday	19:59:12	WHP,HJS,SIS	E					HU	Sonic? slow.
04/25/89	Tuesday	13:50:53	WHP,HJS,SIS	E					HU	Sonic?
04/26/89	Wednesday	13:50:58	WHP,HJS,SIS	E					HU	
04/26/89	Wednesday	20:37:05	WRD,ALP	E			GM			
04/26/89	Wednesday	13:49:06	WHP,HJS,SIS	E					HU	
04/26/89	Wednesday	17:06:11	WHP,HJS,SIS	E					HU	
04/26/89	Wednesday	20:24:52	WHP,HJS,SIS	E					HU	
04/27/89	Thursday	19:15:48	GAR,JMF,EFF	E		PB				
04/27/89	Thursday	17:29:24	GAR,JMF,EFF	E		PB				
04/30/89	Sunday	09:05:16	GAR,JMF,EFF		I	PB				nothing-wrong date-check 05/01/1
04/30/89	Sunday	05:12:30	GAR,JMF,EFF		I	PB				nothing-wrong date-check 05/01/1
04/30/89	Sunday	15:39:10	WHP,HJS,SIS		I				HU	Sonic? slow.
04/30/89	Sunday	16:25:52	WHP,HJS,SIS		I				HU	Sonic? slow.
04/30/89	Sunday	15:37:45	WHP,HJS,SIS		I				HU	Sonic? slow.
05/01/89	Monday	19:37:52	WHP,HJS,SIS	E					HU	
05/01/89	Monday	18:44:55	WHP,HJS,SIS	E					HU	

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

DATE	DAY	TIME (UTC)	STATIONS RECORDI	E	IM	PB	GM	PP	HU	COMMENTS
05/01/89	Monday	05:12:30	GAR,JMF,EFF		I	PB				Blast?
05/06/89	Saturday	19:58:52	WHP,HJS,SIS	E					HU	Sonic?
05/06/89	Saturday	15:30:40	EFF,GAR,JMF		I	PB				blast?
05/06/89	Saturday	12:44:40	EFF,GAR,JMF	E		PB				
05/07/89	Sunday	01:14:45	ALP		I		GM			Sonic?
05/11/89	Thursday	22:58:08	WHP,HJS,SIS	E					HU	Sonic?
05/11/89	Thursday	23:28:05	WHP,HJS,SIS	E					HU	Sonic?
05/12/89	Friday	15:18:31	WHP,HJS,SIS	E					HU	Sonic?
05/13/89	Saturday	02:14:16	EFF,GAR,JMF	E		PB				Sonic?
05/13/89	Saturday	20:27:56	WHP,HJS,SIS	E					HU	Sonic?
05/13/89	Saturday	07:28:37	WHP,HJS,SIS	E					HU	Sonic?
05/13/89	Saturday	02:43:13	EFF,GAR,JMF		I	PB				Sonic?
05/13/89	Saturday	03:26:25	EFF,GAR,JMF	E		PB				Sonic?
05/13/89	Saturday	21:12:26	WHP,HJS,SIS	E					HU	Sonic?
05/14/89	Sunday	06:01:26	WHP,HJS,SIS	E					HU	Sonic?
05/15/89	Monday	18:44:20	WHP,HJS,SIS	E					HU	Sonic?
05/23/89	Tuesday	19:18:00	WHP,HJS,SIS	E					HU	Sonic?
05/23/89	Tuesday	00:15:45	ALP,WRD	E			GM			Sonic?
05/24/89	Wednesday	22:31:10	WHP,HJS,SIS	E					HU	Sonic?
05/24/89	Wednesday	23:56:50	EFF,GAR,JMF		I	PB				Blast?
05/24/89	Wednesday	16:33:10	ALP,WRD	E			GM			Sonic?
05/24/89	Wednesday	02:04:05	WHP,HJS,SIS	E					HU	Sonic?
05/25/89	Thursday	15:30:15	WHP,HJS,SIS	E					HU	Blast?
05/25/89	Thursday	19:26:20	EFF,GAR,JMF	E		PB				Sonic?
05/31/89	Wednesday	16:03:15	WHP,HJS,SIS	E					HU	Sonic?
05/31/89	Wednesday	16:13:05	WHP,HJS,SIS	E					HU	Sonic?
05/31/89	Wednesday	16:02:10	WHP,HJS,SIS	E					HU	Sonic?
05/31/89	Wednesday	19:35:55	WHP,HJS,SIS	E					HU	JMF first, much earlier than others
05/31/89	Wednesday	19:56:10	WHP,HJS,SIS	E					HU	JMF first, much earlier than others
05/31/89	Wednesday	15:55:15	WHP,HJS,SIS	E					HU	Sonic?
05/31/89	Wednesday	16:14:16	WHP,HJS,SIS	E					HU	JMF first, much earlier than others
06/02/89	Friday	16:24:30	WRD,ALP	E			GM			Sonic?
06/05/89	Monday	14:26:00	WHP,HJS,SIS	E					HU	Sonic?
06/06/89	Tuesday	15:11:10	WHP,HJS,SIS	E					HU	Sonic?
06/06/89	Tuesday	16:01:29	WHP,HJS,SIS	E					HU	Sonic?
06/08/89	Thursday	04:05:45	WHP,HJS,SIS	E					HU	Sonic?
06/08/89	Thursday	15:18:40	WHP,HJS,SIS	E					HU	Sonic?
06/08/89	Thursday	15:16:45	WHP,HJS,SIS	E					HU	Sonic?
06/09/89	Friday	15:30:52	EFF,GAR,JMF	E		PB				Sonic?
06/09/89	Friday	15:21:07	EFF,GAR,JMF	E		PB				Sonic?
06/09/89	Friday	15:45:10	EFF,GAR,JMF	E		PB				Sonic?
06/09/89	Friday	19:44:10	WHP,HJS,SIS	E					HU	Sonic?
06/09/89	Friday	19:41:43	WHP,HJS,SIS	E					HU	Sonic?
06/09/89	Friday	19:39:20	EFF,GAR,JMF	E		PB				Sonic?
06/09/89	Friday	19:46:35	WRD,ALP	E			GM			Sonic?
06/09/89	Friday	15:08:00	EFF,GAR,JMF	E		PB				Sonic? check against HU
06/09/89	Friday	20:01:00	EFF,GAR,JMF	E		PB				Sonic?
06/10/89	Saturday	21:14:45	WHP,HJS,SIS	E					HU	Sonic?
06/10/89	Saturday	17:30:30	EFF,GAR,JMF	E		PB				Sonic?
06/11/89	Sunday	21:23:05	WHP,HJS,SIS	E					HU	Sonic?
06/11/89	Sunday	23:18:05	WHP,HJS,SIS	E					HU	Blast? Sonic?
06/11/89	Sunday	17:37:00	WHP,HJS,SIS	E					HU	Sonic?
06/11/89	Sunday	21:40:37	EFF,GAR,JMF	E		PB				Sonic?
06/11/89	Sunday	20:09:12	WHP,HJS,SIS	E					HU	Sonic?

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

DATE	DAY	TIME (UTC)	STATIONS RECORDI	E	IM	PB	GM	PP	HU	COMMENTS
06/11/89	Sunday	20:26:30	EFF,GAR,JMF	E		PB				Sonic?
06/13/89	Tuesday	21:23:16	EFF,GAR,JMF	E		PB				Sonic?
06/13/89	Tuesday	14:24:13	WHP,HJS,SIS	E					HU	Sonic?
06/20/89	Tuesday	02:17:56	WHP,HJS,SIS	E					HU	Sonic?
06/20/89	Tuesday	22:15:20	WHP,HJS,SIS	E					HU	Sonic?
06/20/89	Tuesday	01:14:53	WHP,HJS,SIS	E					HU	Sonic?
06/20/89	Tuesday	01:23:25	WHP,HJS,SIS	E					HU	Sonic?
06/21/89	Wednesday	01:26:47	WHP,HJS,SIS	E					HU	Sonic?
06/21/89	Wednesday	21:44:05	WHP,HJS,SIS	E					HU	Sonic?
06/21/89	Wednesday	01:29:35	WHP,HJS,SIS	E					HU	Sonic?
06/21/89	Wednesday	01:28:30	WHP,HJS,SIS	E					HU	Sonic?
06/22/89	Thursday	14:59:10	WRD,ALP	E			GM			
06/22/89	Thursday	15:11:33	EFF,GAR,JMF	E		PB				Sonic?
06/22/89	Thursday	14:57:00	WRD,ALP	E			GM			
06/22/89	Thursday	18:34:55	EFF,GAR,JMF	E		PB				Sonic?
06/22/89	Thursday	16:50:40	EFF,GAR,JMF	E		PB				Sonic?
06/22/89	Thursday	14:53:55	WHP,HJS,SIS	E					HU	Sonic?
06/22/89	Thursday	14:55:26	WHP,HJS,SIS	E					HU	Sonic?
06/23/89	Friday	02:28:11	WHP,HJS,SIS	E					HU	Sonic?
06/23/89	Friday	02:29:11	WHP,HJS,SIS	E					HU	Sonic?
06/26/89	Monday	15:49:37	WHP,HJS,SIS	E					HU	Sonic?
06/26/89	Monday	22:04:37	WHP,HJS,SIS	E					HU	Sonic?
06/29/89	Thursday	20:23:42	WHP,HJS,SIS	E					HU	Sonic?
07/06/89	Thursday	14:28:15	SIS	E					HU	Sonic?
07/07/89	Friday	01:43:25	EFF,GAR,JMF	E		PB				Sonic?
07/07/89	Friday	21:14:09	EFF,GAR,JMF	E		PB				Sonic?
07/07/89	Friday	15:45:15	WHP,HJS,SIS	E					HU	Sonic?
07/07/89	Friday	01:25:35	WHP,HJS,SIS	E					HU	Sonic?
07/07/89	Friday	21:14:09	WHP,HJS,SIS	E					HU	Sonic?
07/08/89	Saturday	19:42:55	EFF,GAR,JMF	E		PB				Sonic?
07/11/89	Tuesday	02:33:45	WHP,HJS,SIS	E					HU	Sonic?
07/11/89	Tuesday	02:34:40	WHP,HJS,SIS	E					HU	Sonic?
07/13/89	Thursday	02:30:05	WHP,HJS,SIS	E					HU	Sonic?
07/14/89	Friday	01:50:55	WHP,HJS,SIS	E					HU	Sonic?
07/17/89	Monday	22:15:10	WRD,ALP	E			GM			Sonic?
07/19/89	Wednesday	12:09:00	WRD,ALP	E			GM			Sonic?
07/20/89	Thursday	11:17:08	WHP,HJS,SIS		I				HU	Sonic?
07/24/89	Monday	16:55:30	WHP,HJS,SIS	E					HU	Sonic? Check against RR.
07/24/89	Monday	16:58:35	WRD,ALP	E			GM			Sonic?
07/25/89	Tuesday	15:03:08	EFF,GAR,JMF		I	PB				Sonic? Blast?
07/31/89	Monday	23:50:34	EFF,GAR,JMF	E		PB				Sonic? Slow Moving.
08/08/89	Tuesday	22:29:42	EFF,GAR,JMF	E		PB				Sonic?
08/14/89	Monday	06:58:27	ALP,WRD		I		GM			Check against TX,HU.
08/14/89	Monday	07:00:52	GAR,JMF,EFF	E		PB				Sonic? Check HU,RR
08/14/89	Monday	07:00:12	WHP,HJS,SIS		I				HU	Sonic? Check RR,TX
08/27/89	Sunday	20:57:00	ALP,WRD	E			GM			
08/30/89	Wednesday	18:13:50	WHP,HJS,SIS	E					HU	Sonic?
09/18/89	Monday	07:42:15	ALP,WRD		I		GM			?
10/05/89	Thursday	00:13:09	WHP,HJS,SIS	E					HU	Sonic?
10/06/89	Friday	07:26:15	WHP,HJS,SIS	E					HU	Sonic? check TX
10/06/89	Friday	07:17:51	GAR,JMF,EFF	E		PB				Sonic? Check HU
10/23/89	Monday	18:01:07	GAR,JMF,EFF		I	PB				Plant Explosion
10/23/89	Monday	18:15:17	GAR,JMF,EFF	E		PB				Echo of Explosion???
10/23/89	Monday	18:16:00	WHP,HJS,SIS	E					HU	Check Against Texas

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

DATE	DAY	TIME (UTC)	STATIONS RECORDI	E	IM	PB	GM	PP	HU	COMMENTS
10/26/89	Thursday	18:58:55	ALP,WRD	E			GM			Sonic?
10/30/89	Monday	10:54:58	WHP,HJS,SIS	E					HU	Sonic?
11/03/89	Friday	00:36:35	HJS,SIS	E					HU	Sonic?
11/03/89	Friday	22:31:17	GAR,JMF,EFF	E		PB				Sonic? very slow.
11/07/89	Tuesday	00:42:57	WRD,ALP	E			GM			Sonic? Check HU,TX
11/07/89	Tuesday	00:40:00	EFF,GAR,JMF	E		PB				Sonic? Check RR,HU
11/07/89	Tuesday	00:45:52	HJS,SIS	E					HU	Sonic? Check RR,TX
11/08/89	Wednesday	13:48:44	HJS,SIS		I				HU	Sonic?
11/09/89	Thursday	20:10:00	HJS,SIS	E					HU	Sonic?
11/24/89	Friday	08:42:00	GAR,JMF,EFF	E		PB				Sonic? very slow.
11/30/89	Thursday	21:31:40	GAR,JMF,EFF	E		PB				Sonic? Check HU
11/30/89	Thursday	21:32:36	HJS,SIS	E					HU	Sonic? Check TX
12/03/89	Sunday	17:27:00	ALP,WRD,PLR	E	I		GM			Sonic?
12/04/89	Monday	23:42:04	GAR,JMF,EFF	E		PB				Sonic?
01/26/90	Friday	16:58:30	EFF,GAR,JMF	E		PB				Sonic?
02/07/90	Wednesday	01:25:52	EFF,GAR,JMF	E		PB				Sonic?
02/15/90	Thursday	00:15:01	SIS	E					HU	Sonic?
03/04/90	Sunday	05:23:15	WRD,ALP	E			GM			Sonic? check HU
03/04/90	Sunday	05:25:34	HJS,SIS	E					HU	Sonic? check RR
06/29/90	Friday	22:32:55	WHP,HJS	E					HU	Sonic?
07/02/90	Monday	16:15:45	EFF,GAR,JMF	E		PB				? check HU -- check 7/3/90
07/03/90	Tuesday	16:18:33	WHP,HJS	E					HU	? check RR,HU
07/03/90	Tuesday	16:35:06	EFF,GAR,JMF	E		PB				? check HU,RR
07/03/90	Tuesday	16:34:42	ALP,WRD	E			GM			? check TX,HU
07/09/90	Monday	13:20:05	EFF,GAR,JMF	E		PB				Sonic?
07/10/90	Tuesday	03:39:45	WHP,HJS,ACF(BR)	E					HU	Sonic?
07/17/90	Thursday	04:03:28	WHP	E					HU	?-Low Frequency
07/20/90	Friday	07:17:37	WHP	E					HU	?-Low frequency
07/26/90	Thursday	17:42:03	WHP,HJS	E					HU	Sonic? check TX,RR,Demo
07/26/90	Thursday	18:00:36	EFF,GAR,JMF	E		PB				? check HU,RR,DEMO
07/26/90	Thursday	17:47:20	ALP,WRD	E			GM			? check HU,TX,DEMO
08/04/90	Saturday	19:59:11	WRD,ALP	E			GM			Sonic? check HU,TX
08/04/90	Saturday	20:11:40	EFF,GAR,JMF	E		PB				Sonic? check HU,RR
08/04/90	Saturday	19:56:30	WHP,HJS,SIS	E					HU	Sonic? check TX,RR
08/21/90	Tuesday	23:32:54	EFF,GAR,JMF		I	PB				Sonic? Slow.
08/22/90	Wednesday	02:09:30	WHP,HJS	E					HU	Sonic? Slow. Check ACF,TX
09/26/90	Wednesday	01:35:25	WHP	E					HU	Sonic? Low frequency
10/15/90	Monday	19:56:51	WHP		I				HU	Sonic? Check TX
10/23/90	Tuesday	18:30:00	WHP		I				HU	Low frequency. Check TX
10/29/90	Monday	21:46:01	WHP,HJS	E					HU	Sonic?
10/30/90	Tuesday	20:30:50	WHP,HJS	E					HU	Sonic?
10/15/90	Monday	19:59:06	EFF,GAR,JMF	E		PB				Sonic? Check HU.
10/23/90	Tuesday	18:39:39	EFF,GAR,JMF	E		PB				Sonic? Check HU.
10/26/90	Friday	21:13:04	EFF,GAR,JMF		I	PB				Sonic?
10/29/90	Monday	21:46:01	WHP,HJS	E					HU	SONIC?
10/30/90	Tuesday	20:30:50	WHP,HJS	E					HU	SONIC?
11/02/90	Friday	07:01:50	EFF,GAR	E		PB				SONIC?
11/07/90	Wednesday	16:28:06	EFF,GAR,JMF	E		PB				SONIC?
11/10/90	Saturday	15:11:08	GAR,EFF,JMF	E		PB				SONIC?
11/14/90	Wednesday	20:20:52	WHP,HJS	E					HU	SONIC?
11/18/90	Sunday	15:48:35	WHP,HJS,GAR,JMF	E		PB			HU	SONIC?
11/19/90	Monday	17:14:01	WHP,HJS	E					HU	SONIC?
11/29/90	Thursday	16:05:53	GAR,JMF,EFF	E		PB				SONIC?
12/02/90	Sunday	20:04:00	EFF,GAR,JMF		I	PB				SONIC?

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

DATE	DAY	TIME (UTC)	STATIONS RECORDI	E	IM	PB	GM	PP	HU	COMMENTS
12/04/90	Tuesday	20:55:36	EFF,GAR,JMF		I	PB				SONIC?
12/04/90	Tuesday	21:10:02	EFF,GAR,JMF		I	PB				SONIC?
12/12/90	Wednesday	21:21:42	WHP,HJS		I				HU	SONIC?

APPENDIX II

APPENDIX II

World-wide teleseisms recorded by the geopressured-geothermal microearthquake monitoring networks.

DATE	TIME (UTC)	STATIONS	ORIGIN TIME	LAT.	LONG.	REGION	MAG.
30-Jan-89	04:15:21	EFF,GAR,JMF	04:06:22.7	38.824 N	111.614 W	Utah	5.4
04-Feb-89	19:29:45	EFF,GAR,JMF	19:24:07.4	5.862 N	82.697 W	South of Panama	5.9
02-Mar-89	07:18:55	WHP,HJS,EFF,GAR	07:13:46.1	18.383 N	68.659 W	Mona Passage, Puerto Rico	5.6
10-Mar-89	05:23:26	WHP,HJS,EFF	05:19:52.3	17.586 N	101.013 W	Guerrero, Mexico	5.3
11-Mar-89	05:17:47	WRD,ALP,WHP,HJS,EFF,GAR,JMF	05:05:00.6	17.766 S	174.761 W	Tonga Islands	6.4
20-Mar-89	01:15:47	WRD,ALP,PLR,WHP,HJS,EFF,GAR,JMF	01:06:32.9	59.883 N	153.692 W	Southern Alaska	5.1
24-Mar-89	15:35:52	WHP,HJS,EFF,GAR,JMF	15:31:29.9	11.329 N	86.404 W	Nicaragua	5.2
02-Apr-89	10:40:32	EFF,GAR,JMF	10:35:57.1	11.063 N	85.352 W	Nicaragua	5.0
05-Apr-89	23:57:10	EFF,GAR,JMF	23:47:49.3	20.857 S	69.028 W	Northern Chile	5.7
11-Apr-89	04:08:36	EFF,GAR,JMF,ACF,WHP,HJS,SIS	03:56:36.9	49.488 N	159.185 E	Kuril Islands	6.3
20-Apr-89	08:16:36	EFF,GAR,JMF	08:08:51.0	9.259 S	79.033 W	Northern Peru	5.8
23-Apr-89	19:30:21	EFF,GAR,JMF	19:21:06.4	66.960 N	156.289 W	Alaska	5.7
25-Apr-89	14:32:34	WRD,ALP,WFF,GAR,JMF,WHP,HJS,SIS	14:29:00.5	16.773 N	99.328 W	Guerrero, Mexico	6.5
28-Apr-89	02:45:15	EFF,GAR,JMF,WHP,SIS	02:34:25.3	17.830 N	105.174 W	Jalisco, Mexico	5.3
29-Apr-89	08:29:00	WHP,HJS,SIS	08:22:54.0	10.960 N	68.325W	Venezuela	5.9
01-May-89	09:05:16	EFF,GAR,JMF	08:45:21.6	4.200 S	101.366 E	Southern Sumatera	5.6
05-May-89	18:35:58	EFF,GAR,JMF,HJS,SIS,WRD,ALP	18:28:39.4	8.281 S	71.381 W	Western Brazil	6.4
30-May-89	13:53:48	EFF,GAR,JMF,WHP,HJS,SIS	13:50:56.2	17.401 N	94.645 W	Chiapas, Mexico	5.2
16-Jun-89	11:00:06	EFF,GAR,JMF,WHP,HJS,SIS,WRD,ALP	10:51:21.5	57.755 N	153.992 W	Kodiak Island	5.8
22-Jul-89	05:21:07	EFF,GAR,JMF,WHP,HJS,SIS	05:02:11.5	2.299 N	128.142 E	Halmahera	6.4
08-Aug-89	23:53:47	EFF,GAR,JMF,WHP,HJS,SIS	23:44:04.4	22.723 S	68.478 W	Northern Chile	5.3
29-Aug-89	04:20:14	ALP,WRD,EFF,GAR,JMF,WHP,HJS,SIS	04:16:23.0	18.039 N	105.667 W	Jalisco, Mexico	6.6
04-Sep-89	13:24:25	WHP,HJS,SIS,ALP,WRD,EFF,GAR,JMF	13:14:58.2	55.543 N	156.835 W	South of Alaska	6.9
09-Sep-89	01:46:52	EFF,GAR,JMF	01:40:35.7	2.435 N	79.761 W	South of Panama	5.0
16-Sep-89	23:23:55	EFF,GAR,JMF,ALP,WRD,WHP,SIS,HJS	23:20:53.2	16.497 N	93.671 W	Chiapas, Mexico	6.0
20-Sep-89	13:30:15	EFF,GAR,JMF	13:19:31.9	51.184 N	178.821 E	Aleutian Islands	5.5
07-Oct-89	15:59:15	ALP,WRD,WHP,HJS,SIS,EFF,GAR,JMF	15:48:29.0	51.314 N	179.028 W	Andreanof Islands	6.7
09-Oct-89	18:12:30	EFF,GAR,JMF	18:01:07.8	51.780 N	171.869 E	Aleutian Islands	6.0
17-Oct-89	00:09:45	ALP,WRD,WHP,HJS,SIS,EFF,GAR,JMF	00:04:15.2	37.036 N	121.883 W	Central California	7.1
23-Oct-89		GAR,JMF,EFF,WHP,HJS,SIS				TEXAS REFINERY EXPLOSIO	5.7
29-Oct-89	19:21:08	WHP,HJS,SIS,EFF,GAR,JMF	19:09:12.9	36.788 N	2.448 E	Algeria	5.7
31-Oct-89	15:34:55	WHP,HJS,SIS,GAR,EFF,JMF	15:30:00.0	37.263 N	116.491 W	Nevada (Nuke Test)	5.9
01-Nov-89	06:50:02	EFF,GAR,JMF	06:40:30.3	20.995 S	67.954 W	Southern Bolivia	7.4
01-Nov-89	18:38:58	EFF,GAR,JMF	18:25:34.9	39.837 N	142.760 E	Honshu, Japan	5.1
26-Nov-89	19:00:58	EFF,GAR,JMF	19:00:59.8	25.892 N	110.076 W	Gulf of California	6.1
29-Nov-89	01:09:05	EFF,GAR,JMF,HJS,SIS	01:00:14.8	15.808 S	73.242 W	Southern Peru	4.6
29-Nov-89	06:57:38	EFF,GAR,JMF	06:54:38.5	34.455 N	106.891 W	New Mexico	4.6
29-Jan-90	00:32:33	EFF,GAR,JMF	00:16:42.9	51.715 N	175.272	Aleutian Islands	5.0
23-Jan-90	07:55:25	EFF,GAR,JMF	07:47:09.4	12.463 S	75.081 W	Peru	5.5
16-Jan-90	20:14:07	EFF,GAR,JMF	20:08:22.0	40.232 N	124.138 W	Northern California	5.1
29-Jan-90	02:45:00	HJS,SIS	02:41:26.3	18.750 N	102.192 W	Michoacan, Mexico	5.4
04-Jan-90	05:45:21	HJS,SIS	05:32:25.4	15.046 S	172.904 W	Samoa Islands	6.4
25-Mar-90	13:21:02	EFF,GAR,JMF	13:16:05.5	9.693 N	84.940 W	Costa Rica	5.8
25-Mar-90	21:40:20	EFF,GAR,JMF	21:35:23.3	9.603 N	84.748 W	Costa Rica	5.3
16-Mar-90	16:01:50	EFF,GAR,JMF	15:52:42.1	24.848 N	109.098 W	Gulf of California	5.4
23-May-90	05:32:07	EFF,GAR,JMF	05:27:09.1	9.429 N	84.695 W	Costa Rica	4.8
05-Aug-90	17:54:49	WHP	17:42:32.0	1.042 S	13.952 W	North of Ascension Island	6.2
20-Aug-90	00:16:13	EFF,GAR,JMF	00:03:52.2	46.228 N	142.228 E	Sakhalin Island	5.9
21-Aug-90	14:22:55	EFF,GAR,JMF	14:13:04.2	27.57 S	104.11 W	Easter Island Region	6.1
30-Aug-90	18:38:35	EFF,GAR,JMF	18:32:49.2	5.07 N	74.54 W	South of Panama	5.2
14-Sep-90	07:09:32	EFF,GAR,JMF	07:00:01.7	52.018 N	164.296 W	South of Alaska	5.6
12-Oct-90	17:34:32	GAR,JMF	17:00:00.0	37.248 N	116.494 W	Sthrn. Nevada Nuke Test	5.5
22-Jan-90	17:45:47	EFF,GAR,JMF,SIS,HJS,WRD	17:26:12.1	3.848 N	96.103 E	Northern Sumatera	6.0
12-Jan-90	03:29:10	EFF,GAR,JMF,HJS,SIS	03:24:58.5	12.587 N	87.520 W	Nicaragua	5.3
22-Feb-90	19:04:13	EFF,GAR,JMF,HJS,SIS	18:59:45.3	11.599 N	86.719 W	Nicaragua	5.2
16-Mar-90	16:01:50	EFF,GAR,JMF	15:52:42.1			GULF CALIF.	6.1
25-Mar-90	13:27:50	EFF,GAR,JMF,WHP,HJS,SIS	13:22:54.6	9.780 N	84.840 W	Costa Rica	6.3
03-Apr-90	23:16:38	WHP,HJS,SIS	23:12:09	11.0 N	86.4 W	Nicaragua	5.5
03-Apr-90	23:01:30	EFF,GAR,JMF	22:56:56	11.0 N	86.5 W	Nicaragua	6.5

APPENDIX II con't

DATE	TIME	STATIONS	ORIGIN	LAT.	LONG.	REGION	MAG.
04-Apr-90	04:19:16	ALP,WRD	04:19:16	10.6 N	86.4 W	Costa Rica	5.5
28-Apr-90	01:28:16	WHP,HJS,SIS	01:23:12.1	8.857 N	83.563 W	Costa Rica	6.1
01-May-90	16:21:05	EFF,GAR,JMF	16:12:22.0	58.787 N	156.822 W	Alaska Peninsula	6.2
08-May-90	00:07:04	WHP,HJS,SIS	00:01:39.6	6.951 N	82.653 W	South of Panama	6.3
12-May-90	05:02:00	WHP,HJS,SIS	04:50:09.0	49.040 N	141.881 E	Sakhalin Island	6.4
24-May-90	20:27:43	EFF,GAR,JMF	20:00:07.0	5.345 N	31.908 E	Sudan	7.0
30-May-90	10:53:09	EFF,GAR,JMF	10:40:06.2	45.873 N	26.666 E	Romania	6.7
31-May-90	07:39:00	WHP,HJS,SIS	07:35:27.3	17.253 N	100.750 W	Guerrero, Mexico	5.8
16-Jul-90	07:45:45	EFF,GAR,JMF	07:26:35.9	15.675 N	121.257 E	Luzon, Phillipine Islands	7.7
18-Jul-90	05:22:51	WHP,HJS	05:18:31.8	12.399 N	87.740 W	Nicaragua	5.1
27-Jul-90	00:58:24	WHP,HJS	00:54:57.2	16.190 N	86.202 W	Caribbean Sea	5.4
27-Jul-90	12:56:07	EFF,GAR,JMF	12:38:00.4	15.307 S	167.381 E	Vanuatu Islands	6.4
14-Aug-90	15:37:31	EFF,GAR,JMF	15:13:28.8	35.486 N	35.771 W	North Atlantic Ridge	5.8
26-Aug-90	07:57:37	WHP,HJS,EFF,GAR,JMF	07:53:47.1	20.054 N	77.962 W	Cuba	5.6
26-Sep-90	13:44:06	GAR,JMF	13:24:20.7	3.903 S	102.477 E	Southern Sumatera	5.3
15-Oct-90	01:55:41	EFF,GAR,JMF	01:35:44.4	2.182 S	92.287 E	Southwest of Sumatera	6.6
17-Oct-90	14:37:44	WHP,HJS,WRD,ALP,PLR,EFF,GAR,JMF	14:30:15.0	11.004 S	70.864 W	Peru-Brazil Border Region	6.7
29-Oct-90	02:24:53	WHP,HJS,WIS	02:21:13.5	17.90 N	101.81 W	Guerrero, Mexico	5.0
06-Nov-90	20:25:53	WHP,HJS,ALP,WRD,EFF,GAR,JMF	20:14:30.9	53.468 N	169.92 E	Komandorsky Islands	
15-Nov-90	02:34:31	WHP,HJS,GAR,JMF,EFF	02:34:33.2	3.947 N	97.557 E	Northern Sumatera	
23-Nov-90	22:41:26	WHP,HJS,EFF,GAR,JMF	22:35:34.9	4.726 N	75.602 W	Colombia	
14-Nov-90	19:21:20	EFF,GAR,JMF	19:17:00.7	37.227 N	116.37 W	Nevada Nuke Test	
02-Dec-90	14:47:02	EFF,GAR,JMF,WHP,HJS	14:37:27.5	21.681 S	68.304 W	Chile-Bolivia Border	
17-Dec-90	11:05:50	EFF,GAR,WHP,HJS	11:00:22.2	6.654 N	82.031 W	South of Panama	

SUBSIDENCE MONITORING

by

Donald Stevenson

INTRODUCTION

Subsidence monitoring around the geopressured-geothermal well sites continued during the current reporting period of 1 December 1988 to 31 December 1990. The subsidence monitoring project was designed to determine rates of subsidence around the geopressured-geothermal test well sites for comparison with regional rates of subsidence to assess effects of high volume fluid withdrawal. This report presents the most recent results in this ongoing study.

Figure 1 depicts regional subsidence rates for the gulf coastal area with southwestern Louisiana exhibiting rates of 4-5 mm/yr (Holdahl and Morrison 1974). The site in Pleasant Bayou, Texas, in the hatched area near Houston, experiences anomalously high subsidence (<5mm/yr). Movement north of the Louisiana geopressured-geothermal test sites ranges from 1.5-2.0 mm/yr on the Pleistocene terraces to 3.5-4.0 mm/yr eastward on the delta plain. Subsidence, coupled with sea level rise, compaction of sediments, and a sediment deficit, contributes to the critical land loss problem along many gulf coastal areas. Recent studies have shown that land loss occurs at a rate of 50 mi^2/yr, and in some areas, shoreline erosion rates exceed 10-20 m/yr in areas of coastal Louisiana. It has been proposed that geopressured-geothermal test well sites that produce large quantities of geothermal brine can affect up to 100 km^2 around the well (Van Til 1979). Consequently, subsidence monitoring is of particular importance when wells are located in coastal regions.

Vertical movement through compaction over time and potential fault reactivation are basic types of ground movements associated with subsidence. Figure 2 shows locations of Louisiana study sites. With the exception of Gladys McCall, located in the coastal zone where Holocene sediments are more susceptible to compaction, all sites are on the more stable Pleistocene terrace.

Compaction in a reservoir can be reflected in vertical movement of bench marks. Utilization of first-order, bench-mark networks installed around each site permits the study of vertical ground movements related to geopressured-geothermal development and its relationship to regional trends.

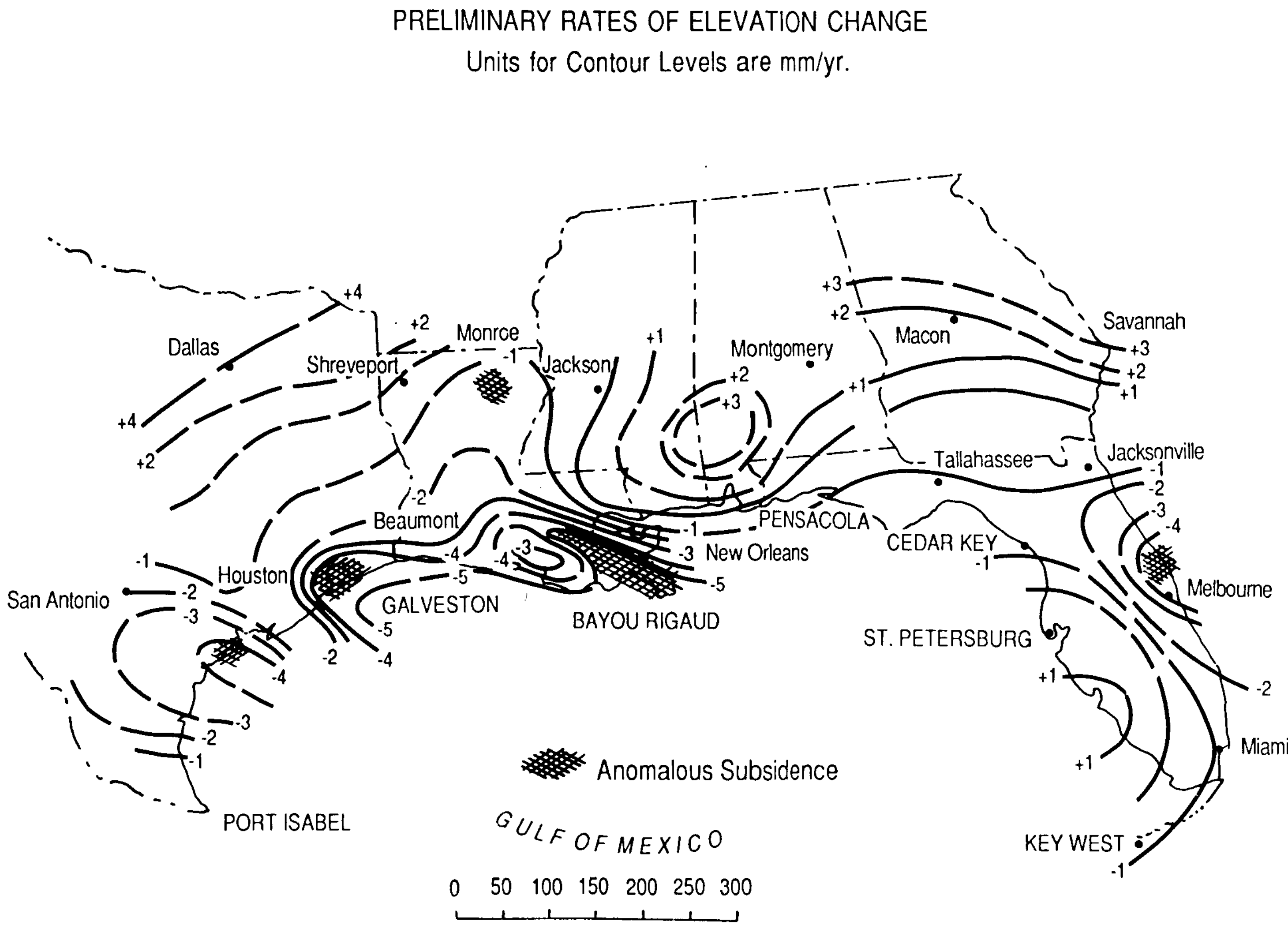

Figure 1. Contour map showing rates of elevation change in the northern coastal zone. Units for contour levels are mm/yr (Holdahl and Morrison 1974).

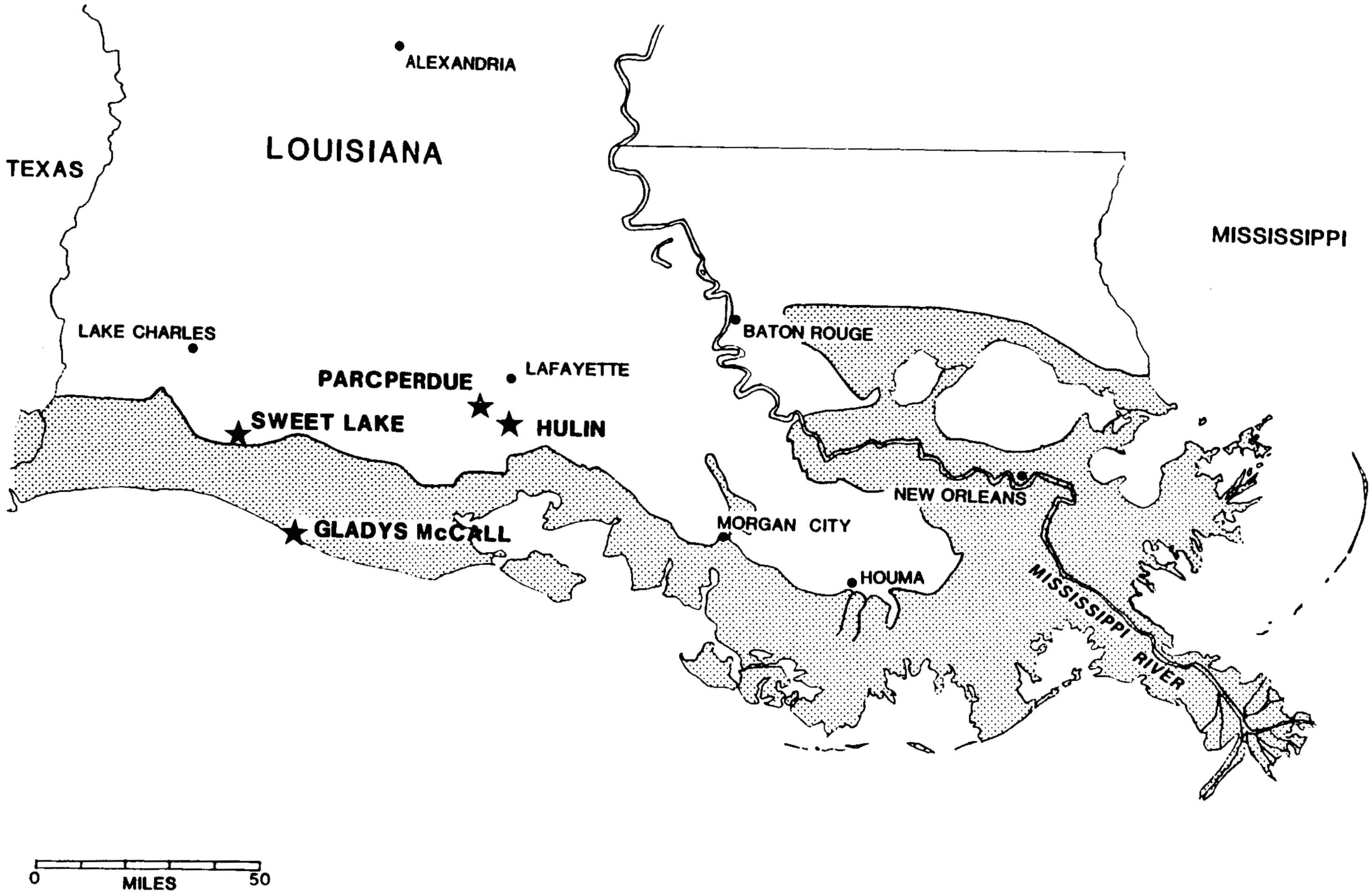

Figure 2. Locations of DOE geopressured-geothermal wells in Louisiana. Shaded area is the coastal zone.

PREVIOUS STUDIES AND RESEARCH METHODS

In previous annual reports, motion rates were referenced to the regional vertical geodetic network and assumed rate of uplift (0.4-1.4 mm/yr) in the Monroe uplift area of northeastern Louisiana (Schumm et al. 1982). However, we are currently using motion rates referenced to Pensacola, Florida, a presumably stable craton, for comparison. Previous investigations by Holdahl (1973, 1975) have shown that using tidal data to determine rates of elevation change is a more reliable method. Each tidal control station is referenced to a nearby bench mark. The observed sealevel heights provide a continuous record of the level of the sea surface with respect to the adjacent land surface. Linear trends in the tidal record consists of two components (1) eustatic or worldwide rise in sea level, and (2) the apparent change in sea level due to local and regional vertical movement of the land. Rates of sea level rise determined from the tidal control stations closest to the well sites are compared to the worldwide eustatic rate. Studies by Gornitz and Lebedeff (1987) and Penland et al. (1988) have shown that the eustatic rate in the Gulf of Mexico (0.23 cm/yr) is slightly higher than the world average. Therefore, a Gulf of Mexico factor also is compared to determine sea level rise at tidal stations along the northern Gulf Coast. Yearly means of sea level heights are calculated at each tidal station and adjusted to mean sea level (MSL). Because Pensacola is located on a presumably stable craton, any sea level rise there can be attributed to eustatic rise in the Gulf of Mexico. Subtracting this Gulf of Mexico eustatic factor from rates determined from similar trends on Louisiana coastal zone stations reveals the portion of the record that could be attributed to eustatic rise and the portion resulting from local subsidence (Ramsey and Penland 1989). Repeated geodetic leveling from tidal bench marks and connecting level lines was used to determine relative rates of vertical movement, which indicate regional subsidence relative to the Gulf of Mexico.

A first-order, leveling geodetic network was established and tied into the National Geodetic Survey (NGS) survey lines using class B monuments installed roughly 1 km apart near the Pleasant Bayou, Texas, and the Hulin, and Gladys McCall, Louisiana, prospects prior to development. These bench marks are classified class B, consisting of capped steel rods driven to a depth of 100 ft or to refusal. Class B refers to the NGS classification for monument quality.

Repeated surveys are conducted to monitor the test sites on a regular basis. To determine local motion, a bench mark outside of the reservoir is held fixed during two or more surveys. In this case, the known rate of movement from the tidal stations can be assumed and used as a base movement. Statistical analysis on bench marks with repeated surveys indicates movement relative to the fixed point.

RESULTS

Gladys McCall

The Gladys McCall test well site is located near the western edge of the Rockefeller Wildlife Refuge in Cameron Parish, Louisiana. A bench mark monitoring network was established at this well site according to NGS specifications in September 1981 before testing was initiated (figure 3). Nine monuments consisting of stainless steel rods with aluminum caps were installed along Highway 82 and around the well head. Eight monuments were installed along Price Lake Road down to the Gulf Coast shoreline, and seven monuments were installed parallel to the shoreline just behind the beach. The monuments along the beach were abandoned two years ago because of severe erosion problems. In this area of Louisiana the beach is retreating so fast that bench marks would not last two years between leveling intervals.

A releveling survey was conducted in July 1990. Figure 4 presents data from table 1 showing differences in elevation for the 1981 survey minus the 1988 and 1990 surveys, respectively, with bench mark GM-3 held constant. In general, all bench marks seem to be subsiding at more or less constant values. The one exception would be WH, which is not a bench mark but an elevation for a bolt on the well head. It has subsided much more than the bench marks. This is probably due to the suspended weight of the 15,000+ feet of drill stem. The one bench mark showing a consistent rise compared to GM-3 is GM-9 located at the end of Price Lake Road. Reasons for this are unknown at this time. The complete report, as submitted by our subcontractor is presented in Appendix I.

We have also noted an interesting phenomena occurring with bench marks located on the ring-levy

Table 1. Leveling data for Gladys McCall study site for 1981 to 1988 and 1981 to 1990.

Bench mark '81-'88	**Elevation Diff.** '81-'90	**mm**
GM-3	0.0	0.0
U-213	0.9144	-5.912
TT-186	-0.6096	-2.7432
T-213	-10.0584	-14.3526
GM-2	-0.3048	-3.9624
S-213	-5.1816	-3.048
GM-1	-3.9624	-1.2192
GM-18	-2.7432	-7.3152
GM-19	-2.4384	-7.62
GM-20	0.3048	-7.9248
GM-21	0.6096	-7.62
GM-23	no reading	-8.2296
WH	-53.9496	-71.0184
GM-4	5.864	-0.3048
GM-5	6.4008	no reading
GM-6	-10.668	-14.6304
GM-7	-7.3152	-8.2296
GM-8	-7.3152	-6.096
GM-9	4.8769	7.0104

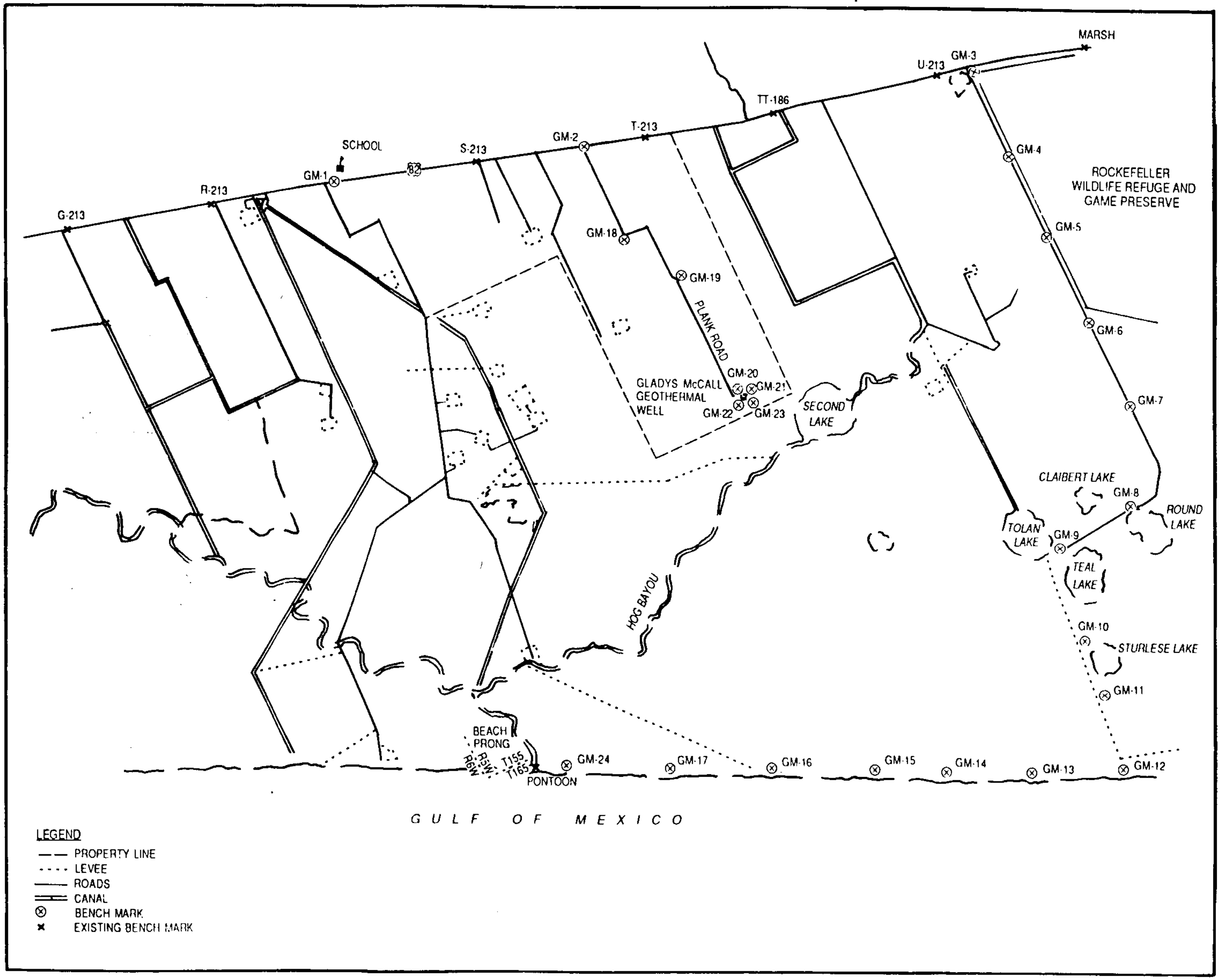

Figure 3. Location of the Gladys McCall geopressured-geothermal well monitoring network.

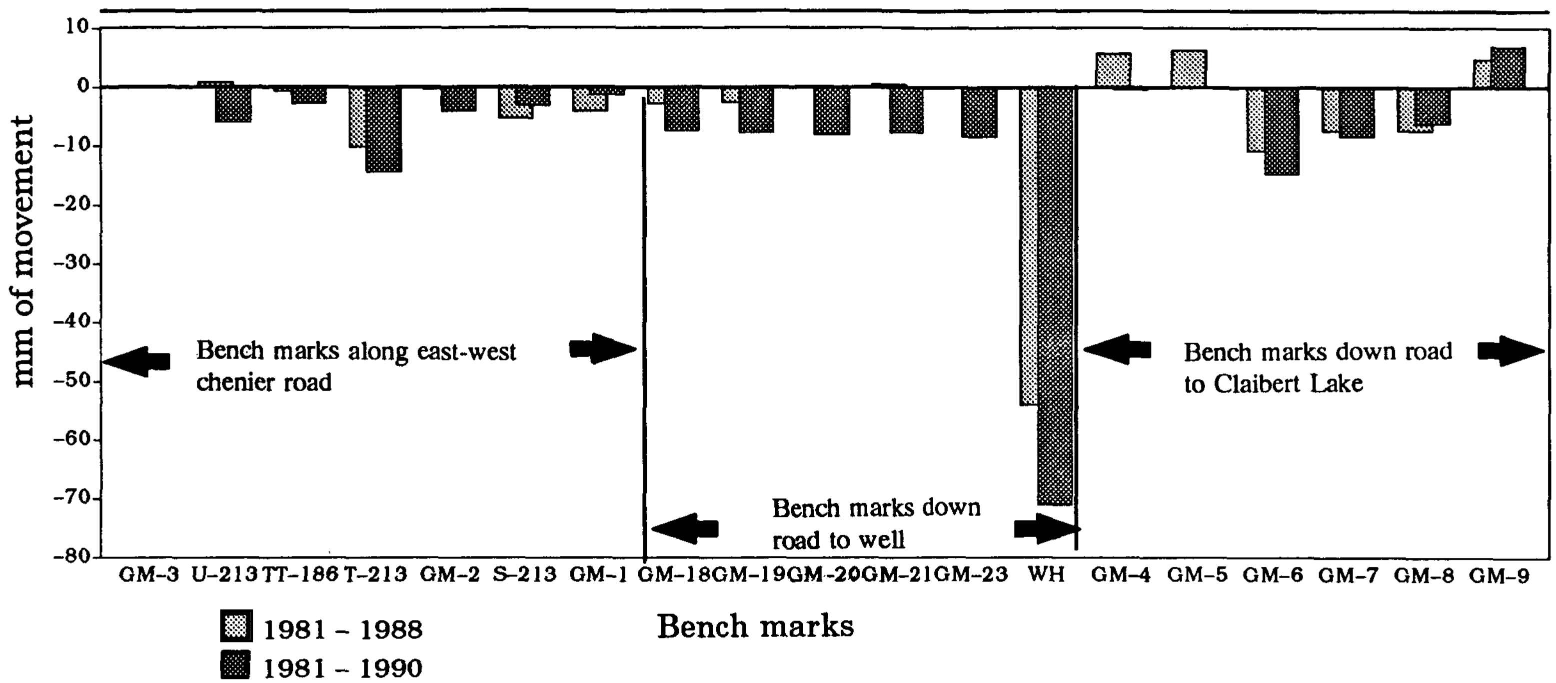

Figure 4. Elevation changes of bench marks in the Gladys McCall area relative to GM-3 (held constant).

around the well. When the bench mark network was originally installed, it was placed inside short pieces of PVC pipe, sticking just above the ground surface for protection. The bench mark cap was positioned just beneath the level of the ground. As the years have passed, the bench mark caps are now well exposed, in some instances 4 to 6 inches. At first this was rather puzzling; however, we now feel certain this probably indicates compaction and/or erosion, over time, of the ring levy rather than subsidence.

Pleasant Bayou

The Pleasant Bayou test well site is located in Brazoria County, Texas, south of where Pleasant Bayou merges into Chocolate Bayou (figure 5). Twelve class B monuments were established in June 1984. These monuments were installed according to NGS specifications for first-order leveling surveys and tied into the NGS network on line #105.

The leveling data and report for Pleasant Bayou was received from our subcontractor at the end of March 1991 and is included in Appendix II. This work was completed in November 1990.

Currently, we have four leveling surveys from the Pleasant Bayou area (1984, 1985, 1988, and 1990). An interesting trend seems to be emerging with the addition of 1990 data. There is a suggestion of uplifting in the area of the well rather than subsidence. When we look at data from the 1984 survey and the subsequent changes in elevation for the two longest time periods 1988 and 1990 (four and five years respectively) it seems as though the bench marks located in close proximity to the geopressured-geothermal well are rising in relation to the bench marks off site. Figure 6 (data from table 2) shows a graph of the change in elevation of the various bench marks from 1984 to 1988 and 1984 to 1990 (the Liverpool bench mark C-1209, figure 5, is held constant). The positive area of the graph indicates uplift compared to the other off-site stations of the bench mark network. The magnitude of change within this area remains a somewhat uniform 5.7 mm over the five years of data collection.

Large amounts of general areawide subsidence have been reported throughout the Houston-Galveston region (figure 1). Estimated subsidence in the area of the LGS bench-mark network is approximately

Table 2. Leveling data for Pleasant Bayou study site 1984 to 1988 and 1984 to 1990.

Bench mark	Elevation '84/'88	Diff. mm '84/'90
C-1209 (HLD)	0	0
BL 26	116.08	-35.28
L-1274	0	-15.33
F 752	5.48	-14.75
BRZ-1	4.85	6.62
BRZ-2	4.63	6.0
BRZ-3	5.65	5.57
BRZ-4	4.55	6.02
BRZ-5	4.25	0
BRZ-6	3.85	5.52
BRZ-7	1.18	4.7
BRZ-8	-1.57	-1.65
BRZ-9	-7.17	-8.45
BRZ-10	-5.22	-5.35
BRZ-11	-3.02	-0.9
BRZ-12	-3.42	1
A-1208	-5.21	6.28
LIVERPOOL 1931	-94.24	-96.17

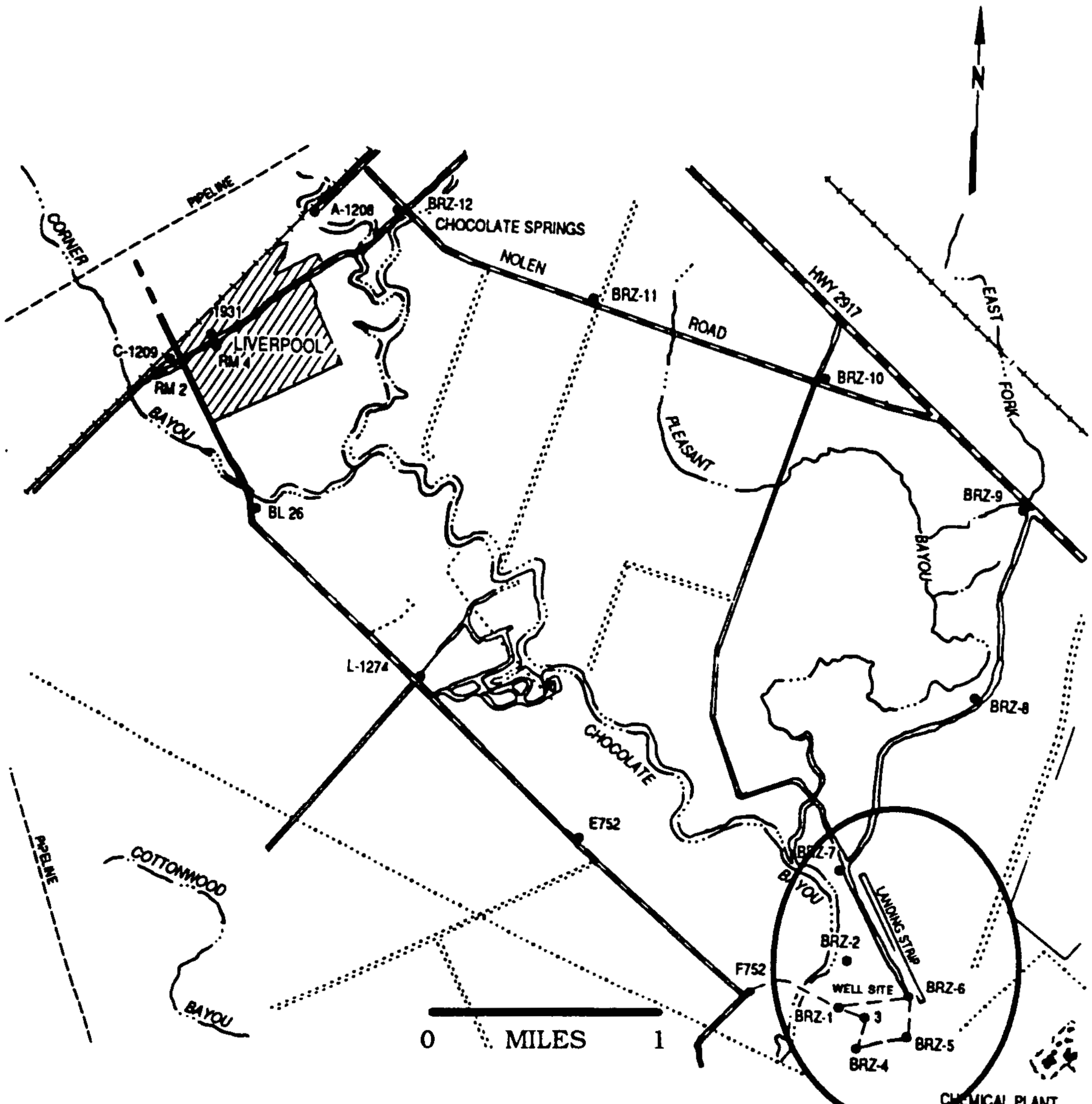

Figure 5. Location of the Pleasant Bayou geopressured-geothermal well with bench-mark locations. Bench marks in oval are showing relative uplift compared to others within the network.

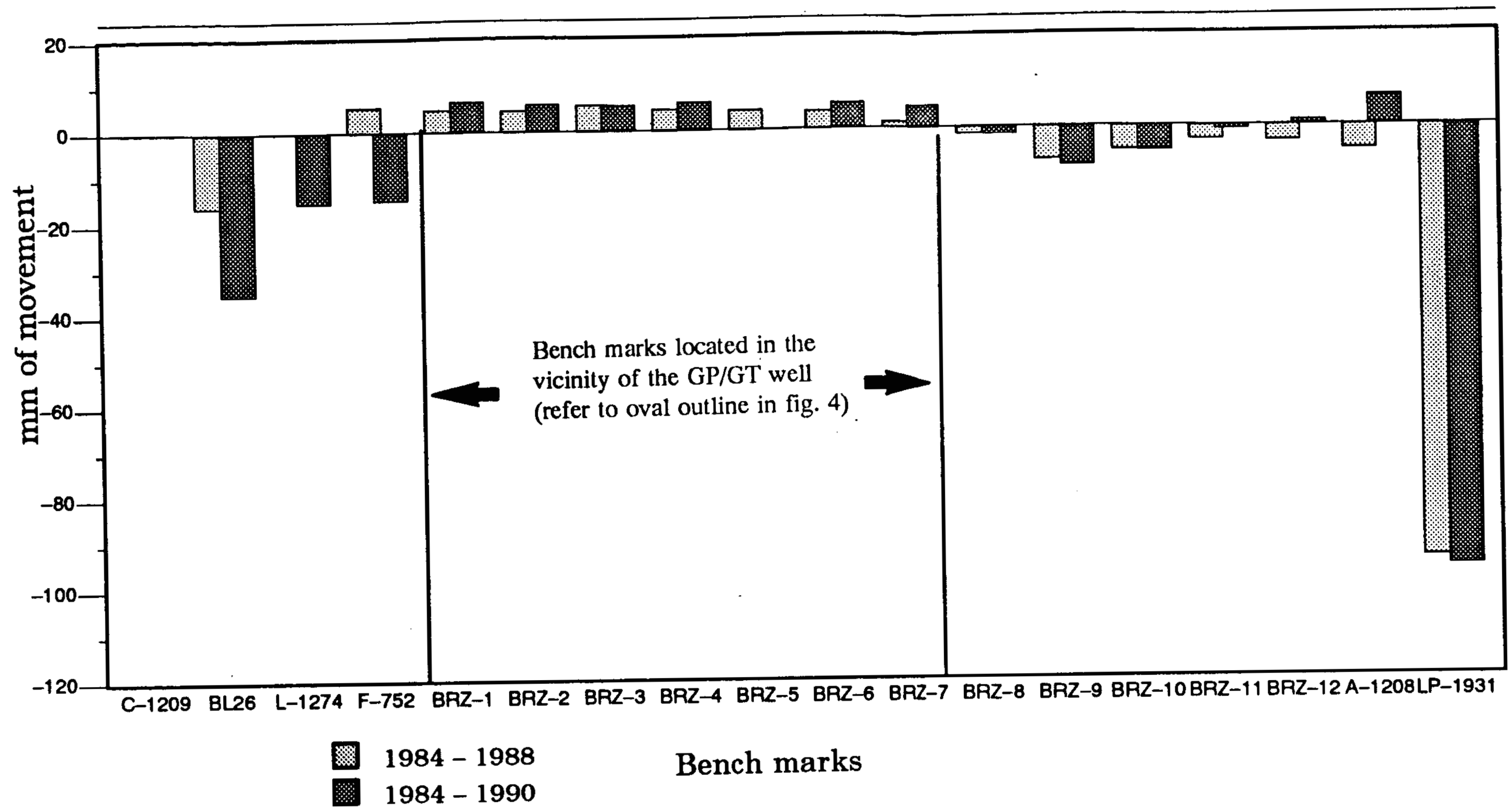

Figure 6. Elevation changes of bench marks in the Pleasant Bayou area relative to C-1209 (held constant).

10.0 mm/yr (Gaybrisch 1982). The apparent small uplifting trend, exhibited by bench marks within the small oval around the well, suggests this area is subsiding at a slightly slower rate than the surrounding region, rather than actually rising (figure 5). Reasons for this apparent uplifting are unknown. One possible cause could be related to injection disposal of brine from the geopressured-geothermal well.

Releveling of the Pleasant Bayou bench marks was completed in November 1990. Leveling data was obtained for the Pleasant Bayou test site during this reporting period. The next round of releveling is to take place during the 1992 contract year.

Hulin

The Hulin test well site is located in Vermilion Parish, Louisiana, six miles south of Erath. Seventeen class B monuments were established between the NGS line along Highway 14 in Erath and the Hulin well site during last contract year. Figure 7 shows bench-mark elevations derived from this first round of leveling (table 3). Figure 8 shows locations of bench marks used for monitoring the Hulin prospect. Those with the HU prefix were installed for this project others were either installed by the state or federal (NGS) agencies. After allowing one year for stabilization, the bench marks were initially leveled in December 1989. A copy of the report submitted by the surveying subcontractor is included as Appendix III. This first leveling episode forms the basis for comparison and interpretation of subsequent leveling data obtained as the project progresses.

CONCLUSIONS

Geopressured-geothermal reservoir sites have been monitored since 1980 to determine whether fluid withdrawal is increasing subsidence. Analysis of the data from the sites monitored to date have shown little or no increase in subsidence has occurred due to fluid withdrawal at any of the sites. However, data from Pleasant Bayou, Texas, seems to be showing a slight uplift when compared to bench marks within the LSU bench-mark network. Additional leveling should clarify this trend. Another round of releveling will be performed at the Gladys McCall and Pleasant Bayou bench-mark networks in the next contract year (1992).

Table 3. First year (1989) leveling data for the Hulin site.

Bench mark	Elevation m
T361	1.6066
V83	1.744
H15	1.382
H14	1.660
V81	2.604
H13	2.473
C4056	2.755
H12	1.986
V78	2.813
B380	1.949
C4051	1.938
H10	1.715
H9	1.494
H5	0.514
H3	1.020
H4	0.704
H1	0.626
H8	0.776
H17	0.788
H6	1.188
WH	0.964

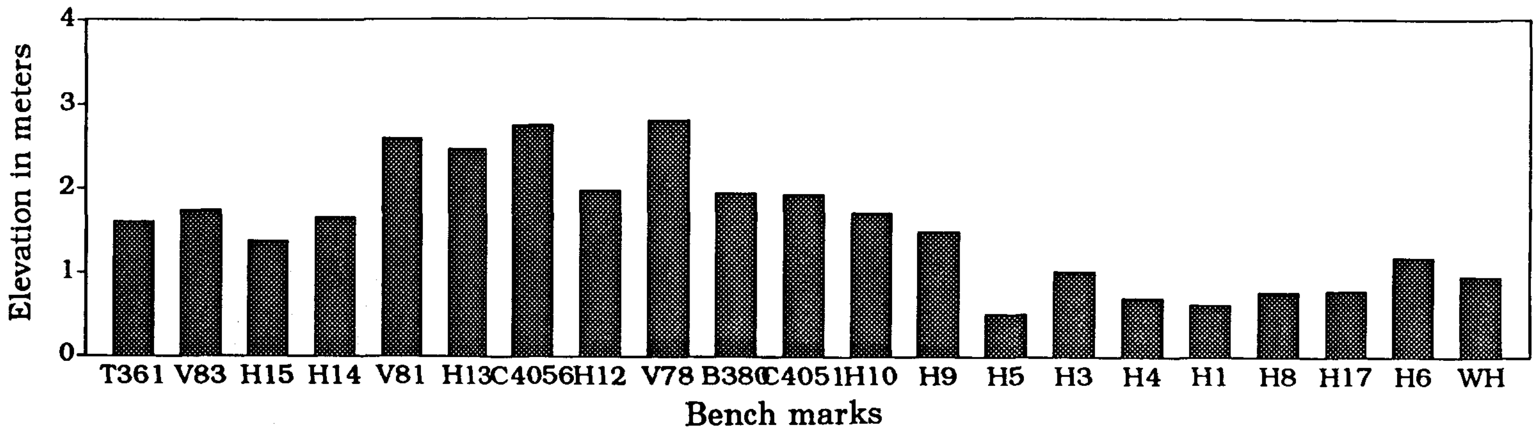

Figure 7. Bench-mark elevations near Hulin site.

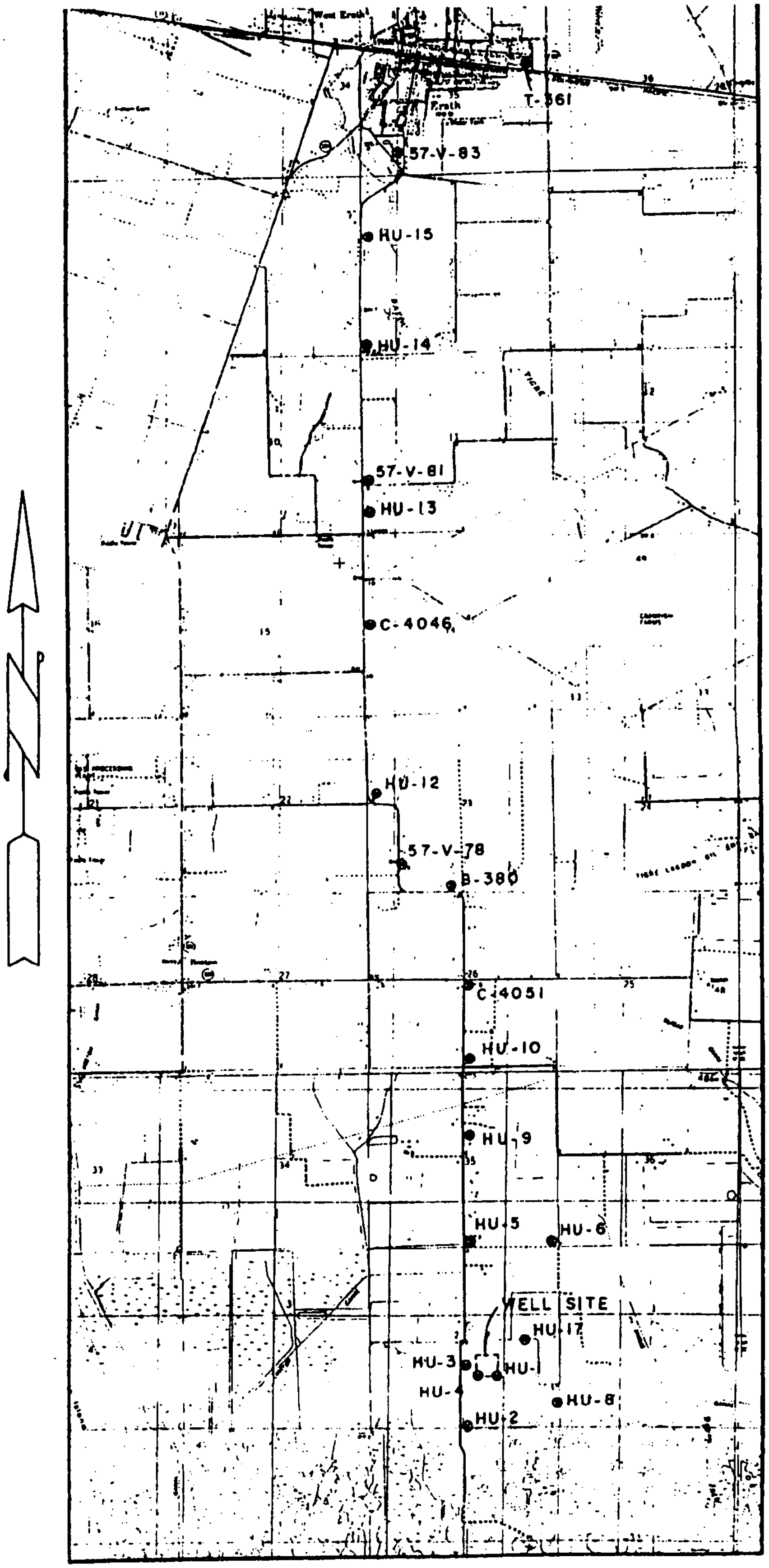

Figure 8. Hulin bench-mark network. Bench marks correspond to those in figure 7 and table 3.

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APPENDIX I

PREFACE TO

GLADYS McCALL GEOPRESSURE-GEOTHERMAL TEST WELL SITE

FIRST ORDER RE-LEVELING

The purpose of this survey was to re-level through and establish elevations for existing bench marks along LA Hwy #82, and along the western side of the Rockefeller Wildlife Refuge, and into the well site.

The re-leveling was performed in July 1990, and was accomplished utilizing procedures and equipment identical to that used by the National Geodetic Survey for their First Order Class I Leveling.

The re-leveling began on bench mark GM-1 and the elevation established in 1981 was used for this survey. The caps were missing from GM-6, GM-7, and GM-8. Bench Mark GM-22 was destroyed in 1988. Bench Mark GM-5 was searched for but not recovered.

Page 1 and 2 shows the results of the re-leveling. Page 3 is a location map which shows the approximate location of all bench marks established in 1981, 1985, and 1987.

Pages 4 through 10 contain the recovery data and description for each bench mark established in 1981, 1985, and 1987 and the elevations established from this re-leveling.

GLADYS McCALL

GEOPRESSURE-GEOTHERMAL TEST WELL SITE

FIRST ORDER LEVELING

STATION TO STATION	PUBLISHED ELEVATION (USCGGS)	DIFFERENCE IN ELEVATION (D.E.)				LENGTH OF SECTION (KILOMETERS)	ALLOWABLE ERROR IN SECTION	ACTUAL ERROR IN SECTION	ELEVATION FROM THIS LEVELING
		USCGGS D.E.	FORWARD RUN	BACKWARD RUN	MEAN D.E.				
GM - 1									8.521
			+1.0603	−1.0533	+1.0568	1.646	0.013	0.007	
S - 213	9.580								9.578
			−3.2509	+3.2499	−3.2504	1.123	0.010	0.001	
GM - 2	* * *	−0.554 (S-213 to T-213)							6.327
			+2.6933	−2.6893	+2.6913	0.637	0.008	0.004	
T - 213	9.026								9.019
		−3.554	−3.5097	+3.5144	−3.5121	1.451	0.012	0.005	
TT - 186	5.472								5.507
		−0.111	−0.1289	+0.1362	−0.1326	1.889	0.013	0.007	
U - 213	5.361								5.374
			−1.6999	+1.7024	−1.7012	0.508	0.007	0.003	
GM - 3	* * *								3.673
			+0.1729	−0.1734	+0.1732	0.864	0.009	0.001	
GM - 4	* * *								3.846
			−0.7780	+0.7799	−0.7790	2.048	0.0187	0.002	
GM - 6 CAP	* * *								3.067
IS MISSING			−1.3357	+1.3323	−1.3340	0.880	0.009	0.003	
GM - 7 CAP	* * *								1.733
IS MISSING			−0.3984	+0.3968	−0.3976	1.020	0.010	0.002	
GM - 8 CAP	* * *								1.336
IS MISSING			+1.1549	−1.1620	+1.1585	1.572	0.012	0.007	
GM - 9	* * *								2.494

* = CLOSURE CRITERIA FOR FIRST ORDER LEVELS
* * * = NEW BENCH MARK ESTABLISHED BY THIS SURVEY
ALL DATA SHOWN UNLESS NOTED IS EXPRESSED IN U.S. SURVEY FEET

DATE: JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

GLADYS McCALL

GEOPRESSURE-GEOTHERMAL TEST WELL SITE

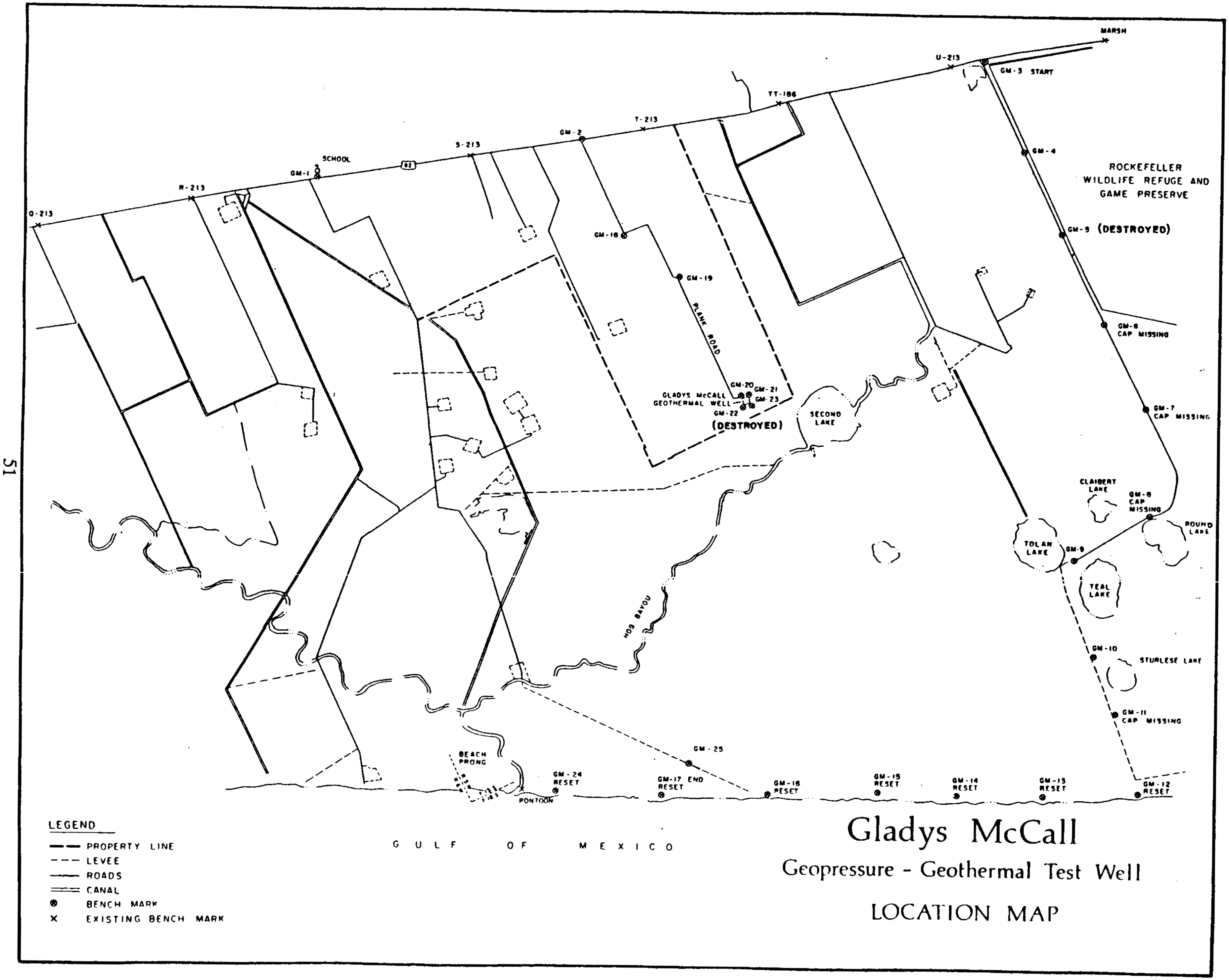
FIRST ORDER LEVELING

STATION TO STATION	PUBLISHED ELEVATION (USC&GS)	DIFFERENCE IN ELEVATION (D.E.) USC&GS D.E.	FORWARD RUN	BACKWARD RUN	MEAN D.E.	LENGTH OF SECTION (KILOMETERS)	ALLOWABLE ERROR IN SECTION	ACTUAL ERROR IN SECTION	ELEVATION FROM THIS LEVELING
GM-2	* * *								6.327
			-2.4944	+2.4567	-2.4956	1.106	0.010	0.002	
GM-18	* * *								3.831
			-1.7221	+1.7286	-1.7254	0.952	0.009	0.007	
GM-19	* * *								2.106
			+0.3742	-0.3679	+0.3711	1.456	0.012	0.006	
GM-20	* * *								2.477
			+0.8314	-0.8310	+0.8312	0.083	0.003	0.0004	
GM-21	* * *								3.308
			-2.0527	+2.0518	-2.0523	0.116	0.003	0.001	
GM-23	* * *								1.256
GM-20	* * *								2.477
			-0.4099	+0.4108	-0.4104	0.114	0.003	0.001	
WELL HEAD	* * *								2.067

* = CLOSURE CRITERIA FOR FIRST ORDER LEVELS
* * * = NEW BENCH MARK ESTABLISHED BY THIS SURVEY
ALL DATA SHOWN UNLESS NOTED IS EXPRESSED IN U.S. SURVEY FEET.

DATE: JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA



Gladys McCall

Geopressure - Geothermal Test Well

LOCATION MAP

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

BENCH MARK GM-1 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION FEET	ELEVATION METERS
September, 1981	8.521	2.5972
November, 1988	8.521	2.5972
July, 1990	8.521	2.5972

DESCRIPTION: Vicinity - Cameron Parish, L.A. #82, in the southeast corner of Section #8, R-5-W, T-15-S.

To reach from the post office in Grand Chenier, go 4.55 miles southeast along L.A. #82 to the Grand Chenier Elementary School, and the station on the left.

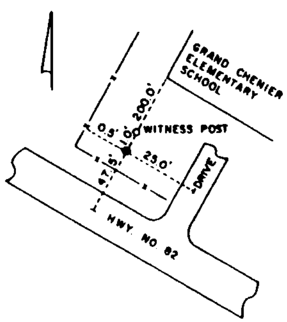
The monument is a stainless steel rod driven to refusal, a depth of 84', with an aluminum cap stamped LSU BM-GM-1-1981 and set in a 4" PVC pipe 0.3' below ground.

The station is located 16,000'± from the Gladys McCall well site in azimuth 143°

Recovered November, 1988

Recovered July, 1990

SKETCH:



SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-2 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION FEET	ELEVATION METERS
September, 1981	6.336	1.9312
June, 1984	6.336	1.9312
November, 1988	6.348	1.9349
July, 1990	6.327	1.9285

DESCRIPTION: Vicinity - Cameron Parish LA #82, in the northwest center of Section #15, R-5-W, T-15-S.

To reach from the post office in Grand Chenier, go southeast along LA #82 6.3 miles to the entrance to the Gladys McCall Well Site, and the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 72', with an aluminum cap, stamped L.S.U. - BM-GM-2, 1981 and set in a 4" PVC pipe 0.3' below ground.

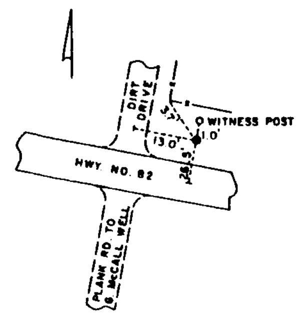
The station is located 10,200'± from the Gladys McCall Well Site in azimuth 172°

RECOVERED JUNE, 1984

RECOVERED NOVEMBER 1988

RECOVERED JULY, 1990

SKETCH:



SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-3 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION FEET	ELEVATION METERS
September, 1981	3.669	1.1183
June, 1984	3.655	1.1140
December, 1985	3.655	1.1140
June, 1987	3.655	1.1140
November, 1988	3.682	1.1223
July, 1990	3.673	1.1195

DESCRIPTION: Vicinity - Cameron Parish

LA #82 The northeast corner of Section #24 R-5-W, T-15-S.

To reach from the post office in Grand Chenier, go southeast along LA #82 11.05 miles to the northwest corner of the Rockefeller Wildlife Refuge, and the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 76', an aluminum cap stamped L.S.U. BM GM-3-1981, and set in a 4" PVC pipe 0.3' below ground.

The station is located 13,300' ± from the Gladys McCall Well Site in azimuth 239° - 30'.

RECOVERED JUNE, 1984

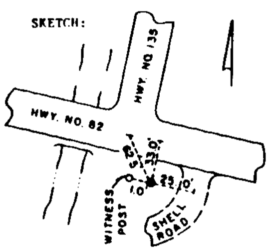
RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987

RECOVERED NOVEMBER 1988

RECOVERED JULY, 1990

SKETCH:



SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-4 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION FEET	ELEVATION METERS
September, 1981	3.843	1.1713
June, 1984	3.831	1.1677
December, 1985	3.829	1.1671
June, 1987	3.826	1.1662
November, 1988	3.874	1.1808
July, 1990	3.846	1.1723

DESCRIPTION: Vicinity - Cameron Parish

On the east edge and near the center of Section #24, R-5-W, T-15-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 0.6 miles to the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 76', with an aluminum cap stamped L.S.U. BM, GM-4-1981, and set in a 4" PVC pipe 0.3' below ground.

The station is located 13,300' ± from the Gladys McCall Well Site in azimuth 239° - 30'.

RECOVERED JUNE, 1984

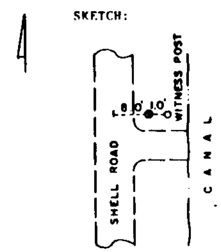
RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

SKETCH:



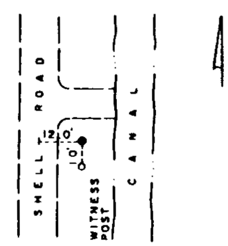
SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

53

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

BENCH MARK GM-5	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	2.785	0.8489
June, 1984	2.783	0.8483
December, 1985	2.775	0.8458
June, 1987	2.773	0.8452
November, 1988	2.819	0.8592

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish

on the east edge and near the north quarter of Section #25, R-5-W, T-15-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82 go south along the west boundary road 1.3 miles to a turnout, and the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 60', with an aluminum cap stamped L.S.U. BM GM-5, 1981, and set in a 4" PVC pipe 0.3' below ground.

The station is located 11,400' + from the Gladys McCall Well Site in azimuth 269.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987

RECOVERED NOVEMBER, 1988

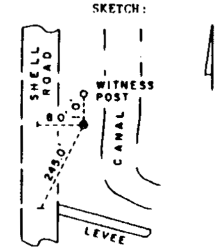
DESTROYED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-6	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	3.111	0.9482
June, 1984	3.107	0.9470
December, 1985	3.047	0.9287
June, 1987	3.048	0.9290
November, 1988	3.089	0.9415
July, 1990	3.067	0.9348

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish

On the east edge, and near the southeast corner of Section #25, R-5-W, T-15-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 1.85 miles to the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 80', with an aluminum cap stamped L.S.U. BM, GM-6, 1981, and set in a 4" PVC pipe 0.3' below ground.

The station is located 11,800' + from the Gladys McCall Well Site in azimuth 283°.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985
(Cap missing, shot on top of rod)

RECOVERED JUNE, 1987
(Cap missing, shot on top of rod)

RECOVERED NOVEMBER, 1988
(Cap missing, shot on top of rod)

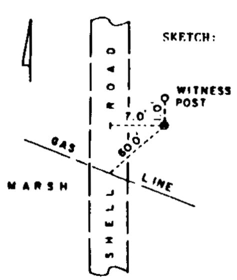
RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-7	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	1.756	0.5352
June, 1984	1.751	0.5337
December, 1985	1.742	0.5310
June, 1987	1.705	0.5197
November, 1988	1.745	0.5319
July, 1990	1.733	0.5282

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish

On the east edge and near the center of Section #36, R-5-W, T-15-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA#82, go south along the west boundary road 2.4 miles to the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 88', with an aluminum cap stamped LSU BM-GM-7-1981, and set in a 4" PVC pipe 0.3' below ground.

The station is located 12,600' + from the Gladys McCall Well Site in azimuth 295° - 30'.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987
(Cap missing, shot on top of rod)

RECOVERED NOVEMBER, 1988
(Cap missing, shot on top of rod)

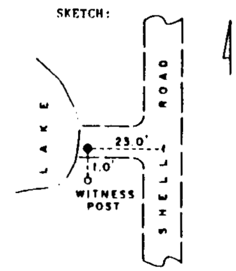
RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-8	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	1.352	0.4121
June, 1984	1.344	0.4097
December, 1985	1.342	0.4090
June, 1987	1.305	0.3978
November, 1988	1.341	0.4087
July, 1990	1.336	0.4072

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish

In the northeast corner of Section 1, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 3.05 miles to a turn out, and the station on the right.

The monument is a stainless steel rod driven to a depth of 100', with an aluminum cap stamped L.S.U. BM-GM-8-1981, and set in a 4" PVC pipe 0.03' below ground.

The station is located 14,200' + from the Gladys McCall Well Site, in azimuth 307°.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987
(cap missing, shot on top of rod)

RECOVERED NOVEMBER, 1988
(cap missing, shot on top of rod)

RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-9 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	2.467	0.7519
June, 1984	2.463	0.7507
December, 1985	2.453	0.7477
June, 1987	2.461	0.7501
November, 1988	2.496	0.7608
July, 1990	2.494	0.7602

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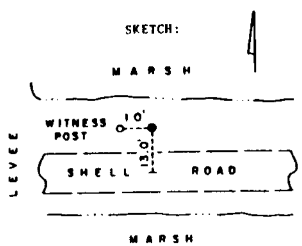


DESCRIPTION: Vicinity - Cameron Parish

In the northwest corner of Section #1, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82 go south and west along the west boundary road 3.95 miles to the end of the road, and th the station on the right.

The monument is a stainless steel rod driven to a depth of 100' with an aluminum cap stamped L.S.U. BM-GM-9-1981, and set in a 4" PVC pipe 0.3' below ground.

The station is located 12,000' ± from the Gladys McCall Well Site, in azimuth 323°.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

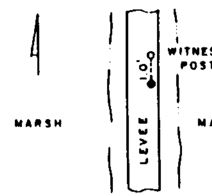
SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-10 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	2.526	0.7699
June, 1984	2.529	0.7708
December, 1985	2.520	0.7681
June, 1987	2.037	0.6209

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish
Near the southwest corner of Section #1, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge and LA #82, go south along the west boundary road 4.52 miles to the station on the left.

The monument is a stainless steel rod driven to a refusal, a depth of 80', with an aluminum cap stamped L.S.U. BM-GM-10-1981, and set in a 4" PVC pipe projecting 0.2' above ground.

The station is located 14,100' ± from the Gladys McCall Well Site in azimuth 333°.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987
BM-GM-10-1981 has been disturbed due to levee construction. Mud was pumped onto levee to a height of 2' ±.

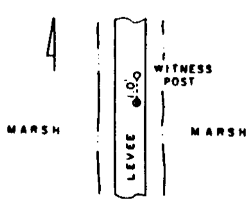
SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-11 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	3.180	0.9693
June, 1984	3.188	0.9717
December, 1985	3.176	0.9681
June, 1987	2.852	0.8693

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish
On the west edge, and near the center of Section #12, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, go south along the west boundary road 3.95 miles, then continue south along a levee 0.97 miles to the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 92', with an aluminum cap stamped L.S.U. BM-GM-11 1981, and set in a 4" PVC pipe projecting 0.2' above ground.

The station is located 16,200' ± from the Gladys McCall Well Site in azimuth 336°-30'.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RECOVERED JUNE, 1987
(Cap missing, shot on top of rod)
BM-GM-11-1981 has been disturbed due to levee construction. Mud was pumped onto levee to a height of 2' ±.

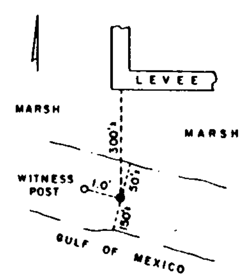
SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-12 Reset DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December, 1985	3.844	1.1717
June, 1987	3.870	1.1796

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish
At the northwest corner of Section #13, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, go south along the west boundary road, 5.62 miles to the coast, and the station set in line with a north-south levee.

The monument is a stainless steel rod driven to a depth of 100', with an aluminum cap stamped L.S.U. BM-GM-12-1985, and set in a 4" PVC pipe projecting 0.8' above ground.

The station is located 19,800' ± from the Gladys McCall Well Site in azimuth 341°.

RESET DECEMBER, 1985

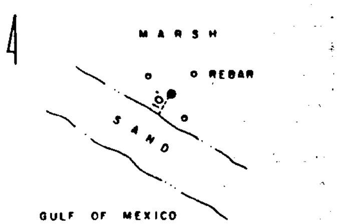
RECOVERED JUNE, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-13 RESET	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
June, 1987	3.460	1.0546

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish
In the southwest corner of Section #11, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 5.62 miles to the Gulf Coast, then northwest along the coast 0.66 miles to the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 54' with an aluminum cap stamped L.S.U. BM-GM-13-RESET 1987, and set in a 6" PVC pipe projecting 1.5' above ground.

The station is located 16,900'± from the Gladys McCall Well Site in azimuth 351°-30'.

RECOVERED JUNE, 1984

DESTROYED

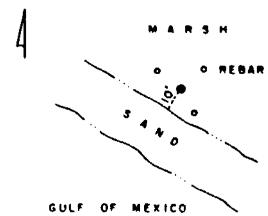
RESET JUNE, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-14 RESET	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
June, 1987	4.057	1.2366

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #10, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, Go south along the west boundary road 5.62 miles to the Gulf Coast, then northwest along the coast 1.4 miles to the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 94'; with an aluminum cap stamped L.S.U. BM-GM-14-RESET 1987, and set in a 6" PVC pipe projecting 1.5' above ground.

The station is located 15,300'± from the Gladys McCall Well Site in azimuth 01°.

NOT RECOVERED (JUNE, 1984)

RECOVERED DECEMBER, 1985

Reset June, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-15 Reset	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December, 1985	3.460	1.0546
June, 1987	3.464	1.0558

SKETCH:

DESCRIPTION: Vicinity - Cameron Parish
Near the northwest corner of Section #10, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 5.62 miles to the Gulf Coast, then northwest along the coast 1.84 miles to the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 86', with an aluminum cap stamped L.S.U. BM-GM-15, 1985, and set in a 4" PVC pipe projecting 0.8' above ground.

The station is located 14,600'± from the Gladys McCall Well Site, in azimuth 09°.

RESET DECEMBER, 1985

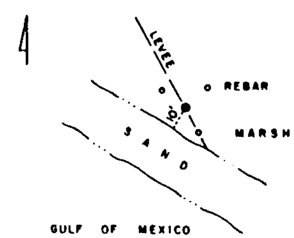
RECOVERED JUNE, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-16 RESET	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
June, 1987	3.402	1.0369

SKETCH:



DESCRIPTION: Vicinity - Cameron Parish
Near the southeast corner of Section #4, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 5.62 miles to the Gulf Coast, then northwest along the coast, 2.60 miles to the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 56', with an aluminum cap stamped L.S.U. BM-GM-16-RESET 1987, and set in a 6" PVC pipe projecting 1.5' above ground.

The station is located 14,000'± from the Gladys McCall Well Site in azimuth 21°.

RECOVERED JUNE, 1984

RECOVERED DECEMBER, 1985

RESET JUNE, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-17 Reset	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December, 1985	4.356	1.3277
June, 1987	4.363	1.3298

SKETCH:

DESCRIPTION: Vicinity - Cameron Parish
Near the southwest corner of Section #4, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 5.62 miles to the Gulf Coast, then northwest along the coast, 2.97 miles to the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 92', with an aluminum cap stamped L.S.U. BM-GM-17-1985, and set in a 4" PVC pipe projecting 0.8' above ground.

The station is located 13,900'± from the Gladys McCall Well Site in azimuth 33°.

RESET DECEMBER, 1985

RECOVERED JUNE, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-18	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	3.851	1.1738
June, 1984	3.848	1.1729
November, 1988	3.855	1.1750
July, 1990	3.831	1.1677

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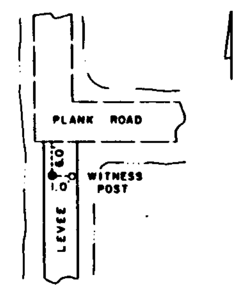

DESCRIPTION: Vicinity - Cameron Parish
Near the north quarter of Section #22, R-5-W, T-15-S.

To reach from the intersection of the plank road to the Gladys McCall Well Site, and LA #82, go south along the plank road 0.65 miles to a 90° turn to the left, and the station on the right.

The monument is a stainless steel rod driven to refusal, a depth of 84', with an aluminum cap stamped L.S.U. BM-GM-18-1981, and set in a 4" PVC pipe projecting 0.5' above ground.

The station is located 6,600'± from the Gladys McCall Well Site in azimuth 165°

RECOVERED JUNE, 1984

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-19	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	2.127	0.6483
June, 1984	2.122	0.6468
November, 1988	2.132	0.6498
July, 1990	2.106	0.6419

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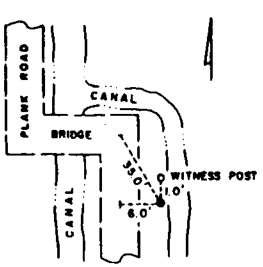

DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #22, R-5-W, T-15-S.

To reach from the intersection of the plank road to the Gladys McCall Well Site, and LA #82, go south along the plank road 1.25 miles to the station on the left.

The monument is a stainless steel rod driven to refusal, a depth of 58', with an aluminum cap stamped L.S.U. BM-GM-19-1981, and set in a 4" PVC pipe flush with the ground.

The station is located 4,100'± from the Gladys McCall Well Site in azimuth 175°

RECOVERED JUNE, 1984

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLI A

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

BENCH MARK GM-20	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	2.499	0.7617
June, 1984	2.498	0.7614
November, 1988	2.513	0.7660
July, 1990	2.477	0.7550

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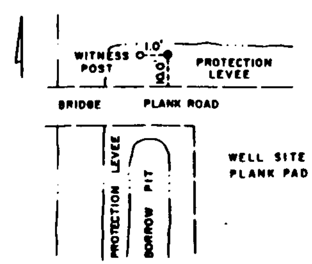

DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #27, R-5-W, T-15-S.

To reach from the intersection of the plank road to the Gladys McCall Well Site, and LA #82, go south along the plank road 2.0 miles to the well site, and the station in the northwest corner of the protection levee around the site.

The monument is a stainless steel rod drive to refusal, a depth of 80', with an aluminum cap stamped L.S.U. BM-GM-20-1981, and set in a 4" PVC pipe, flush with the ground.

The station is located 275'± northwest of the well head.

RECOVERED JUNE, 1984

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-21 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	3.329	1.0147
June, 1984	3.332	1.0156
November, 1988	3.344	1.0193
July, 1990	3.308	1.0083

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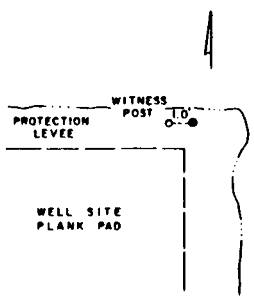

DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #27, R-5-W, T-15-S.

To reach from the intersection of the plank road to the Gladys McCall Well Site, and LA #82, go south along the plank road 2.0 miles to the well site, and the station in the northeast corner of the protection levee around the well site.

The monument is a stainless steel rod driven to refusal, a depth of 92', with an aluminum cap stamped L.S.U. BM-GM-21 1981, and set in a 4" PVC pipe flush with the ground.

The station is located 250'± northeast of the well head.

RECOVERED JUNE, 1984

RECOVERED NOVEMBER 1988

RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-22 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	1.075	0.3277
June, 1984	1.077	0.3283
November, 1988	Destroyed	

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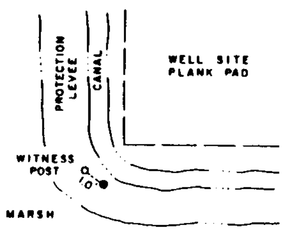

DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #27, R-5-W, T-15-S.

To reach from the intersection of the plank road to the Gladys McCall Well Site, and LA #82, go south along the plank road 2.0 miles to the well site, and the station in the southwest corner of the protection levee around the well site.

The monument is a stainless steel rod, driven to refusal, a depth of 88', with an aluminum cap stamped L.S.U. BM-GM-22-1981, and set in a 4" PVC pipe flush with the ground.

The station is located 200'± southwest of the well head.

RECOVERED JUNE, 1984

NOT RECOVERED, NOVEMBER, 1988

NOT RECOVERED, JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-23 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
September, 1981	1.279	0.3898
June, 1984	1.282	0.3908
November, 1988	1.292	0.3938
July, 1990	1.256	0.3828

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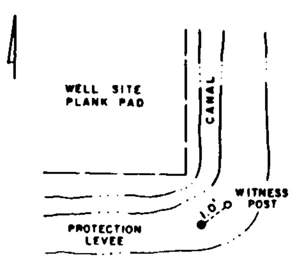

DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #27, R-5-W, T-15-S.

To reach from the intersection of the plank road to the Gladys McCall Well Site, and LA #82, go south 2.0 miles to the well site, and the station in the southeast corner of the protection levee around the well site.

The monument is a stainless steel rod driven to refusal, a depth of 88', with an aluminum cap stamped L.S.U. BM-GM-22-1981, and set in a 4" PVC pipe flush with the ground.

The station is located 200'± southeast of the well head.

RECOVERED JUNE, 1984

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

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

BENCH MARK GM-24 RESET DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
June, 1987	4.157	1.2671

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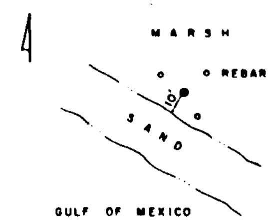


DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #5, R-5-W, T-16-S.

To reach from the northwest corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary road 5.62 miles to the Gulf Coast, then northwest along the coast 3.60 miles to the station on the right.

The monument is a stainless steel rod driven to a depth of 66' with an aluminum cap stamped L.S.U. BM-GM-24-RESET 1987, and set in a 6" PVC pipe projecting 1.5' above ground.

The station is located 14,700'± from the Gladys McCall Well Site in azimuth 46°

RECOVERED JUNE, 1984

DESTROYED

RESET JUNE, 1987

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

GLADYS McCALL

GEOPRESSURE - GEOTHERMAL TEST WELL

CAMERON PARISH, LOUISIANA

BENCH MARK GM-25	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December, 1985	3.095	0.9434
June, 1987	3.091	0.9421

DESCRIPTION: Vicinity - Cameron Parish near the southwest corner of Section #4, R-5-W, T-16-S.

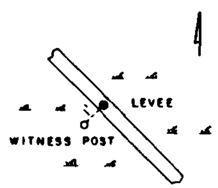
To reach from the northwest Corner of the Rockefeller Wildlife Refuge, and LA #82, go south along the west boundary levee 5.62 miles to the Gulf Coast, then northwest along the coast, 2.41 miles to a levee intersection, then go northwest along the levee 0.42 miles to the station on the left.

The monument is a stainless steel rod driven to refusal a depth of 56' with an aluminum cap stamped L.S.U. BM.GM-25-1985, and set in a 6" PVC pipe.

The station is located 12,700'± from the Gladys McCall Well Site in azimuth 30°.

RECOVERED JUNE, 1987

SKETCH:



SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

GLADYS McCALL

GEOPRESSURE - GEOTHERMAL TEST WELL

CAMERON PARISH, LOUISIANA

BENCH MARK Well Head	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
June, 1984	2.282	0.6956
November, 1988	2.132	0.6498
July, 1990	2.067	0.6300

DESCRIPTION: Vicinity - Cameron Parish
Near the center of Section #27, R-5-W, T-15-S.

To reach from the intersection of the Plank Road to the Gladys McCall Well Site, and LA #82, go south 2.0 miles to the well site.

Top of bolt on south, southeast side of well head just east of the first valve above ground on south side of well head.

RECOVERED NOVEMBER, 1988

RECOVERED JULY, 1990

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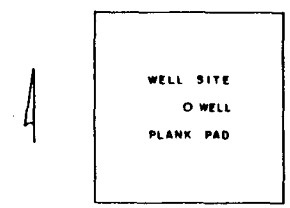


SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

APPENDIX II

PREFACE TO

HULIN GEOPRESSURE-GEOTHERMAL TEST WELL SITE

FIRST ORDER LEVELING

The purpose of this survey was to level through and establish elevations for existing benchmarks along LA Highway No. 685 from Erath, Louisiana south to well site.

The leveling was performed in December 1989, and was accomplished using procedures and equipment identical to that used by the National Geodetic Survey for First Order Class I Leveling.

The leveling began on benchmark NGS T-361 located in Erath, Louisiana and the published elevation of 5.271 feet was used for this survey.

The results of the leveling and the recovery data and description for each benchmark is made a part of this report.

HULIN

GEOPRESSURE-GEOTHERMAL TEST WELL SITE

FIRST ORDER LEVELING

VERMILION PARISH, LOUISIANA

STATION TO STATION	PUBLISHED ELEVATION NGS	DIFFERENCE IN ELEVATION (D. E.) NGS D.E.	FORWARD RUN	BACKWARD RUN	MEAN D.E.	LENGTH OF SECTION (KILOMETERS)	ALLOWABLE ERROR IN SECTION	ACTUAL ERROR IN SECTION	ELEVATION FROM THIS LEVELING
T-361	5.271								5.271
		+0.490	+0.4499	-0.4545	+0.4522	1.928	0.0137	0.046	
V-57-V-83	5.761								5.723
			-1.1891	+1.1887	-1.1889	0.857	0.0067	0.0004	
HU-15									4.534
		+2.894	+0.9121	-0.9085	+0.9103	1.087	0.0103	0.0036	
HU-14									5.445
			+3.1016	-3.0937	+3.0977	1.166	0.0106	0.0079	
57-V-81	8.655								8.542
			-0.4277	+0.429	-0.4284	0.266	0.0051	0.0013	
HU-13		+0.971							8.114
			+0.9284	-0.9192	+0.9238	1.080	0.0102	0.0092	
C-4046	9.626								9.038
			-2.5285	+2.5171	-2.5228	1.462	0.0119	0.0114	
HU-12		-0.266							6.515
			+2.7141	-2.7123	+2.7132	0.774	0.0087	0.0018	
57-V-78	9.360								9.228
		-3.267	-2.8312	+2.8379	-2.8346	0.648	0.0079	0.0067	
B-380	6.093								6.394
			-0.0342	+0.0344	-0.0343	0.904	0.0094	0.0002	
C-4051	NONE	NONE							6.359
			-0.7309	+0.7325	-0.7317	0.694	0.0082	0.0016	
HU-10									5.628
			-0.7296	+0.7236	-0.7266	0.668	0.0081	0.0060	
HU-9									4.901
			-3.2115	+3.2160	-3.2138	1.039	0.0100	0.0045	
HU-5									1.687
			+1.6582	-1.6615	+1.6599	1.020	0.0100	0.0033	
HU-3									3.347
			-1.0369	+1.0385	-1.0377	0.164	0.0040	0.0016	
HU-4									2.309
			-0.2542	+0.2542	-0.2542	0.112	0.0033	0.0000	
HU-1									2.055
			+0.4879	-0.4909	+0.4894	0.663	0.0080	0.0030	
HU-8									2.545
			+0.0384	-0.0414	+0.0399	0.876	0.0092	0.0030	
HU-17									2.584

* - CLOSURE CRITERIA FOR FIRST ORDER LEVELS
*** - NEW BENCH MARK ESTABLISHED BY THIS SURVEY

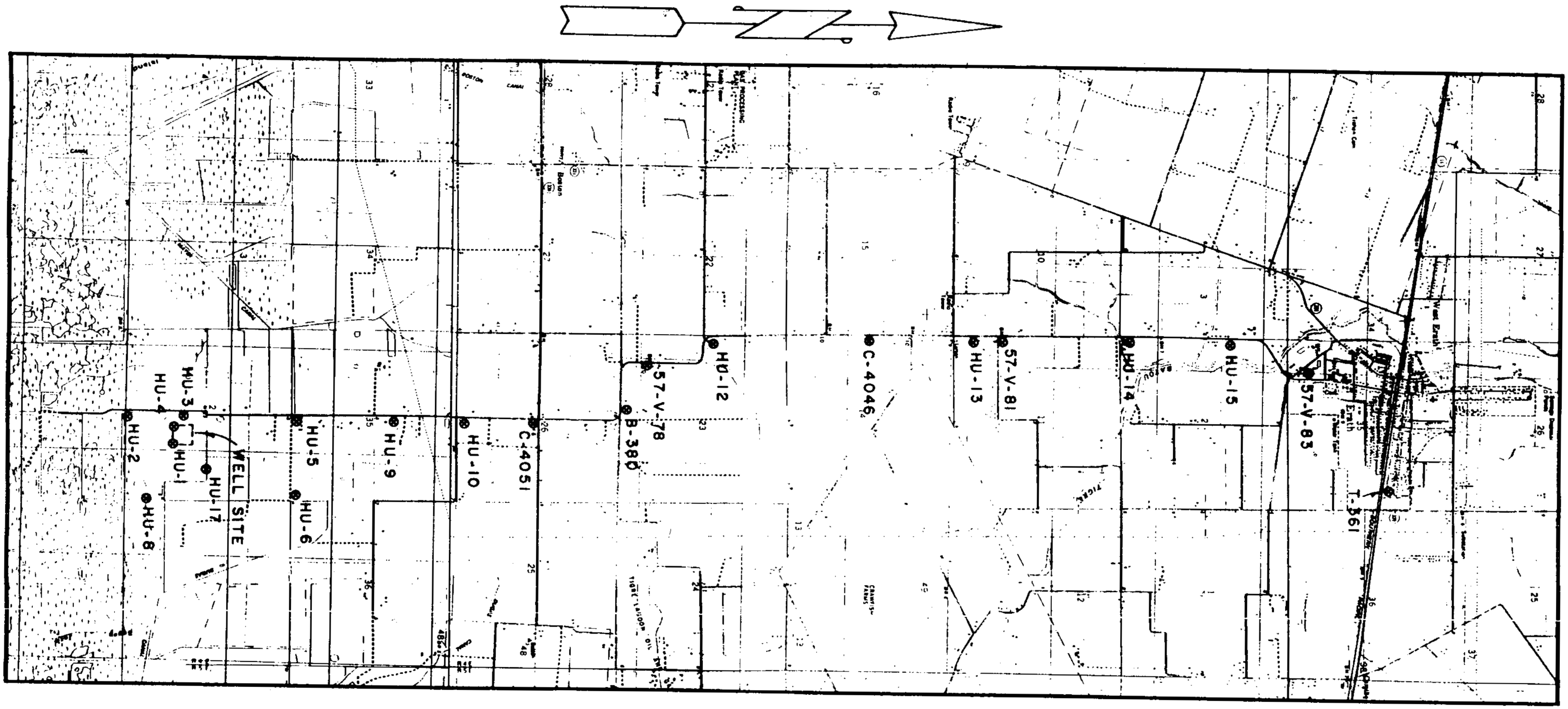
SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA

HULIN
GEOPRESSURE-GEOTHERMAL TEST WELL SITE
FIRST ORDER LEVELING
VERMILION PARISH, LOUISIANA

STATION TO STATION	PUBLISHED ELEVATION NGS	DIFFERENCE IN ELEVATION (D.E.) NGS D.E.	FORWARD RUN	BACKWARD RUN	MEAN D.E.	LENGTH OF SECTION (KILOMETERS)	ALLOWABLE ERROR IN SECTION	ACTUAL ERROR IN SECTION	ELEVATION FROM THIS LEVELING
HU-5									1.687
			+2.2096	-2.2142	+2.2119	0.797	0.0088	0.0046	
HU-6									3.899
HU-3									3.347
			+1.0928	-1.0975	+1.0952	0.627	0.0078	0.0047	
HU-2									4.442
HU-4									2.309
			+0.8551	-0.8550	+0.85505	0.090	0.0030	0.0001	
WELL HEAD									3.164

* - CLOSURE CRITERIA FOR FIRST ORDER LEVELS
*** - NEW BENCH MARK ESTABLISHED BY THIS SURVEY

SURVEY BY
T & R ASSOCIATES
ASHEBORO, NORTH CAROLINA



HULIN

GEOPRESSURE – GEOTHERMAL TEST WELL

LOCATION MAP

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

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.

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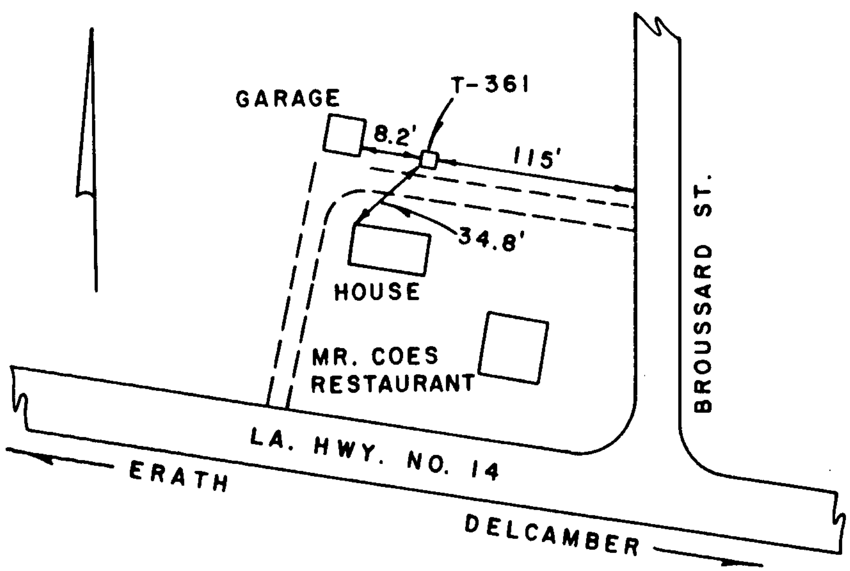

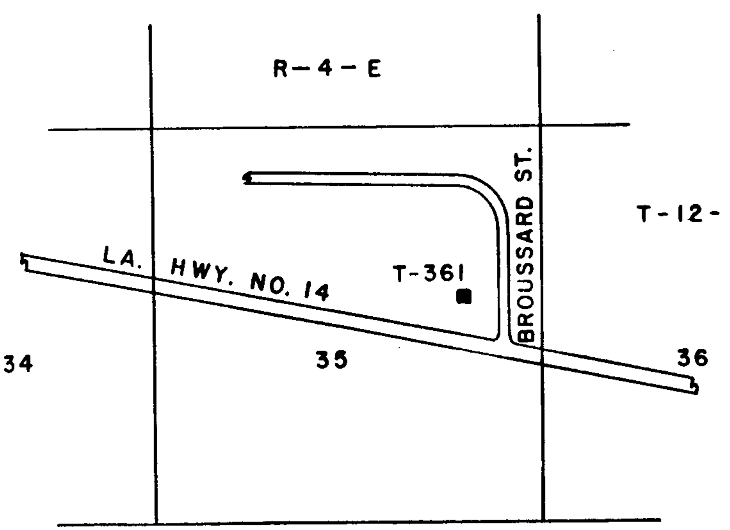

BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

BENCH MARK NGS 57-V-83	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.723	1.744

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.

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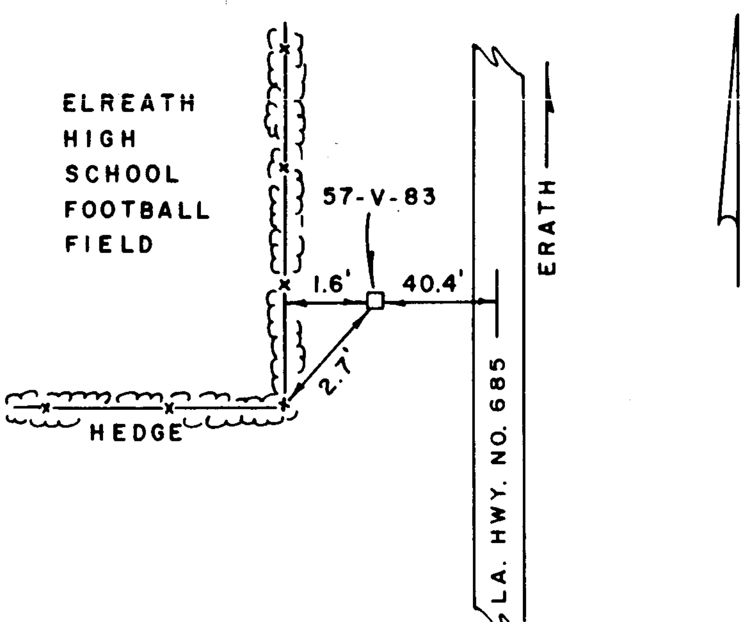

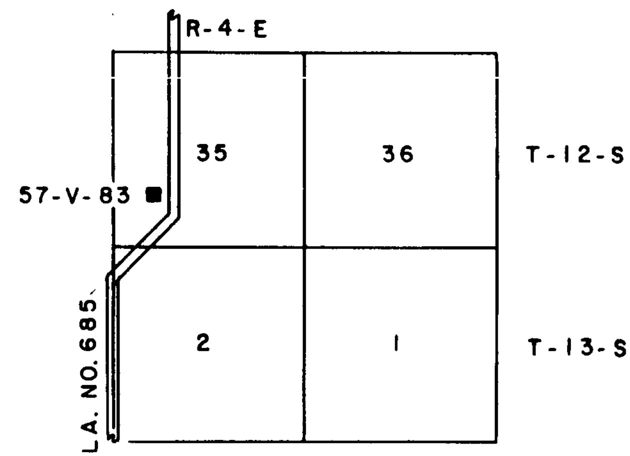

BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

BENCH MARK HU-15 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	4.534	1.382

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.

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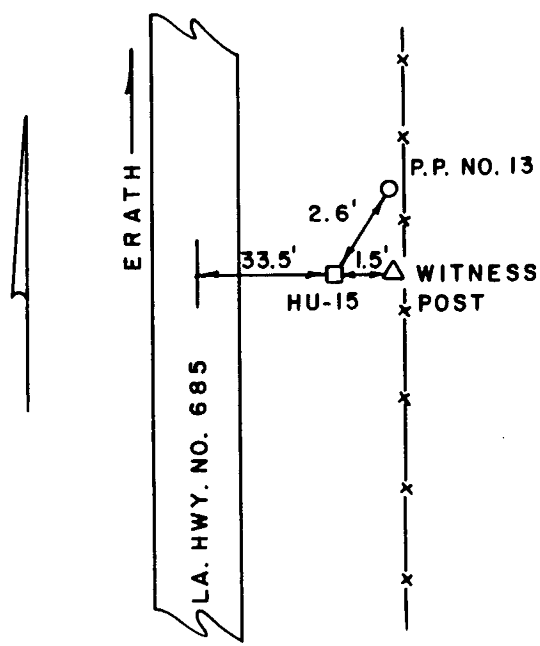

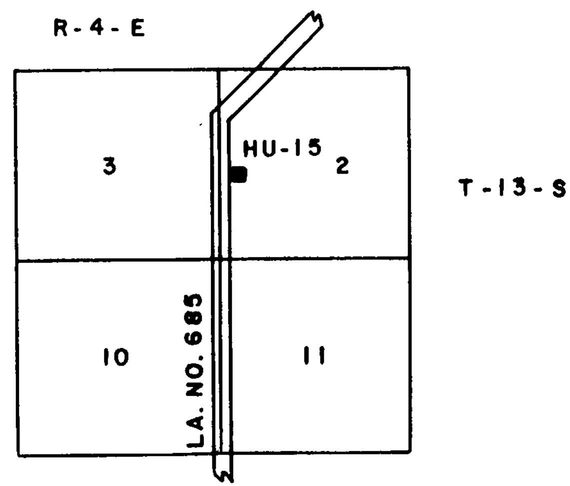

BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

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

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.

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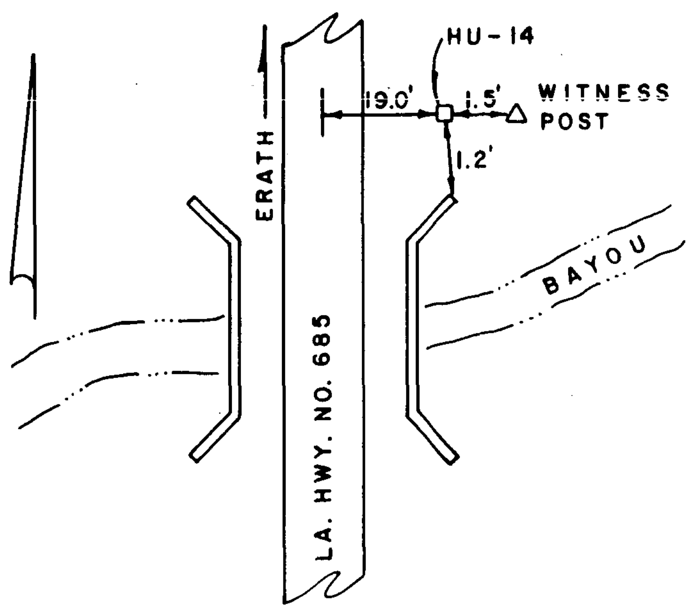
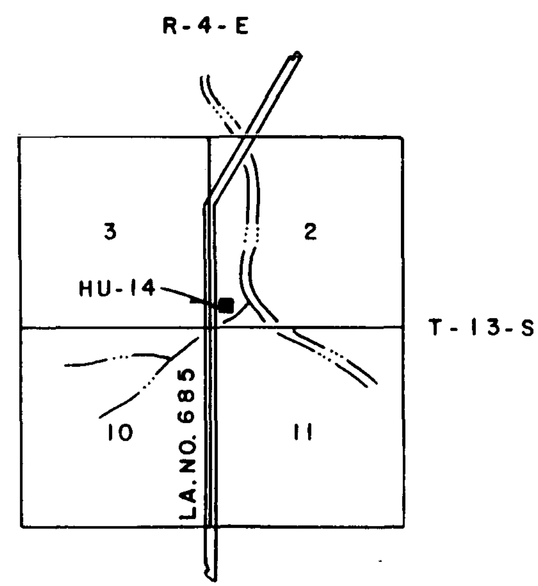




BENCH MARK DATA

U. S. DEPARTMENT OF ENERGY

HULIN

GEOPRESSURE – GEOTHERMAL TEST WELL

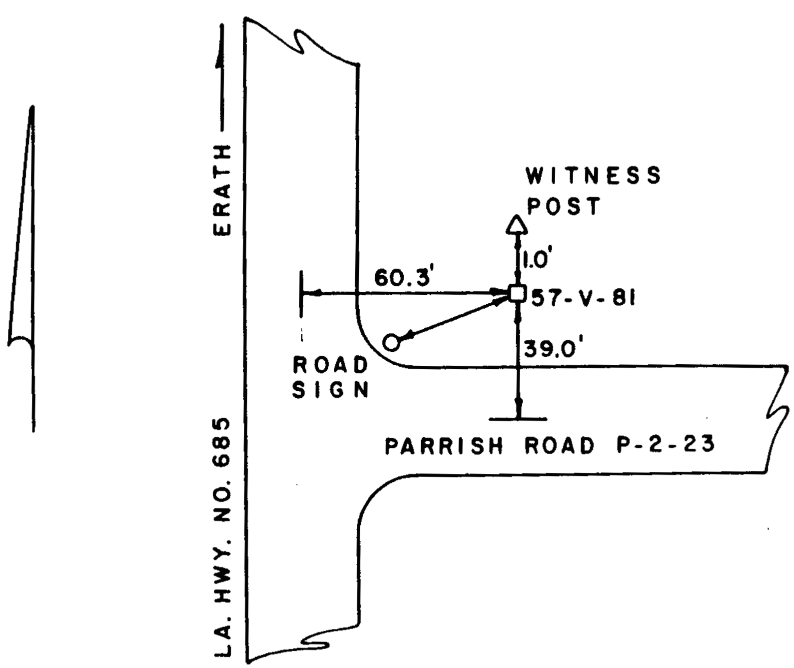
VERMILION PARISH, LOUISIANA

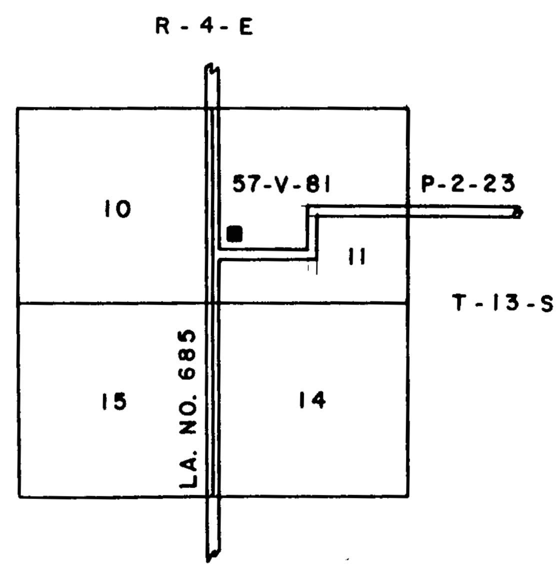
BENCH MARK 57-V-81	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	8.542	2.604

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

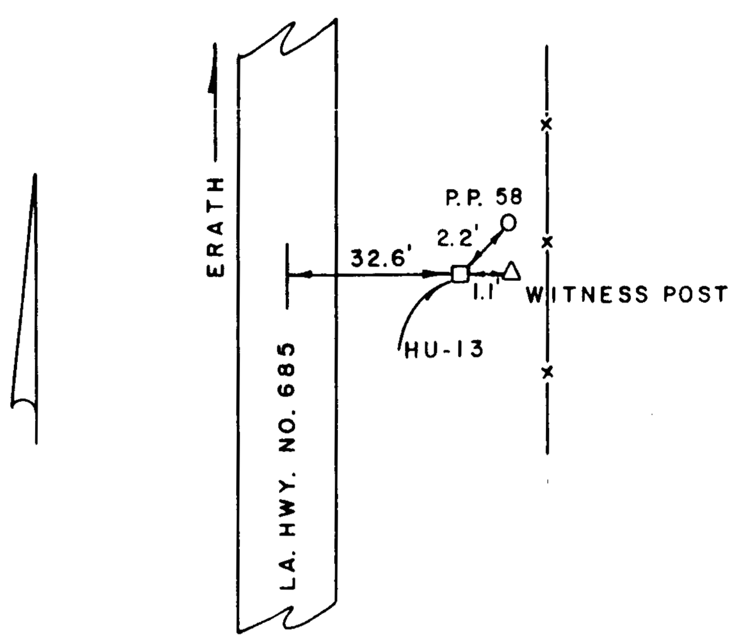
VERMILION PARISH, LOUISIANA

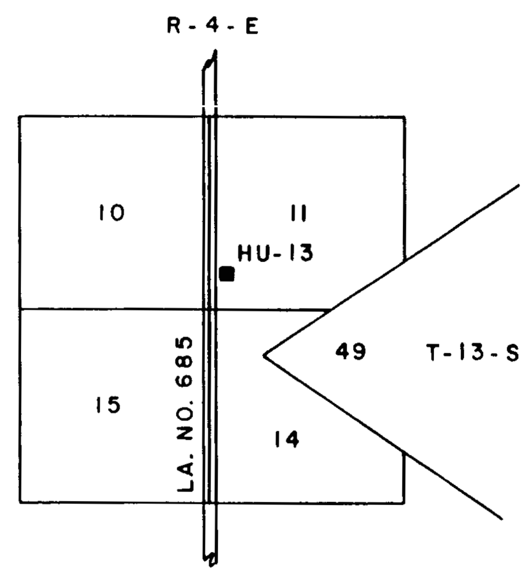
BENCH MARK HU-13	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	8.114	2.473

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

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

VERMILION PARISH, LOUISIANA

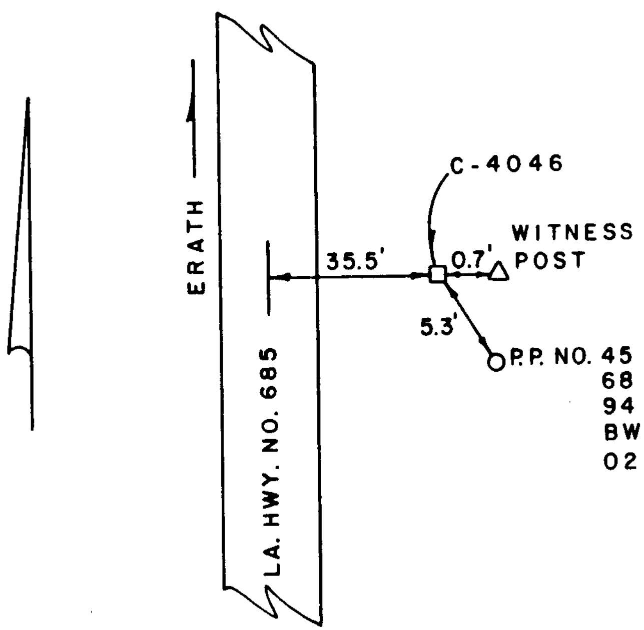
BENCH MARK C-4046 DATUM: NGVD 1929

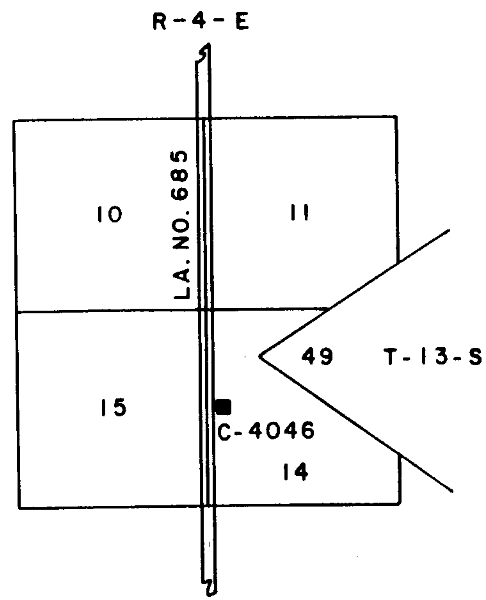
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	9.038	2.755

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

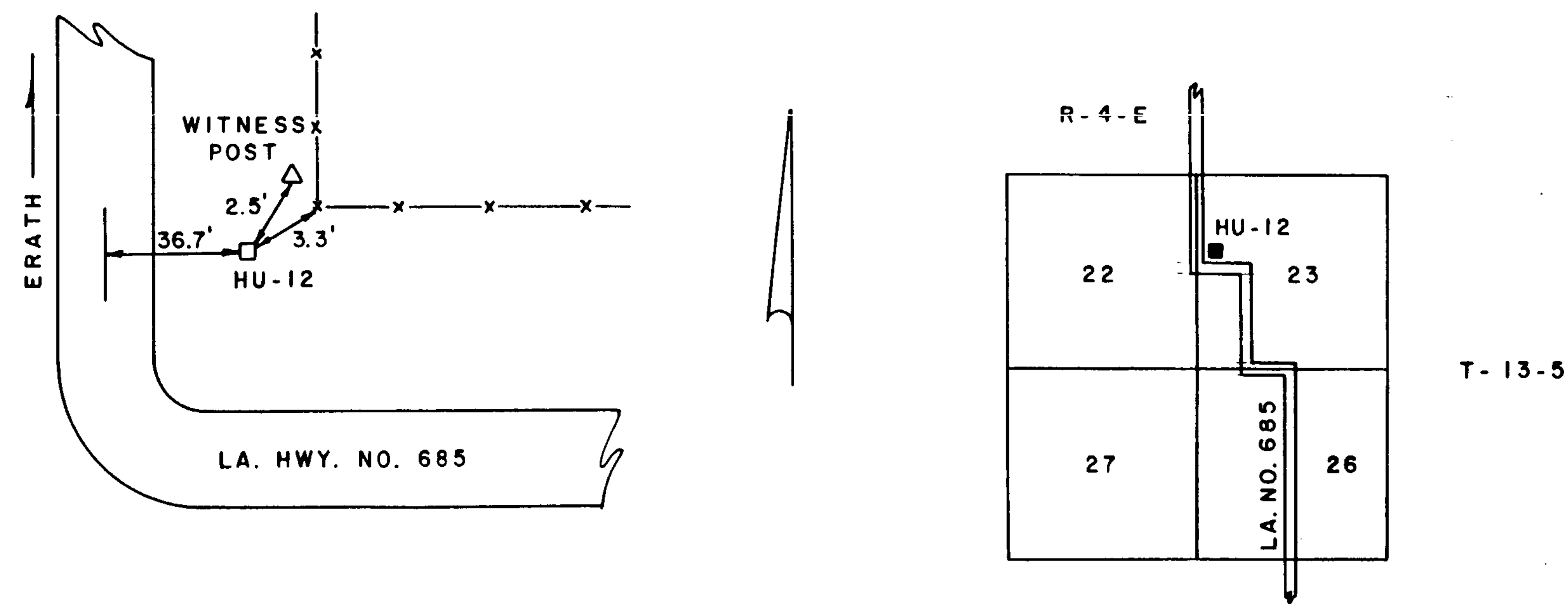
BENCH MARK HU-12 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	6.515	1.986

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

HULIN

GEOPRESSURE - GEOTHERMAL TEST WELL

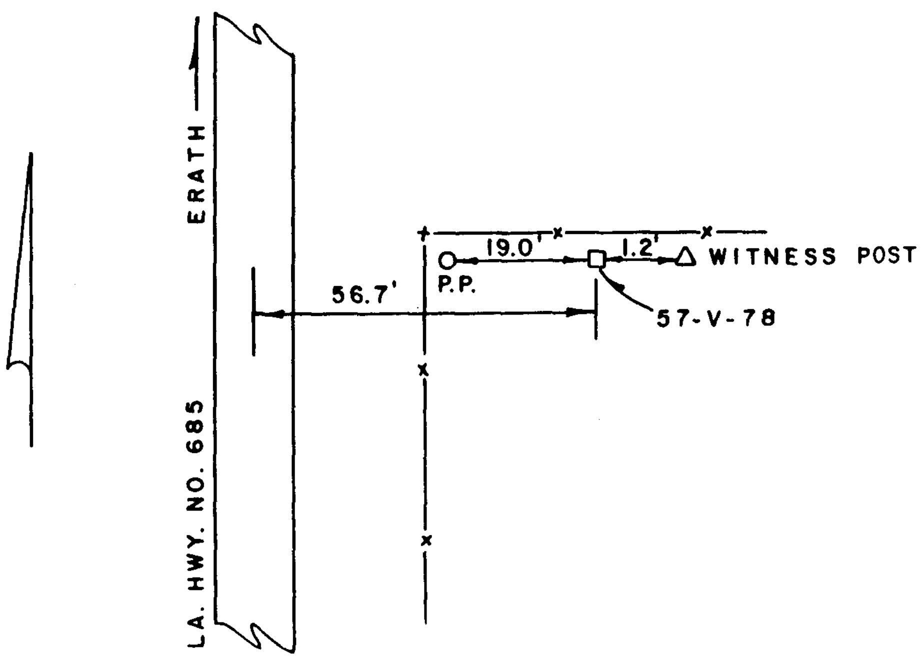
VERMILION PARISH, LOUISIANA

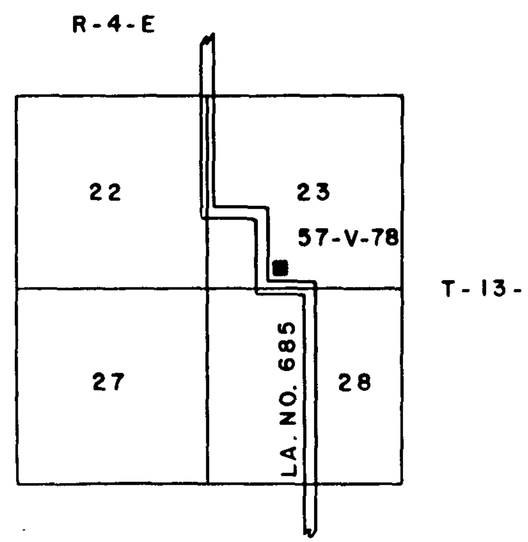
BENCH MARK 57-V-78	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	9.228	2.813

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:





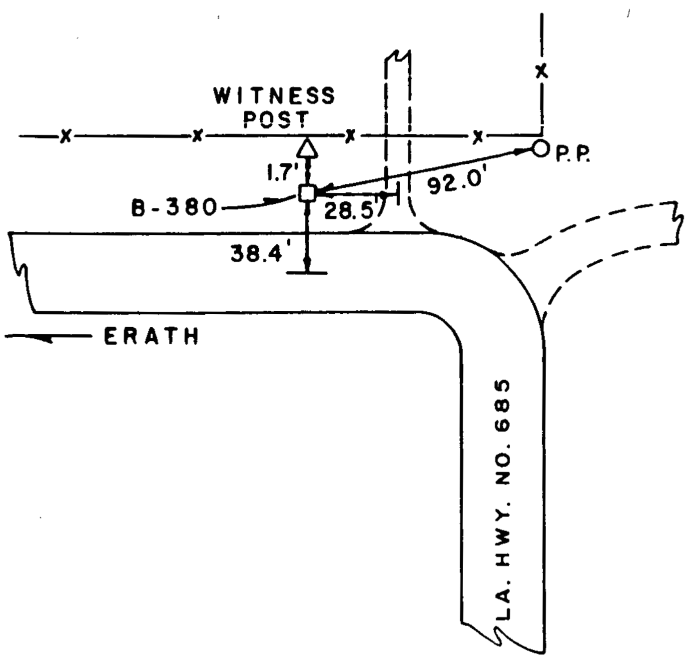
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE – GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

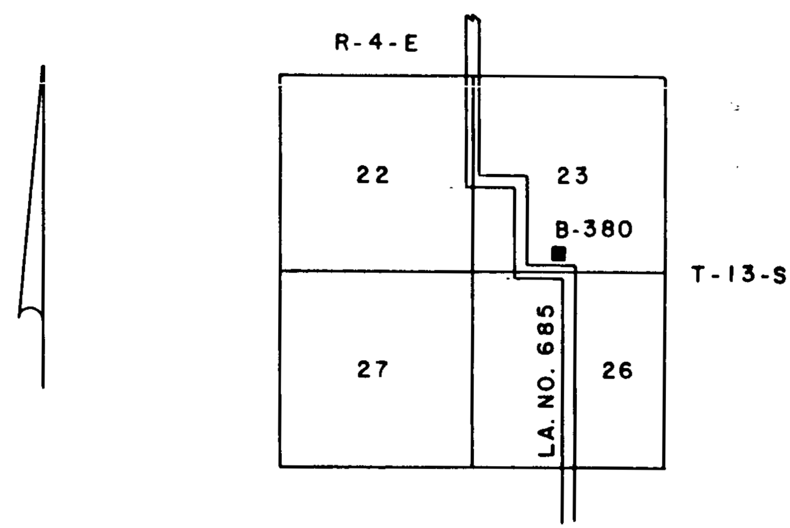
BENCH MARK B-380	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	6.394	1.949

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:





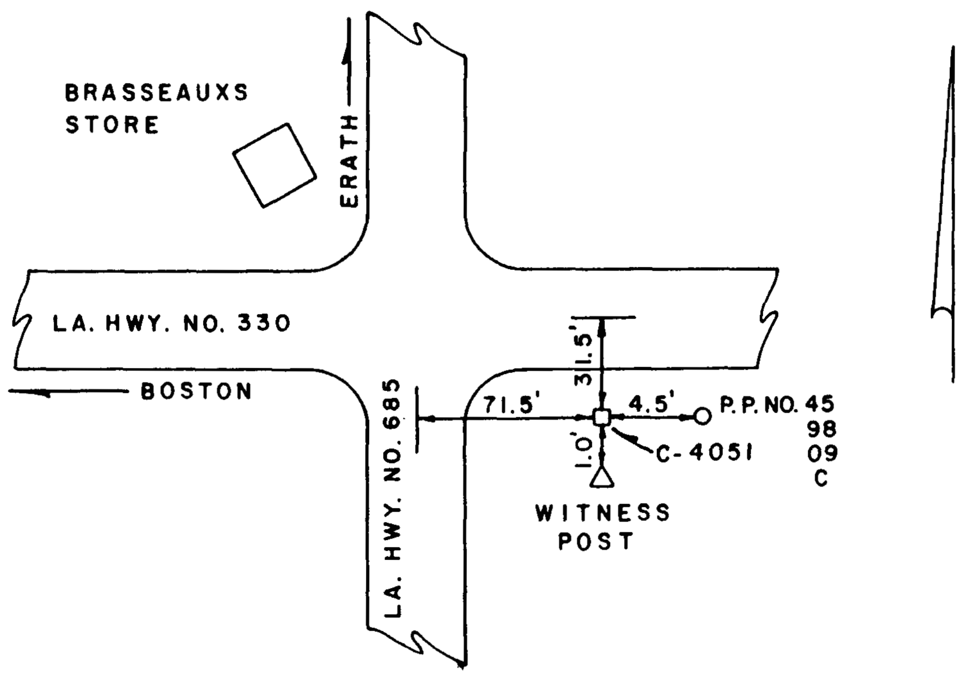
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

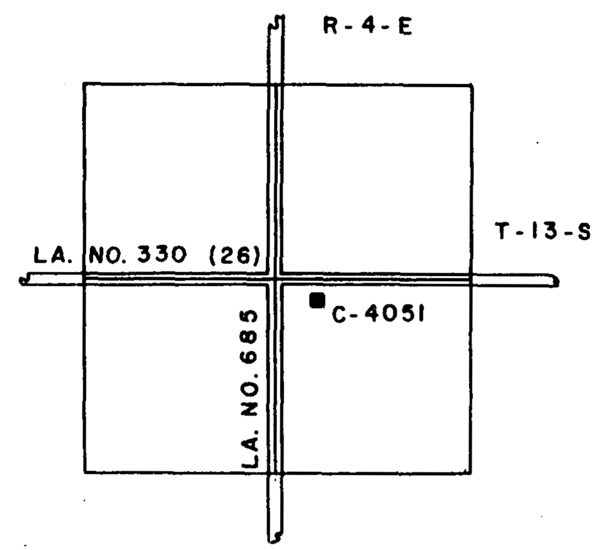
BENCH MARK C-4051	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	6.359	1.938

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

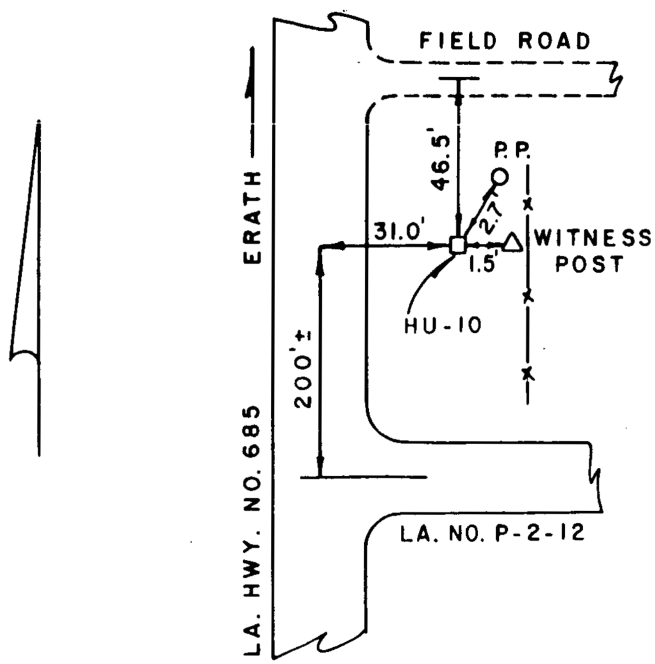
VERMILION PARISH, LOUISIANA

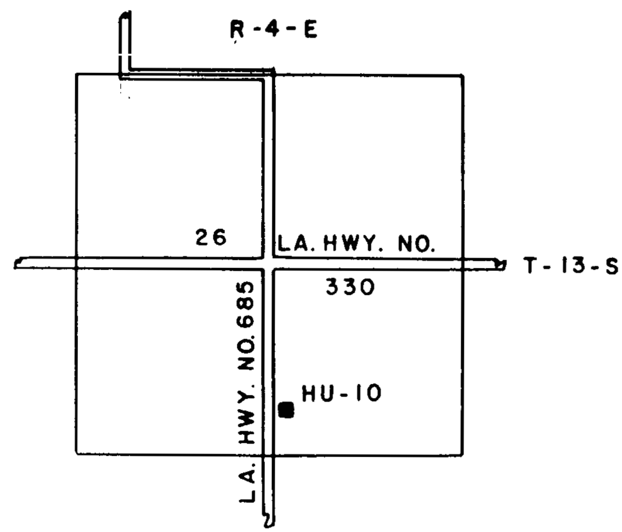
BENCH MARK HU-10	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	5.628	1.715

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:





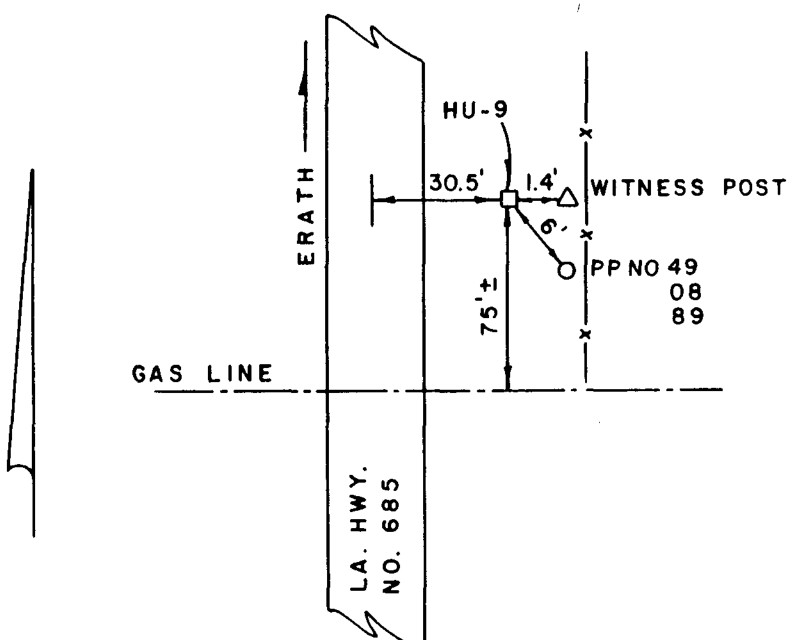
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE – GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

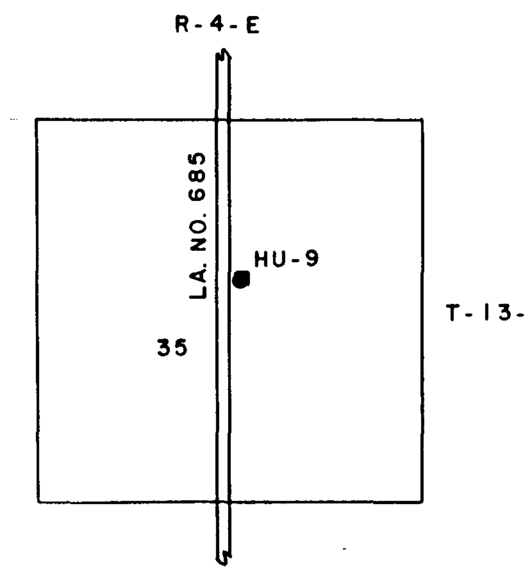
BENCH MARK HU-9	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	4.901	1.494

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

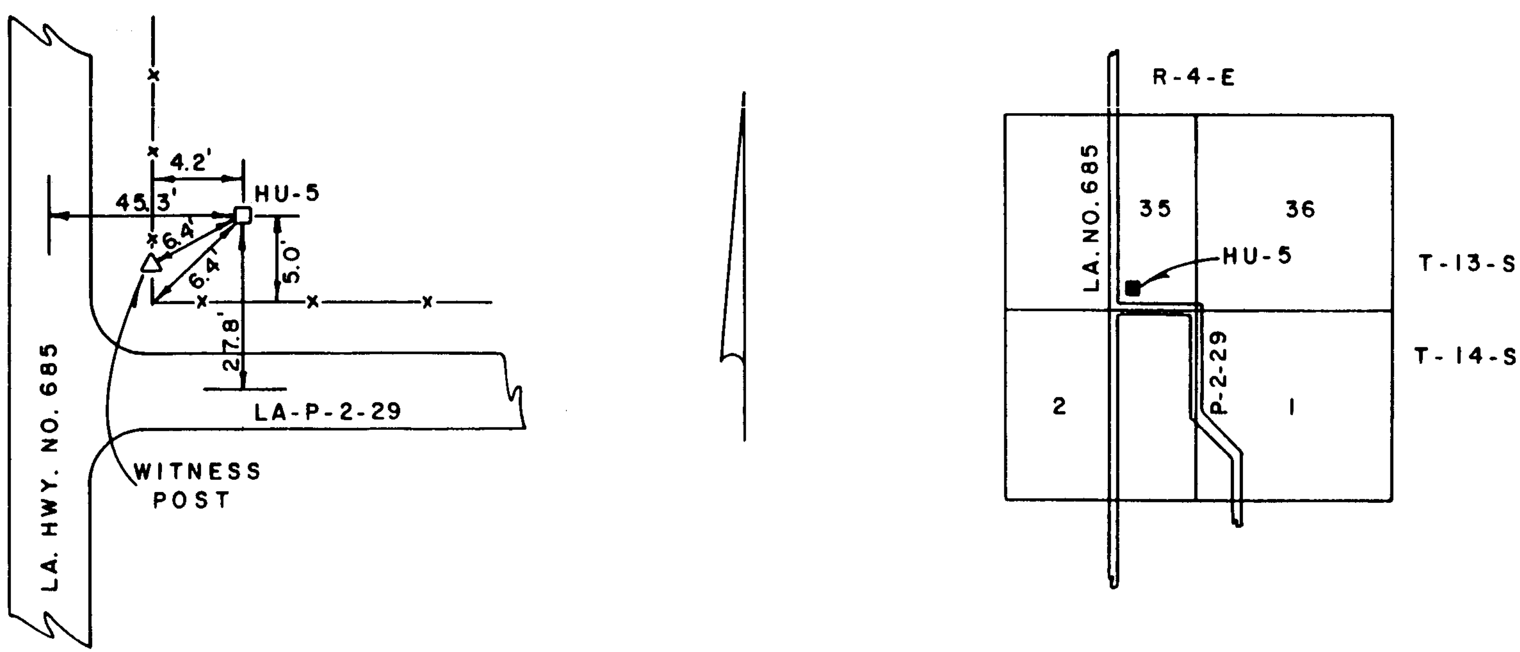
VERMILION PARISH, LOUISIANA

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

DESCRIPTION:

The mark is located 0.65 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

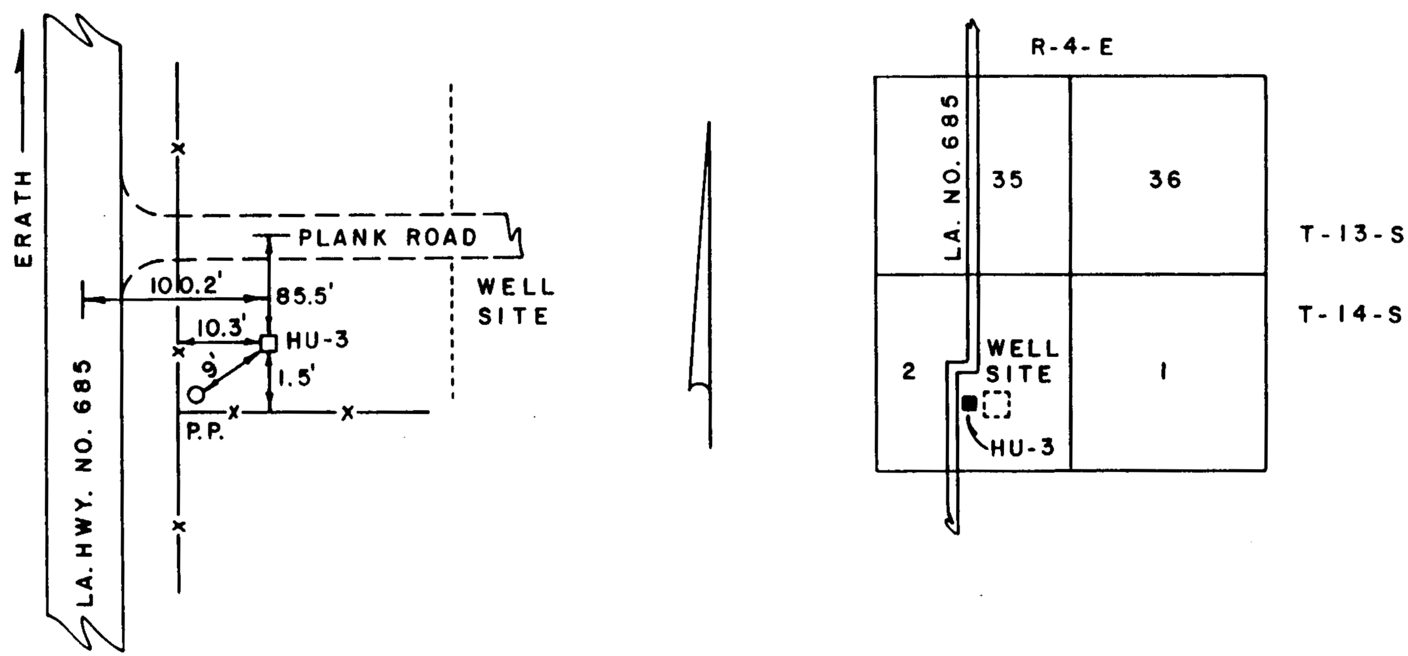
BENCH MARK HU-3 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	3.347	1.020

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:



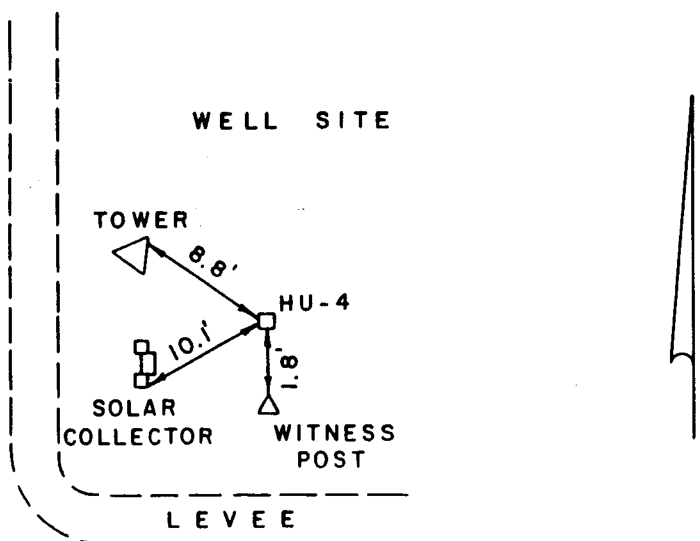
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

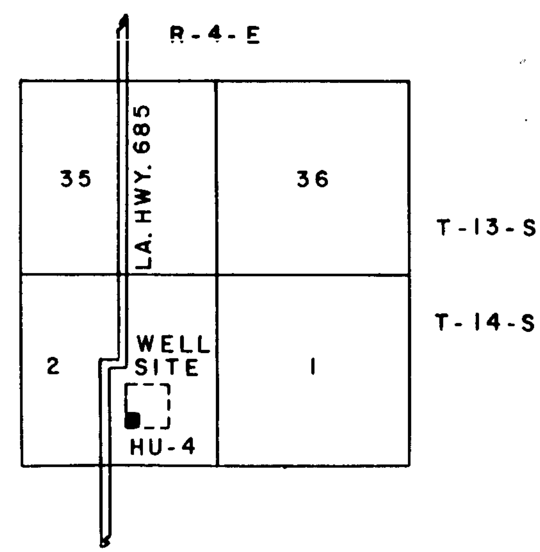
BENCH MARK HU-4	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.309	0.704

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:





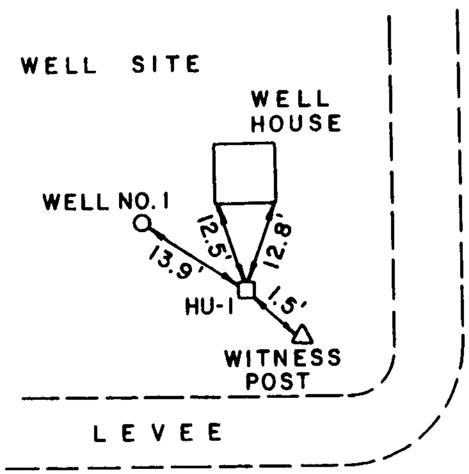
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

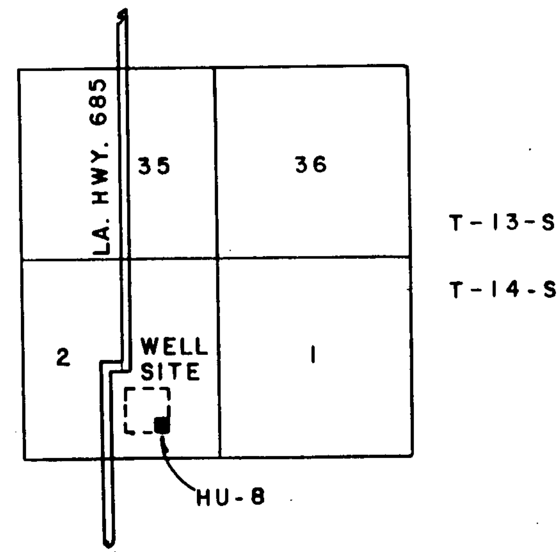
BENCH MARK HU-1	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.055	0.626

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

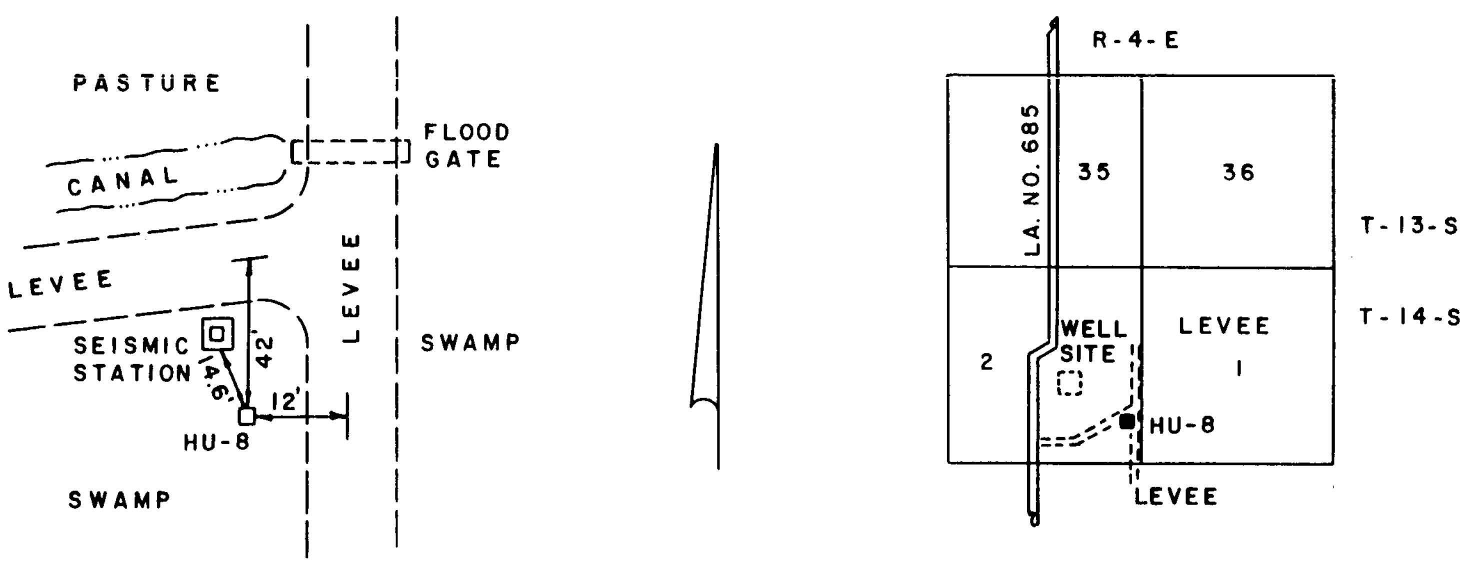
VERMILION PARISH, LOUISIANA

BENCH MARK HU-8	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.545	0.776

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

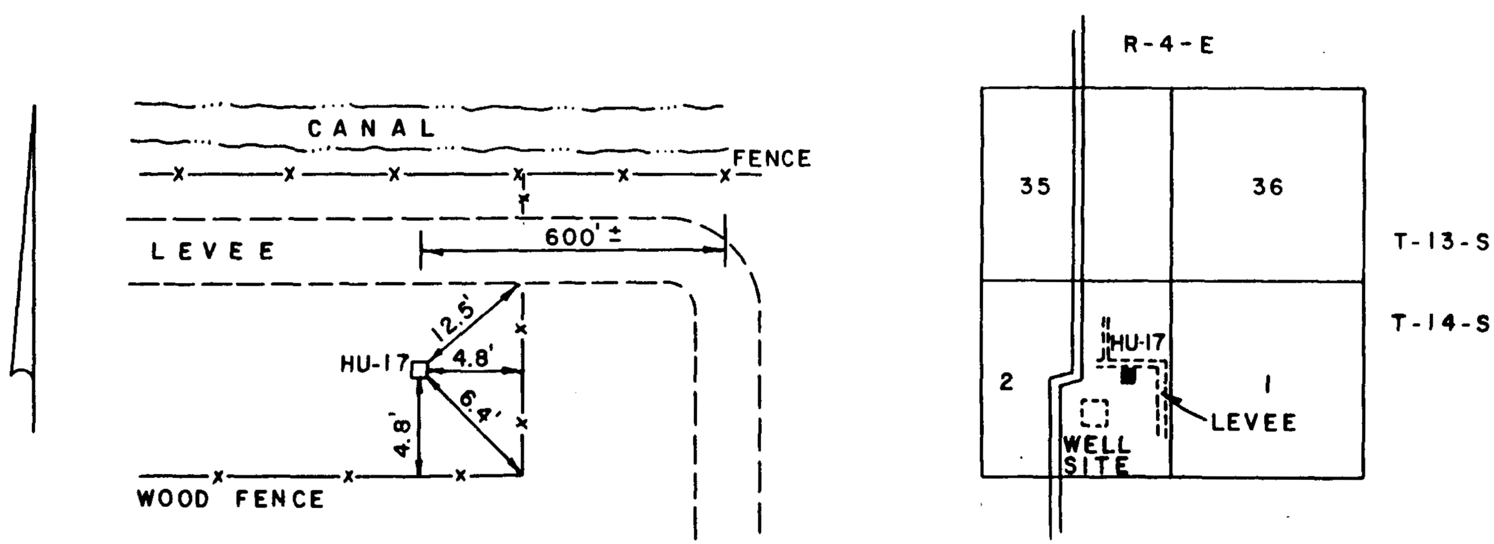
BENCH MARK HU-17 DATUM: NGVD 1929

DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	2.584	0.788

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

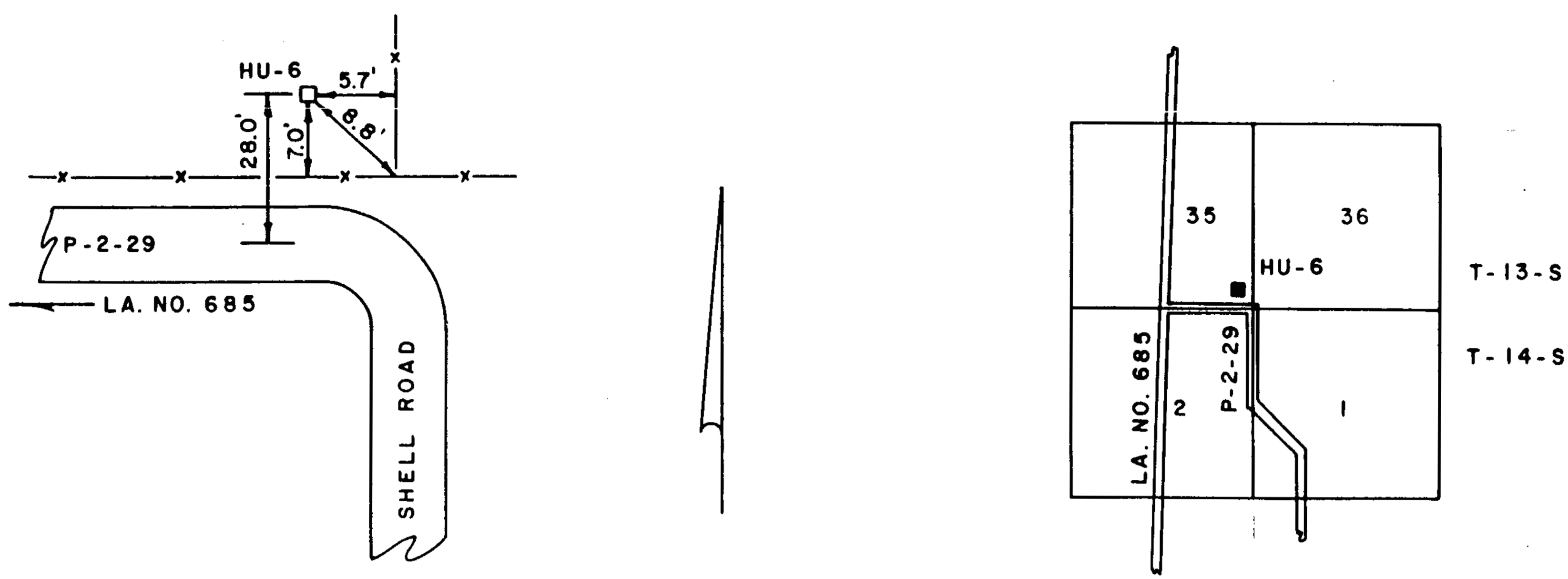
VERMILION PARISH, LOUISIANA

BENCH MARK HU-6	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	3.899	1.188

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:



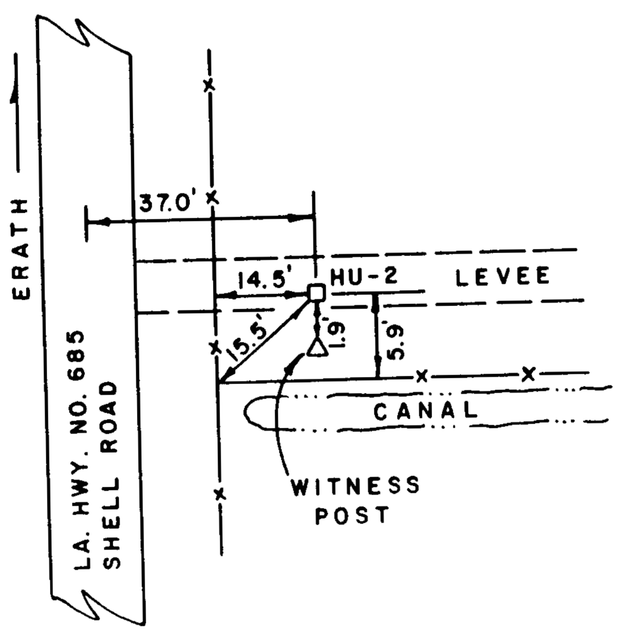
BENCH MARK DATA
U. S. DEPARTMENT OF ENERGY
HULIN
GEOPRESSURE - GEOTHERMAL TEST WELL
VERMILION PARISH, LOUISIANA

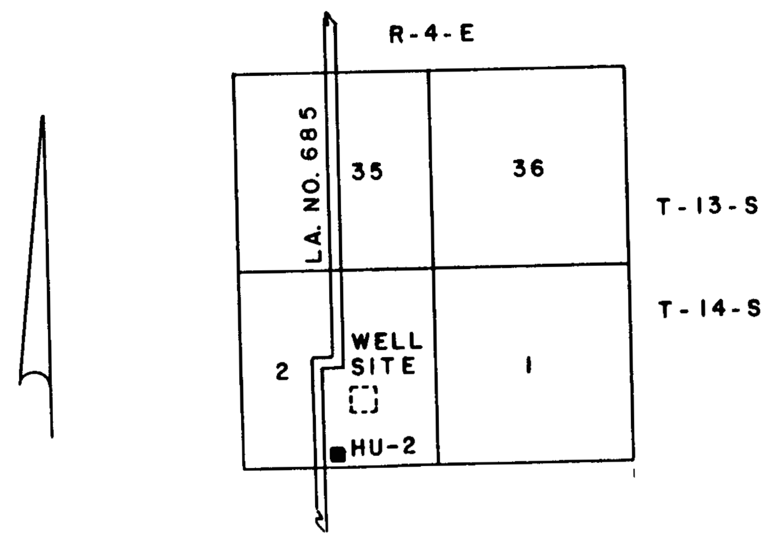
BENCH MARK HU-2	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	4.442	1.354

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

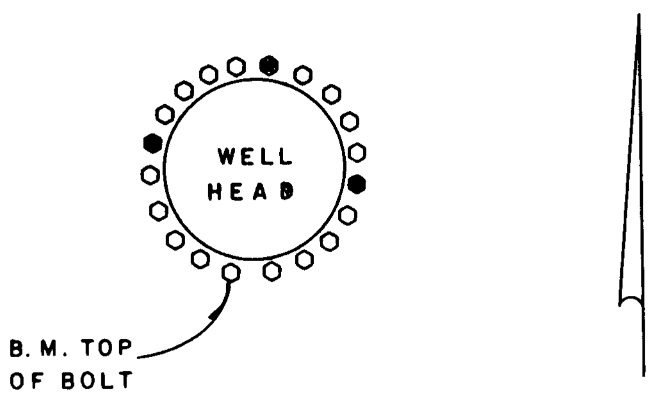
VERMILION PARISH, LOUISIANA

BENCH MARK Well Head	DATUM: NGVD 1929	
DATE OF SURVEY	ELEVATION	
	FEET	METERS
December 1989	~~3.164~~	0.964
	5.114	1.559

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 III

PROJECT REPORT
VERNON F. MEYER AND ASSOCIATES, INC.
1ST ORDER LEVELING: PLEASANT BAYOU GEOTHERMAL TEST SITE
BRAZORIA COUNTY, TEXAS
DECEMBER, 1990

I. INTRODUCTION

A. Authority

Office of the Director of Purchasing, Louisiana State University.

B. Purpose

To conduct first order leveling surveys as part of an ongoing environmental monitoring program for geopressured-geothermal test wells.

C. Scope

Conduct First Order, Class I, leveling to monitor subsidence of previously installed and leveled bench marks, established by the National Geodetic Survey (NGS) and Vernon F. Meyer and Associates, Inc., in the area of the Pleasant Bayou geopressured test well. All leveling surveys to conform to NGS standards and specifications.

II. LOCATION

A. Locality

Releveling was performed in the area of Pleasant Bayou, Brazoria County, Texas, from NGS level line #101 at Liverpool, Texas southeasterly along NGS level line #105, then southeasterly across Chocolate Bayou to the Pleasant Bayou geopressured well site; then north along gravel road to Highway No. 2917; then northwesterly along Highway No. 2917 and Nolen Road to NGS level line #101 at the Missouri Pacific Railroad; then, following said railroad southwesterly along level line #101 to Liverpool, Texas.

B. Area Covered

Releveling: 19.00 Kilometers of 1st order double run

1.29 Kilometers of 1st order single run

19.00 X 0.62137 = 11.806 mi. X 2 = 23.61 miles

1.29 X 0.62137 = 0.80 mi. X 1 = 0.80 miles

Total = 24.41 miles

III. CONDITIONS AFFECTING PROGRESS

A. Climate

The leveling was performed in November, 1990. The weather was warm, humid and mild in the early morning hours and cloudy on the final day.

B. Topography

The terrain was generally flat with the level lines routed along railroad tracks, county and state roads, dirt roads, and some cross country. Chocolate Bayou crossed the major level loop.

C. Transportation

One 3/4 ton suburban was used on the entire assignment for crew and equipment transportation and some parts of the operation. In areas featuring heavy traffic and along the railroad the leveling assignment was accomplished on foot.

IV. ORGANIZATION

A. Party Personnel

The observing unit consisted of an observer who was the unit chief, a recorder, and two rodmen. The observer and recorder alternated duties on site, one of the rodmen served as a back-up recorder and the rodmen took turns with the pacing duties.

B. Equipment

Observations were accomplished using a Wild NA2 automatic level with parallel plate micrometer; one set of double-scale, Wild 1-centimeter matched rods with rod struts. Turning pins with removable driving caps were used to support the rods during observations. The Hewlett Packard 97 programmable printing calculator was used to record observations.

V. FIELD WORK

A. Chronology

The unit chief and crew taveled to Liverpool, Texas on Tuesday, November 5, 1990 to perform reconnaissance. During performance of this phase, Benchmark E 752 was not found and L-1274 was found to be destroyed.

Levels began on NGS level line #101 at Benchmark Liverpool (1931). Double run levels were then transferred in a southwesterly direction along the Missouri Pacific Railroad and line #101 to include Benchmarks Liverpool RM4, Liverpool RM2 and C-1209. They were then transferred in a southeasterly direction along County Road #203 and level line #105 across Chocolate Bayou to BRZ-1 a Class "B" deep rod mark established previously by Vernon F. Meyer and Associates, Inc. A double run spur line north to involve BRZ-2 was then performed. A single loop was run from BRZ-1 through BRZ-3, and 4 to BRZ-6 thus encompassing the well site. Double run levels then continued from BRZ-1 to BRZ-6, northerly up a gravel road through BRZ-7, 8 and 9 to FM 2917; thence northwesterly along FM 2917 to Nolen Road, continuing northwesterly along Nolen Road through BRZ-10 and 11 to Benchmark BRZ-12. From BRZ-12 the levels continued northwesterly along Nolen Road to an intersection with the Missouri Pacific Railroad and NGS Line #101; thence southwest, along said railroad and #101 to Benchmark Liverpool (1931).

The final sighting at Liverpool thus concluded the assignment and the leveling party then proceeded back to Sulphur, Louisiana.

B. Methods

All sections were recorded on the Hewlett Packard 97 calculator, using the program for First Order, Class I, one centimeter-matched rods. First Order, Class I observing methods were used. The procedure for reading the rods at each set up is as follows: Backsite Lower Scale, Backsite Stadia, Foresite Lower Scale, Foresite Stadia (the compensator is then checked), proceed to read Foresite High Scale, and finally Backsite High Scale.

The backrod is always read first at each set up, holding the stadia interval to two meters per set up and five meters per section. After completion of the set up, the rear rodman moves forward and becomes the forward rodman for the second set up and the forward rodman remains in place to become the rear rodman. This leapfrogging method used with even number of set ups for each section reduces the effect of the rod index and the rod verticality errors.

The direction of running levels was alternated on most days.

Collimation checks were made in accordance with NGS specifications.

C. Adjustments

The field elevations were not adjusted. They are used in comparison with previous adjusted elevations as published by the National Geodetic Survey and as previously established elevations by Vernon F. Meyer and Associates, Inc. as reported in the Project Report prepared by Mr. Stephen Hebert of Vernon F. Meyer and Associates, Inc.

D. Summary

11.806 miles of double-run first order levels and 0.80 miles of single-run first order levels were run to NGS specifications. The adjusted elevation of Bench Mark C-1209 was used as a starting elevation and is based on a supplementary adjustment of April 6, 1979, by NGS.

Monuments E-752 and L-1274 were found to have been destroyed prior to the 1988 resurvey and temporary benchmarks (spikes) were set at that time. One of the spikes (E-752 spike) was found to have been destroyed prior to this resurvey. A new one was set to replace the destroyed one.

The closure for the loop around the well site is -0.15 millimeters. The distance around the loop is 1.94 kilometers; the allowable error of closure was 5.57 millimeters.

The first order level tie to line #101 (C-1209) was -13.75 millimeters in 19.00 kilometers. The allowable error of closure was 17.44 millimeters.

The assignment was concluded without loss of time due to weather, water crossings, equipment or instrument failure. Any evidence of subsidence or monument inconsistency which may have been discovered is so noted in the attached abstract.

E. <u>Recommendations</u>

It is recommended that new deep rod marks be established near the intervals of the destroyed benchmarks for future monitoring.

F. <u>Attachments</u>

(1) Comparison Chart
(2) Abstract
(3) Site Map with Monument Locations
(4) Forty-One (41) Data Cards

PLEASANT BAYOU GEOTHERMAL TEST SITE
ELEVATION COMPARISON CHART

BENCH MARK	NGS 1984 ELEV	VFM 1984 ELEV	NGS/VFM DIFF MM	VFM 1985 ELEV	84/85 DIFF MM	VFM 1988 ELEV	84/88 DIFF MM	VFM 1990 ELEV	84/90 DIFF. MM
LIVERPOOL 1931	5.55000	5.77430	224.30	N.A.		5.68175	92.55	5.65970	114.60
LIVERPOOL RM4	5.64100	5.67530	34.30	N.A.		5.64692	28.38	5.63935	35.95
LIVERPOOL RM2	6.01100	6.01757	6.57	N.A.		6.01745	0.12	6.01740	0.17
C1209 "HELD"	5.86100	5.86100	0.00	N.A.		5.86100	0.00	5.86100	0.00
BL26	4.67200	4.67203	0.03	N.A.		4.65595	16.08	4.63675	35.28
L 1274	4.77800	4.78423	6.23	N.A.		5.11963			15.33
L 1274 RESET SPIKE 1990								4.76890	
E 752	5.26300	5.27105	8.05	5.27105	0.00				
E 752 RESET SPIKE 1988						5.62258	0.00	5.61780	4.78
F752	5.37200	5.39310	21.10	5.39468	-1.58	5.39858	-5.48	5.37835	14.75
BRZ 1		0.91328		0.91860	-5.32	0.91813	-4.85	0.91990	-6.62
BRZ 2		2.18450		2.19068	-6.18	2.18913	-4.63	2.19050	-6.00
BRZ 3		3.94013		3.94550	-5.37	3.94578	-5.65	3.94570	-5.57
BRZ 4		4.44738		4.45115	-3.77	4.45193	-4.55	4.45340	-6.02
BRZ 5		4.09438		4.09785	-3.47	4.09863	-4.25	DESTROYED	
BRZ 6		4.28288		4.28675	-3.87	4.28673	-3.85	4.28840	-5.52
BRZ 7		4.90775		4.91233	-4.58	4.90893	-1.18	4.91245	-4.70
BRZ 8		5.21915		5.22396	-4.81	5.21758	1.57	5.21750	1.65
BRZ 9		4.92100		4.92301	-2.01	4.91383	7.17	4.91255	8.45
BRZ 10		5.70915		5.71321	-4.06	5.70393	5.22	5.70380	5.35
BRZ 11		6.22985		6.23506	-5.21	6.22683	3.02	6.22895	0.90
BRZ 12		4.96135		4.96548	-4.13	4.95793	3.42	4.96235	-1.00
A 1208	8.43800	8.44137	3.37	8.44736	-5.99	8.43616	5.21	8.44765	-6.28

NOAA FORM 76-187
(8-76)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

GEODETIC LEVELING FIELD ABSTRACT

32 L

SHEET 1 OF 3 SHEETS

TITLE

Brazoria County
Geothermal Well

November, 1990

DISTANCE UNITS: KM SM   D/F.E. UNITS: MT FT

	Mo./Day	F/B	DISTANCE Δ/Σ	D	-(B+F) Δ/Σ	D/F.E.
30 FROM						
TO LIVERPOOL 1931						5.65970
30 FROM LIVERPOOL 1931	11/06	F	0.03	-0.0205	.0003	-0.02035
	11/06	B	0.03	+0.0202		
TO LIVERPOOL RM4			0.03		.0003	5.63935
30 FROM LIVERPOOL RM4	11/06	F	0.30	+0.3791	-.0021	+0.37805
	11/06	B	0.30	-0.3770		
TO LIVERPOOL RM2			0.33		+.0018	6.01740
30 FROM LIVERPOOL RM2	11/06	F	0.02	-0.1563	-.0002	-0.15640
	11/06	B	0.02	+0.1565		
TO C 1209 (HELD THIS SURVEY)			0.35		-.0020	5.861
	11/06	F	1.20	-1.2256		
30 FROM C 1209	11/06	F	1.20	-1.2229	-.0027	-1.22425
	11/06	B	1.20	+1.2276		
TO BL 26			1.55		-.0047	4.63675
30 FROM BL 26	11/06	F	1.67	+0.1317	+.0009	+0.13215
	11/06	B	1.65	-0.1326		
TO L 1274 (NEW SPIKE)			3.20		-.0038	4.76890
30 FROM L 1274 (NEW SPIKE)	11/07	F	1.78	+0.8479	+.0020	+0.84890
	11/07	B	1.77	-0.8499		
TO E 752 (SPIKE)			4.97		-.0018	5.6178
30 FROM E 752 (SPIKE)	11/07	F	1.39	-0.2391	-.0007	-0.23945
	11/07	B	1.39	+0.2398		
TO F 752			6.36		-.0025	5.37835
30 FROM F 752	11/12	F	0.53	-4.4592	+.0015	-4.45845
	11/12	B	0.52	+4.4577		
TO BRZ 1			6.88		-.0010	0.91990
30 FROM BRZ 1 (SPUR)	11/12	F	0.31	+1.2706	0	+1.27060
	11/12	B	0.31	-1.2706		
TO BRZ 2			7.19		-.0010	2.19050

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U.S. Government Printing Office: 1977—

NOAA FORM 76-187 (8-76)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

GEODETIC LEVELING FIELD ABSTRACT

JZ L

SHEET 2 OF 3 SHEETS

TITLE

Brazoria County
Geothermal Well

November, 1990

DISTANCE UNITS: KM SM — D/F.E. UNITS: MT FT

Station	Mo./Day	F/B	DISTANCE Δ/Σ	D	-(B+F) Δ/Σ	D/F.E.
FROM BRZ 1 (LOOP AROUND WELL)	11/12	F	0.33	+3.0258		+3.02580
TO BRZ 3			7.52			3.94570
FROM BRZ 3	11/12	F	0.25	+0.5077		+0.50770
TO BRZ 4			7.77			4.45340
FROM BRZ 4	11/12	F	0.71	-0.1650		-0.1650
TO BRZ 6 (BRZ 5 DESTROYED)			8.48			4.28840
FROM BRZ 6	11/12	F	0.65	-3.3685	-.0003	-3.36865
	11/12	B	0.65	+3.3688		
TO BRZ 1			9.13		-.0013	0.91975
	11/12	F	1.06	+0.6244		
FROM BRZ 6	11/12	F	1.05	+0.6237	-.0007	+0.62405
	11/12	B	1.06	-0.6189		
TO BRZ 7			10.18		-.0020	4.91245
FROM BRZ 7	11/13	F	1.59	+0.3047	+.0007	+0.30505
	11/13	B	1.60	-0.3054		
TO BRZ 8			11.77		-.0027	5.21750
FROM BRZ 8	11/13	F	1.44	-0.3047	-.0005	-0.30495
	11/13	B	1.44	+0.3052		
TO BRZ 9			13.21		-.0032	4.91255
FROM BRZ 9	11/13	F	1.78	+0.7895	-.0035	+0.79125
	11/13	B	1.78	-0.7930		
TO BRZ 10			14.99		-.0067	5.70380
FROM BRZ 10	11/14	F	1.63	+0.5253	-.0003	+0.52515
	11/14	B	1.61	-0.5250		
TO BRZ 11			16.60		-.0070	6.22895
FROM BRZ 11	11/14	F	1.51	-1.2649	-.0034	-1.26660
	11/14	B	1.51	+1.2683		
TO BRZ 12			18.11		-.0104	4.96235

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NOAA FORM 76-187 (8-76)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

GEODETIC LEVELING FIELD ABSTRACT

32 L

SHEET 3 OF 3 SHEETS

TITLE

Brazoria County
Geothermal Well

November, 1990

DISTANCE UNITS: KM SM — D/F.E. UNITS: MT FT

		Mo./Day	F/B	DISTANCE Δ/Σ	D	-(B+F) Δ/Σ	D/F.E.
30 FROM	BRZ 12	11/14	F	0.83	+3.4864	-.0022	+3.48530
		11/14	B	0.82	-3.4842		
TO	A-1208			18.93		-.0126	8.44765
30 FROM	A-1208	11/15	F	1.36	-2.7736	-.0012	-2.77420
		11/15	B	1.36	+2.7748		
TO	LIVERPOOL 1931			20.29		-0.0138	5.67345
30 FROM							
TO							
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SUPERSEDES NOAA FORM 76-148 (11-72) WHICH IS OBSOLETE AND EXISTING STOCK SHOULD BE DESTROYED UPON RECEIPT OF REVISION.

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HULIN PROSPECT GEOLOGY

by Chacko J. John

INTRODUCTION

The U.S. Department of Energy (DOE) geopressured-geothermal research program, initiated in 1975, currently has three wells in various stages of developmental testing. Two of these test wells are in south Louisiana (Gladys McCall #1 and Superior Hulin #1) and a third in the flow test stage in Texas (Pleasant Bayou #2). The Gladys McCall well was tested continuously for four years and is presently shut in to observe pressure buildup. Plans to initiate long-term production testing of the Superior Hulin #1 well in the 1991-92 fiscal year are being made, subject to appropriate budget allocations. Results of the three test wells are summarized in Table 1.

The geopressured-geothermal resource of the northern Gulf of Mexico has been estimated to contain approximately 250 TCF of natural gas which is equivalent to about 137% of the presently known conventional reserves in the United States (Dorfman 1988.) The general geologic and depositional history of the Gulf of Mexico basin is very well documented in the geologic literature (Rainwater 1967, 1968; Bornhauser 1958, Murray 1957, 1961; Woodbury 1973) because it is a prolific hydrocarbon-producing region. Figure 1 illustrates the geopressured-geothermal zone of the northern Gulf of Mexico basin, which is bounded on the north by the

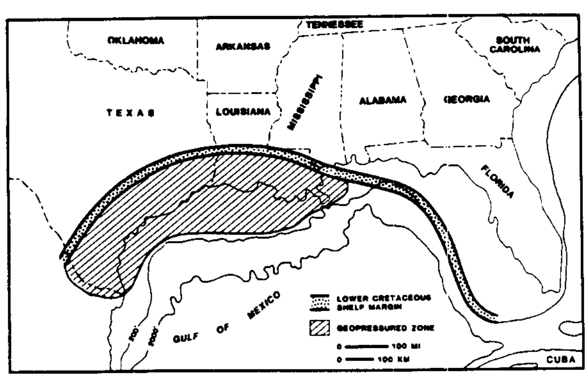

Figure 1. The geopressured zone of the Northern Gulf of Mexico basin (Adapted from Bebout, 1982).

Table 1. Comparison of well characteristics for the current three DOE geopressured-geothermal wells (from Negus de-Wys, 1990).

	Gladys McCall	Pleasant Bayou	Hulin (short-term test)
Depth of Reservoir (ft)	15,831	16,465	21,546
Maximum Flow Rate (bbd)	40,000	25,000	15,000
Bottom-hole Pressure (psia)	12,784	9,800	18,500
Flowing Wellhead Pressure (psia)	2,000	3,000	3,500
Bottom-hole Temperature (°F)	298	302	360
Flowing Wellhead Temperature (°F)	268	292	330
Gas/Water Ratio (scf/bbl)	27	24	34
Methane (% of gas)	85	85	93
CO_2 (% of gas)	9.7	10	4
Estimated Reservoir Size (billion bbl)	4	8	14
Total Dissolved Solids (mg/l)	95,000	127,000	195,000
Chlorides (mg/l)	57,000	70,000	115,000

Lower Cretaceous shelf margin. The oldest growth-faulted and geopressured sandstones are found seaward of this shelf margin (Bebout 1982).

The geopressured-geothermal prospects identified for testing were selected based on regional geologic studies conducted at the Louisiana Geological Survey (LGS) in the early stages of this project by D. G. Bebout (1982) and others (Bebout and Gutierrez 1981; Bebout et al. 1983; Wallace 1982; McCulloh et al. 1984). These studies provided valuable data concerning subsurface structure, geopressured-geothermal sandstone distribution, porosity, permeability, temperature, brine salinity, formation pressures, and the distribution and depths to the top of geopressured sandstones in south Louisiana (figure 2). The Hulin prospect lies in the Miocene geopressured-geothermal fairway as defined by the regional studies.

LOCATION AND WELL HISTORY

The Hulin #1 well was drilled by Superior Oil Company in 1978 in Section 2, Township 14 South, Range 4 East to 21,549 ft. The well site is located approximately 7 miles south of Erath in Vermilion Parish, Louisiana (figure 3). A maximum log recorded a temperature of 338°F and a thick, geopressured sandstone section, which makes this well an excellent candidate for long-term geopressured-geothermal testing. The well was perforated by Superior Oil Company between 21,059 and 21,094 ft in a poorly developed sand and produced 0.3 BCF of gas during 19 months of production. Declining well-head pressure resulted in efforts to restore production, which led to a packer/tubing failure. At this point, Superior Oil Company decided to abandon the well, and it was later transferred to DOE for testing under its geopressured-geothermal program (John et al. 1990). Eaton Operation Company, Inc., Houston, Texas, was contracted by DOE to clean and recomplete the well and to correct problems that were causing a pressure buildup. This process was completed in February 1989, and the well was plugged back to 20,725 ft just below the geopressured-geothermal sandstone earmarked for long-term testing, which is planned to begin during the 1991-92 fiscal year.

A short-term flow test was conducted from December 5, 1989, to January 11, 1990. Initially, the well was perforated between 20,670 and 20,690 ft. Later additional perforations were made between 20,602 and

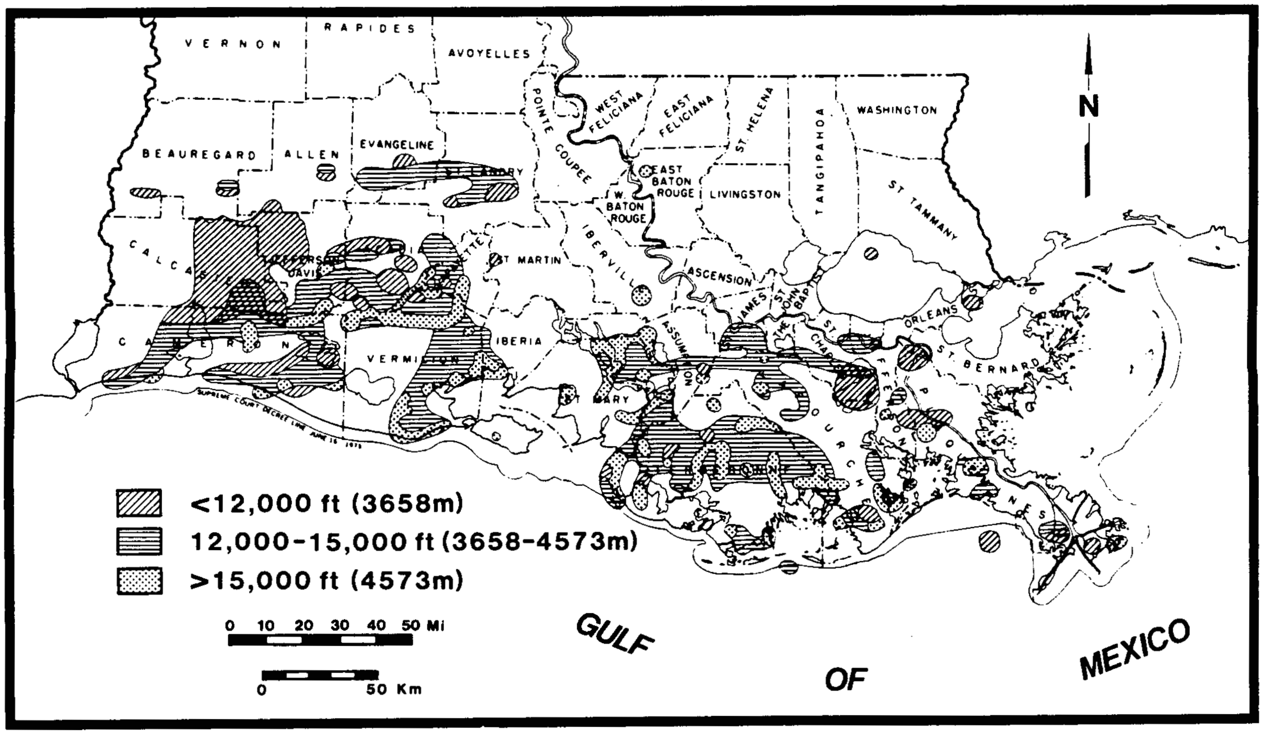

Figure 2. Distribution and depths to Tertiary geopressured sandstones in South Louisiana (Modified from McCulloh et al. 1984).

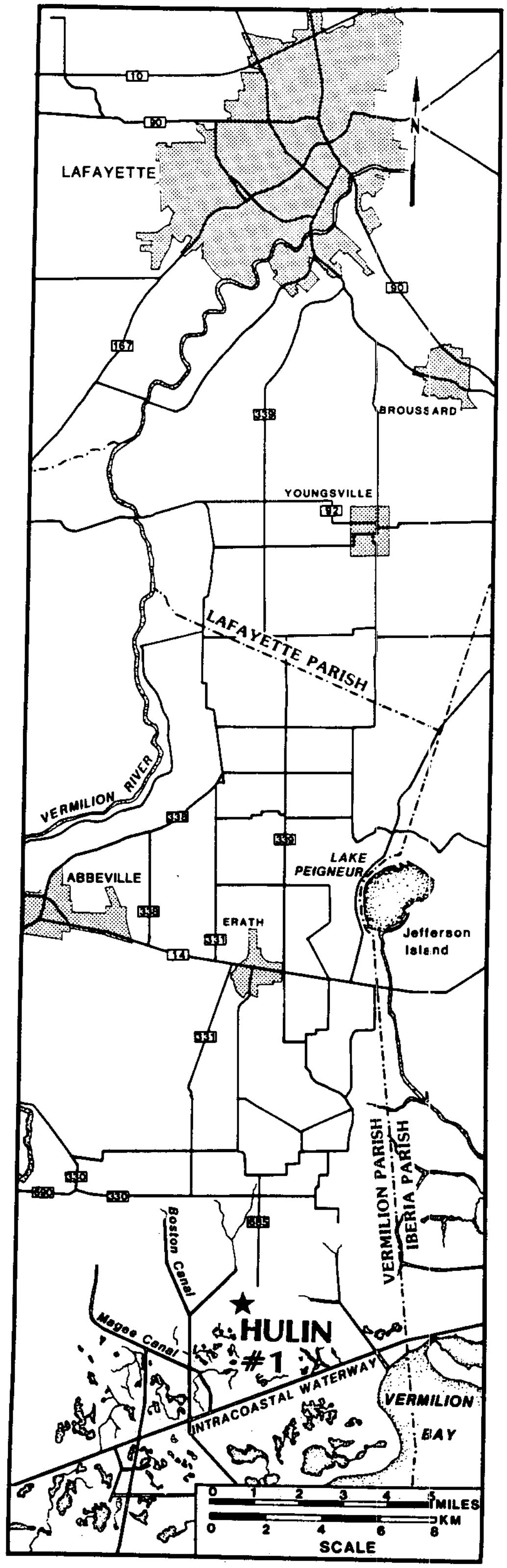

Figure 3. Map showing the location of the Superior Hulin #1 Well.

20,666 ft and 20,220 to 20,260 ft to determine if any free gas was present. During this short-term test, 40,163 bbl of brine and 1,245.9 MCF of gas were produced (Eaton Operating Company 1990). This gives an average gas-to-brine ratio of 31 SCF/bbl. This limited duration testing did not provide any evidence of free gas. The well is presently shut in and awaiting long-term testing.

PROSPECT GEOLOGY

The DOE Superior Hulin #1 well is the deepest well in the area, and sections correlatable to the target section in the Hulin well have not been penetrated by any other wells in the vicinity. It is, therefore, difficult to determine the details about the depositional environment and the stratigraphic-structural relationship of the geopressured-geothermal target sandstone section. This sandstone has a gross thickness of 570 ft (20,120 to 20,690 ft), and a maximum log recorded a bottom-hole temperature of 338°F.

Paleontological analysis provided to LGS by Paleodata Inc. (appendix I) indicates that the Hulin well penetrated the Lower Miocene Planulina zone and was in it at 13,090 ft. The top of the Planulina zone could not be exactly determined because of poor quality samples. Sloane (1971) states that the Planulina Formation of south Louisiana consists of interbedded sands and deep-water shales beneath the Siphonina davisi zone and extends westward as a narrow band from Lake Verret in Assumption Parish through Cameron Parish in Louisiana into the coastal area of Texas. This zone is characterized by complex structural relationships and irregular sandstone distribution making log correlations difficult. Seismic data clarity is also hampered at greater depths where sandstones occur. The depth together with geopressures results in drilling difficulties, which translates into high drilling costs. A structure map of the Hulin Prospect area contoured at the top of the 15,400 ft sand in the Lower Planulina section used by DOE in its discussion on the Hulin prospect is shown in figure 4. The Erath field situated to the north of the Hulin well, the Boston Bayou field to the south and the Tigre Lagoon field to the northeast are all fault separated by major regional down to the basin faults. No major faulting is indicated west of the Hulin well.

A dip and strike section of the Hulin prospect incorporating the Hulin #1 well are shown in figures

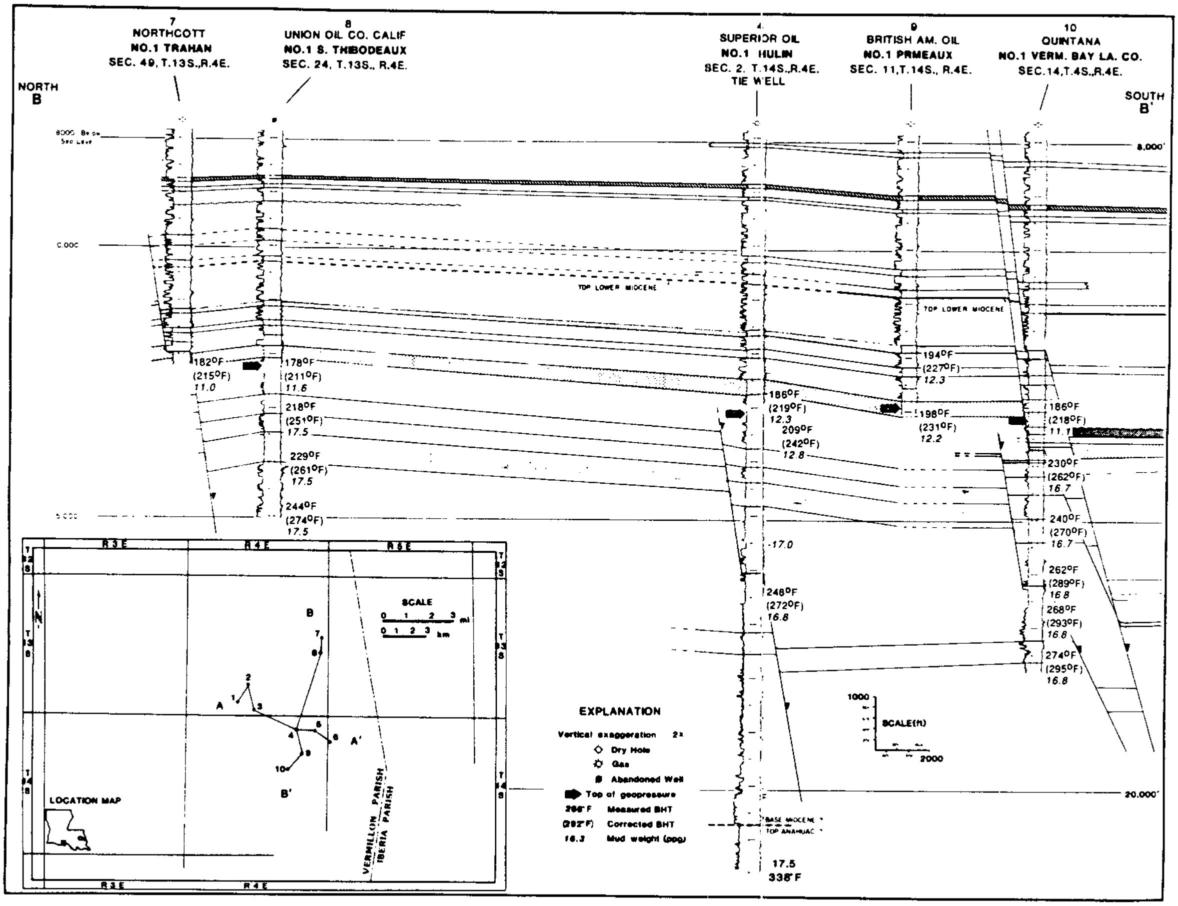

Figure 4. Lower Planulina structure map of the Hulin prospect area (adapted from U. S. Department of Energy 1988).

5 and 6. The top of geopressure is located approximately at the base of the main series of Miocene sands (Dickinson 1953), and the base is at about 12,500 ft in the Hulin #1 well. Because the geopressured-geothermal sandstone of interest in the Hulin well was penetrated at a depth greater than that reached by other wells in the area, the areal extent of this sandstone cannot be accurately determined.

An electric log of the Hulin sandstone to be tested is shown in figure 7. Preliminary short-term tests were conducted on this sandstone, and the results were presented in the preceding section. Detailed well-log interpretation by the University of Texas Petroleum Engineering Department indicated that this sandstone may contain free gas and solution natural gas at several zones, but the short-term tests did not provide evidence of free gas. If additional free gas is proved when long-term testing is initiated, it would provide additional income from gas sales, making the operation more economical.

During the course of this study, LGS and LSU were able to purchase approximately 45 line miles of seismic data in the Hulin prospect area on a proprietary basis (figure 8). Using this data, a new seismic structure was constructed at the top of the geopressured-geothermal sandstone section (figure 9). This structural interpretation was used to estimate the volume of recoverable brine. Earlier estimates of 14 billion barrels of brine were based on a different structural map constructed at a much higher level in the section (figure 4). The present interpretation represents a more accurate picture relative to the sandstone of interest. For brine volume estimation using the new seismic structural map, an areal extent of 2.6 m^2 was used along with a net sandstone thickness of 470 ft and a porosity of 20% (figure 9). Approximately one billion barrels of brine were obtained for the Hulin geopressured-geothermal target sandstone reservoir. This figure was obtained using the following standard calculation for recoverable fluids as reported in the quarterly report to DOE for July, August, and September 1990.

A = 7,758 barrels in an acre foot
B = 0.20 assumed porosity
C = 0.80 assumed recovery factor
A x B x C = 1,241 barrels/acre (X)

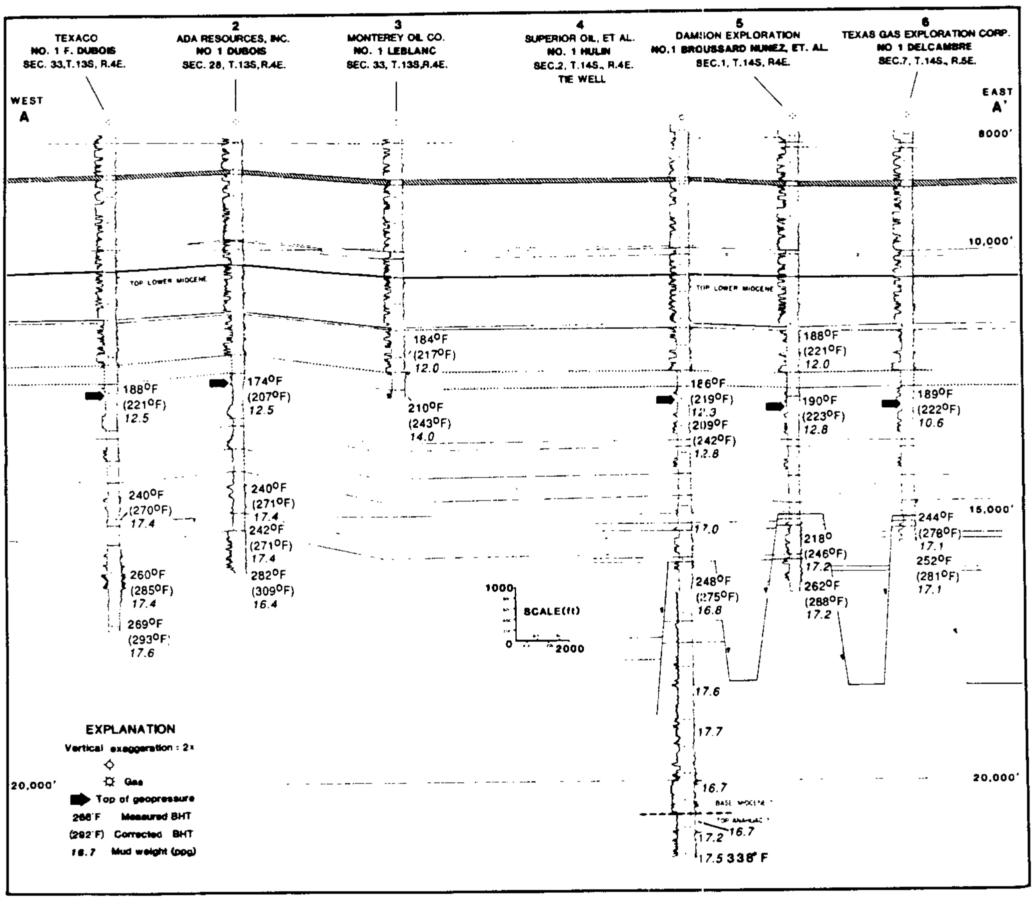

Figure 5. A north-south (dip) cross section of the Hulin prospect area (modified from McCulloh and Pino, 1983).

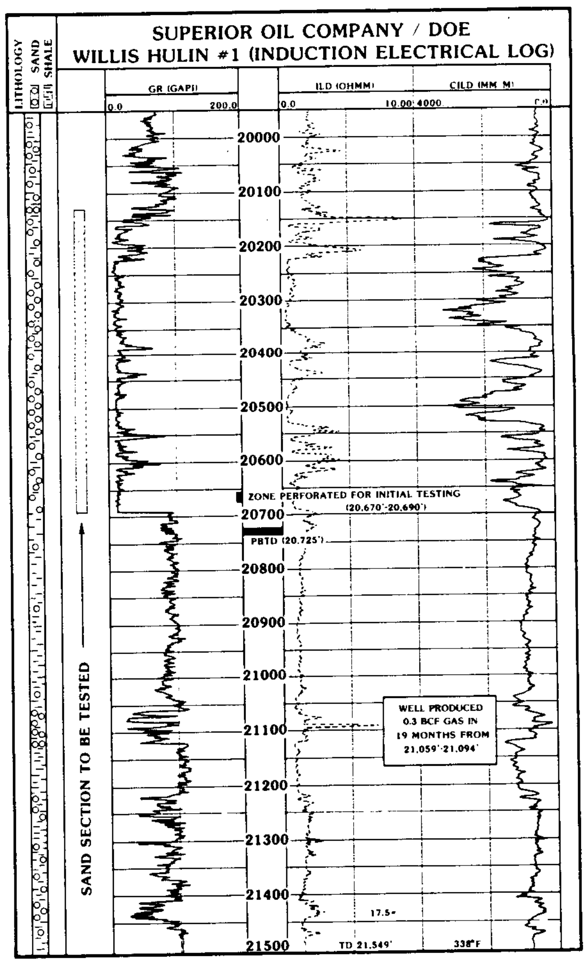

Figure 6. A strike (east-west) cross section through the Superior Hulin #1 well (adapted from McCulloh and Pino, 1983). The line of cross section is shown in figure 5 (inset).

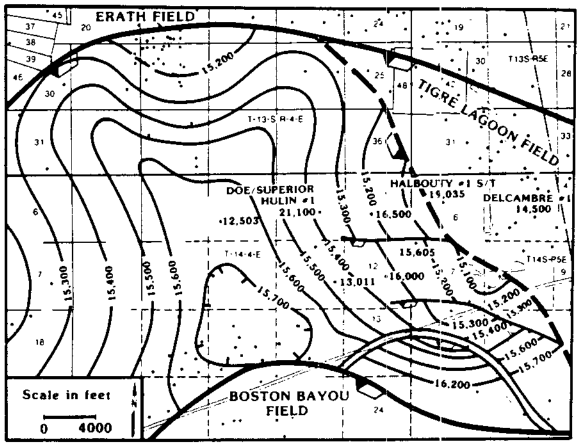

Figure 7. Electric log of the Hulin test well showing the geopressured-geothermal sand section to be tested and generalized lithology.

T = 470 assumed net thickness in feel (from log)
F = 1,665 areal extent in acres (from structure map)
X = 1,241 barrels/acre
T x F x X = 971,144,550 barrels of brine

Rounding the above figures gives an approximate value of 1 billion barrels of brine reserves in the Hulin geopressured-geothermal sandstone reservoir. However, this figure is only an estimate, and as experience has proved many times (e.g., Gladys McCall well test), such estimates are not very accurate. The structure map indicates fault closure on the north, south and east but none on the west side. Long-term, high-volume production testing could cause virtually unlimited recharge of the reservoir. Furthermore, the areal extent of this sandstone from the well is undetermined, and details about lateral and vertical stratigraphic relationships between adjoining reservoirs and fluid communication between reservoirs caused by faults remain unknown. Such factors are difficult to quantify accurately; hence, predictions of brine volume and reservoir longevity do not reflect the reality of such subsurface geological conditions.

Regional geologic studies by Conover (1987) and Hamlin and Tyler (1988) have indicated that the geopressured sands to be tested in the Hulin well represent dip elongated canyon sandstone facies. A net

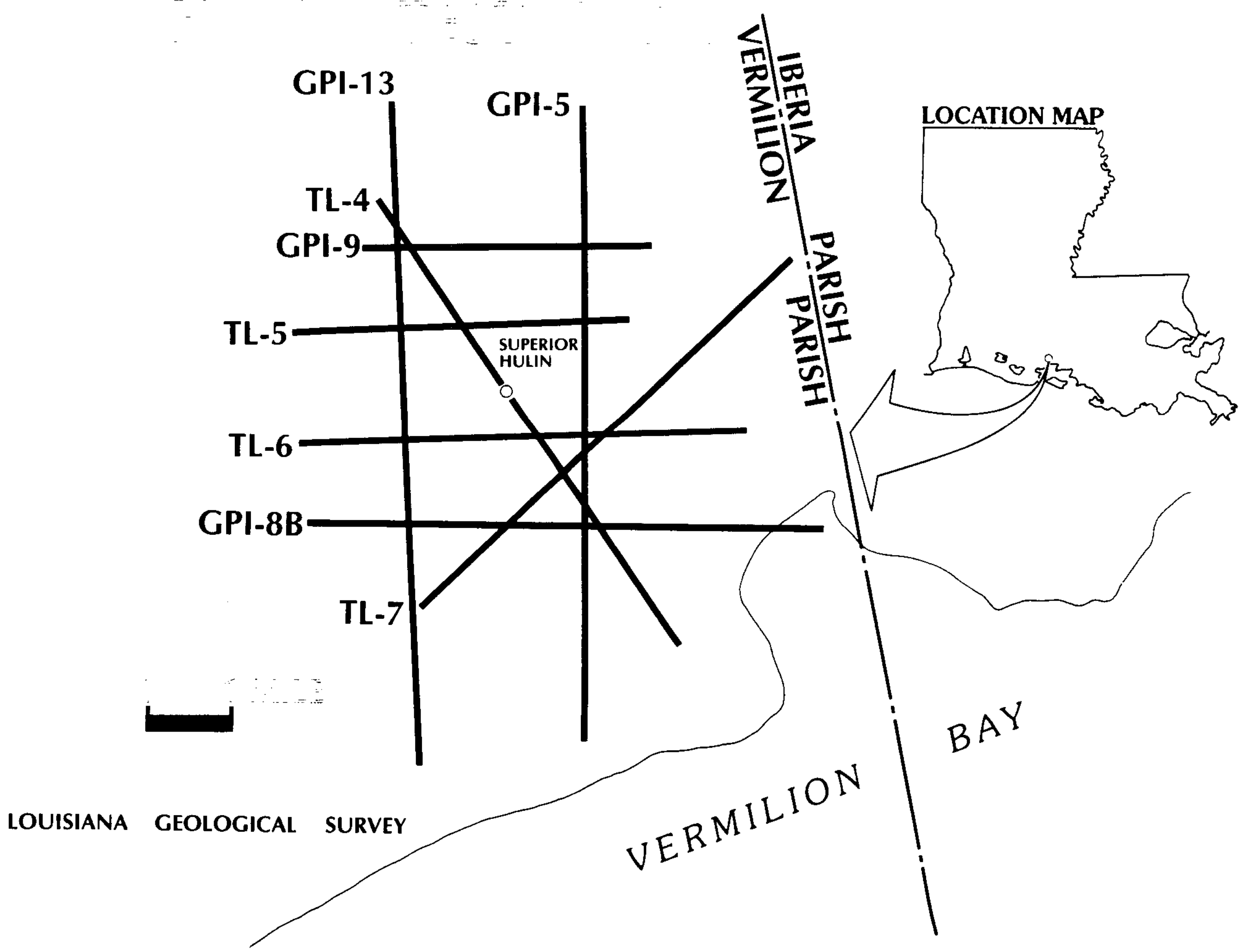

Figure 8. Generalized map showing locations and directions of the reflection seismic lines in the Hulin prospect area acquired for this study.

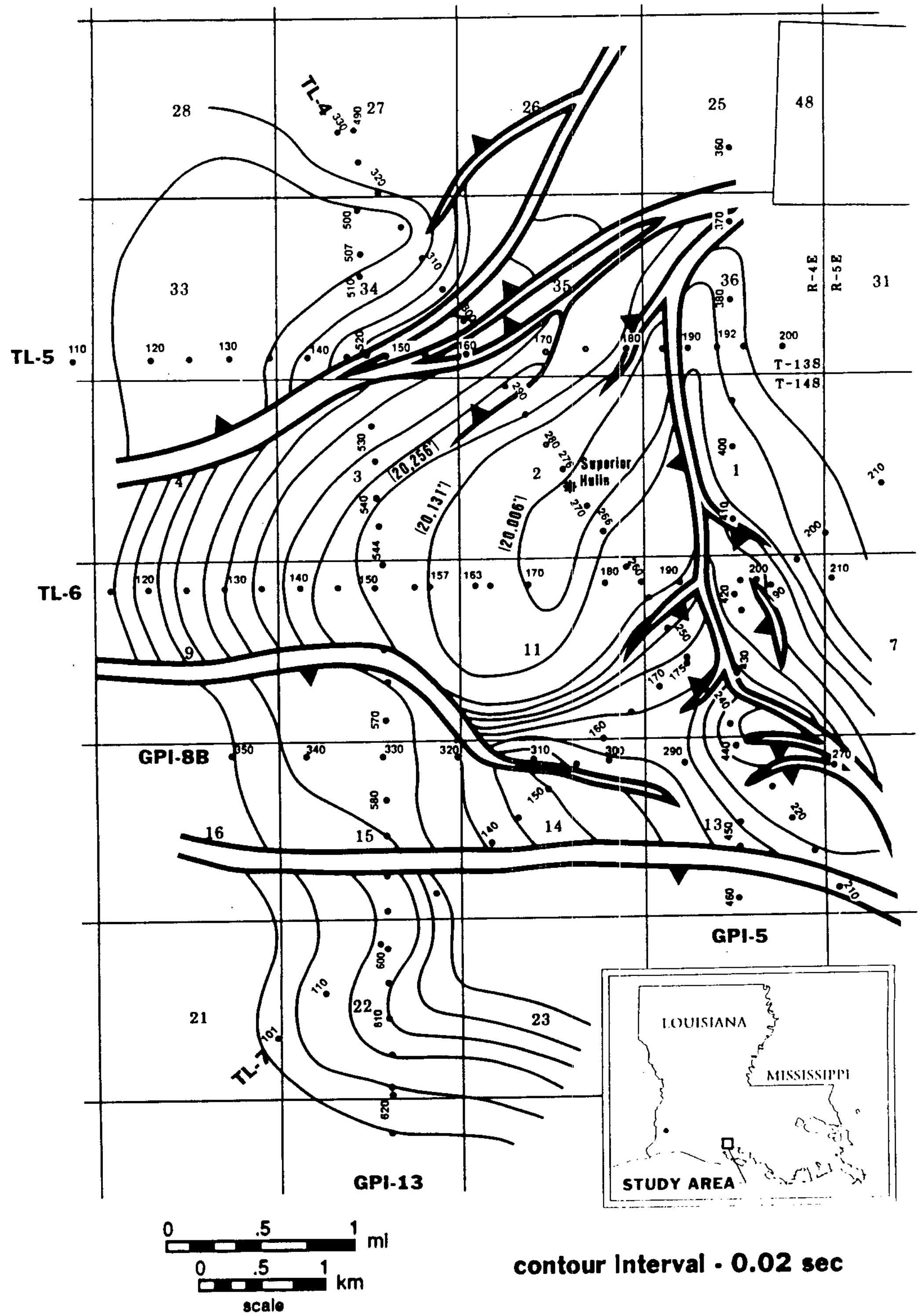

Figure 9. Seismic structure map of the Hulin prospect contoured at the top of the geopressured-geothermal sandstone to be production tested (map by Don Stevenson).

sandstone isopach map of the Planulina zone in the Hulin prospect area and its depositional setting is shown in figure 10, and a representative cross section of this area is presented in figure 11. If the Hulin sandstone is laterally bounded by channel walls, it may be of very limited extent in the east-west direction.

Another possible explanation for the depositional environment of the Hulin target sandstone is that it represents an unstable shelf delta wherein the sands were deposited on a subsiding shelf, accounting for the great thickness of the sandstone. Such unstable shelf deltas develop by deposition in interdomal areas on rich prodelta shales and are usually growth-faulted to result in rollover anticlines a butting against the faults to provide the hydrocarbon trapping structures (Saxena 1990). Diapiric activity around the sand depocenter is common. Final delta abandonment and bypassing because of switching of major distributary channels is followed typically by a period of marine transgression during which the sands in the upper parts of the old delta are reworked into relatively clean sand bodies surrounded by thick marine shale. In the Hulin well, the top of the target sandstone (20,120 to 20,200 ft) may represent a reworked sand situated above the main delta. The Hulin wildcat was possibly drilled on the basis of this concept, and British Petroleum is planning to test these geopressured sands to the northeast of the Hulin prospect for hydrocarbons on the basis of this model for depositional environment. Unfortunately, the lack of detailed paleontologic information from the Hulin well, it is difficult to confirm which of the two above mentioned depositional environments is the more representative model.

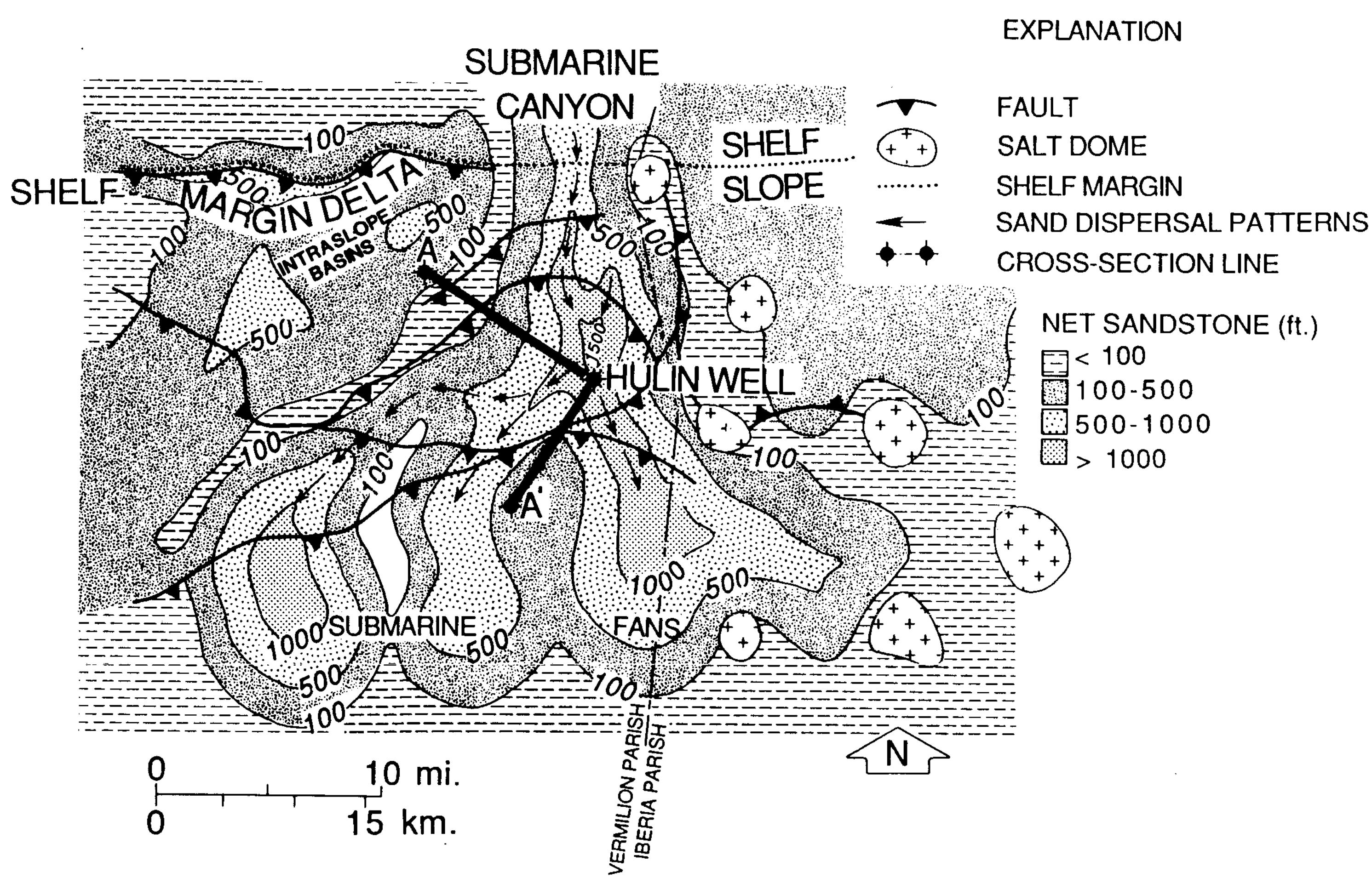

Figure 10. Depositional setting and sandstone thickness of the Planulina zone of the Hulin prospect area (modified from Hamlin and Tyler, 1958).

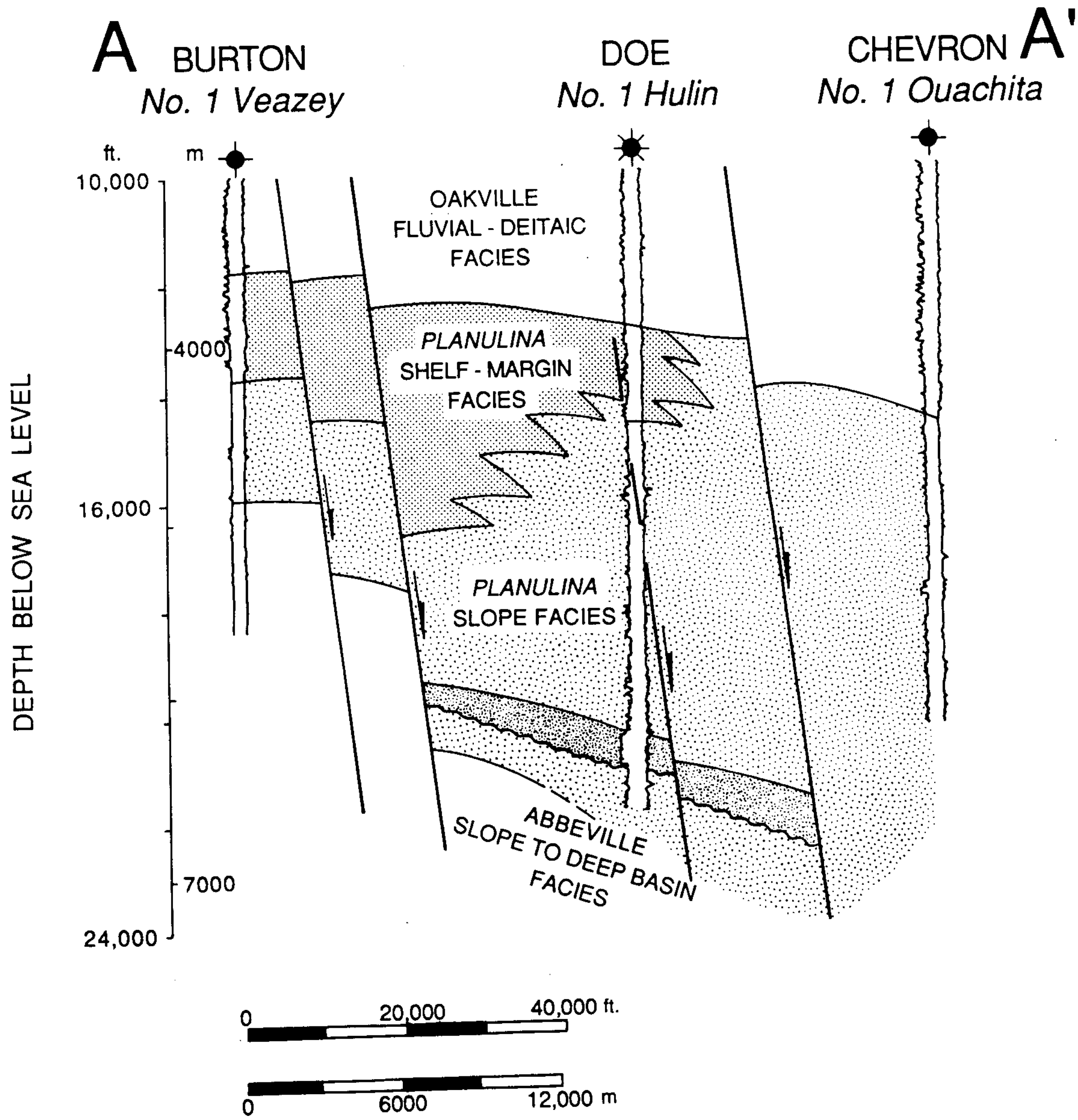

Figure 11. Representative dip cross section of the depositional setting shown in figure 10. Line of cross section is shown in figure 10 (from Hamlin & Tyler, 1988).

SUMMARY

The DOE/Superior Hulin #1 well has the deepest geopressured reservoir at a higher temperature (338°F). The earlier estimates of up to 14 billion barrels of recoverable brine for this reservoir were made based on a structure map at a higher horizon. Calculations based on the latest interpretation of the Hulin reservoir structure using recently acquired seismic data in this prospect area give a recoverable brine estimate of 1 billion barrels. However, this is a very conservative estimate and due to various subsurface geological factors, which cannot be quantified, mentioned earlier in this report, long-term production testing would in all probability yield a much larger volume of brine for this reservoir. The Gladys McCall test well is a case in point where the volume of brine produced during testing far exceeded the initial projections of recoverable brine. Though initial log analysis indicated free gas in various zones within the geopressured sandstone, the short-term testing done at Hulin did not provide any evidence of free gas. Perforating the target sandstones at the top of other zones within it and more importantly, at a higher zone than presently perforated for the short-term test still has the potential of yielding free gas. Accessibility to the Hulin well site provides an ideal location for experimental site set-ups for potential industrial uses of geopressured-geothermal energy.

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APPENDIX I

(504) 488-3711

PALEO-DATA, INC.
6619 FLEUR De LIS DRIVE
NEW ORLEANS, LOUISIANA 70124

T. WAYNE CAMPBELL
JOHN B. DUNLAP, JR.

July 2, 1979

The Superior Oil Company
Erath South Field
Section 2 14S-4E

#1 Willis-Hulin
Vermilion Parish, La.

10000	First sample. In Ecologic Zone 2
11020	Cristellaria A - Ecologic Zone 3
11050-410	Gap
12400	Siphonina davisi
13090	In Planulina palmerae - Lenticulina hanseni
21100	Sample total depth Original Hole
20174	First sample Side Track Hole
21550	Sample total depth Side track Hole. Note: From 16570to 21550 (S/T #1) samples were very poor due to burned shale

Respectfully submitted,

Francis V. Bifano

PALEO-DATA INC.
6619 Fleur de Lis Drive
NEW ORLEANS, LOUISIANA 70124

Mr. Chacko John
La. Geological Survey
P.O.Box G
University Station
Baton Rouge, La. 70893

10000	(Lithology of washed cuttings) 70% shale, 30% medium sand Rotalia beccarii, Amphistegina sp.,
10030	(L) Same Same fauna
10060	(L) 60% shale, 40% sand Same fauna - very sparse plus Globigerina sp.
10090	(L) 70% shale, 30% sand Same fauna plus Textularia sp.
10120	(L) Same Same fauna
10150	(L) Same Same fauna & Siphonina sp.
10180	(L) Same Same fauna & Quinqueloculina sp.
10210	(L) Same Same fauna
10240	(L) Same Same fauna plus Robulus americanus, Nonion sp.
10270	(L) Same Same fauna
10300	(L) 70% shale, 30% sand Same fauna
10330	(L) Same Same fauna
10360	(L) Same Same fauna & Eponides antillarum
10390	(L) 80% shale, 20% sand Same fauna
10420	(L) Same Same fauna
10450	(L) Same Same fauna
10480	(L) Same Same fauna
10510	(L) Same Same fauna

10540 (Lithology of washed cuttings) 80% shale, 20% sand & shell fragments
Eponides sp., Eponides parantillarum, Cibicides concentricus

10570 (L) Same
Same fauna plus quinqueloculina sp., Rotalia beccarii plus abundant shell fragments

10600 (L) 90% shale, 10% sand & shell fragments
Same fauna plus Robulus americanus

10630 (L) 80% shale, 20% sand & shell fragments
Same fauna plus Globigerina sp., -rare
Siphonina advena-rare, Candona sp.,

10660 (L) Same
Eponides parantillarum, Robulus americanus, Globigerina sp.-rare, Discorbis sp.-rare & small, Nonion sp.note: fauna rare

10690 (L) Same
Same fauna plus Polymorphina

10720 (L) 80% shale, 20% sand & shell fragments
Same fauna plus Amphistegina sp.,

10750 (L) Same
Same fauna

10780 (L) Same
Same fauna plus Discorbis cf. bolivarensis-very rare & small

10810 (L) 90% shale, 10% sand
No fauna

10840 (L) 70% shale, 30% sand & shell fragments
Amphistegina sp., Globigerina sp-rare, Rotalia beccarii, Eponides parantillarum, Cibicides concentricus

10870 (L) Same
Same fauna plus Textularia sp.-very rare, Eponides ornate-very rare

10900 (L)Same
Same fauna but reduced

10930 (L) Same
No fauna

10960 (L) Same
Globigerina sp.-rare, Robulus americanus, Eponides parantillarum, Amphistegina sp., Quinqueloculina sp.

10990	(L) 90% shale, 10% sand & shell fragments Same fauna plus Rotalia beccarii, Siphonina advena-common, Discorbis sp.-small, Robulus americanus-common, Uvigerina peregrina-very rare, Quinqurloculina sp.note: slight faunal increase
11020	(L) Same Same fauna plus Lenticulina jeffersonensis (Cristellaria cf. R), Eponides parantillarum, Cristellaria A (Robulus chambersi)-common, Uvigerina peregrina-rare, note: faunal increase
11050 -11410	Gap
11410	(L) 70% shale, 30% sand Globigerina sp.,
11440	(L) Same No fauna
11470	(L) Same No fauna
11500	(L) 60% shale, 40% sand No fauna
11530	(L) 70% shale, 30% sand Globigerina sp.,
11560	(L) Same No fauna
11590	(L) Same No fauna
11620	(L) 80% shale, 20% sand Quinqueloculina sp., Robulus sp., Globigerina sp., Cristellaria A, Lenticulina jeffersonensis,
11650	(L) 60% shale, 40% sand Same fauna
11680	(L) 80% shale, 20% sand Cristellaria A,
11710	(L) 70% shale, 30% sand Robulus sp.,
11740	(L) Same No fauna
11770	(L)Same Lenticulina jeffersonensis, Robulus sp.,

11800	(L) Same Same fauna
11830	(L) 80% shale, 20% sand Discorbis bolivarensis,
11860-90	Gap
11890	(L) 80% shale, 20% sand Same fauna
11920	(L) Same Robulus sp., Cristellaria A, Globigerina sp. Cibicides concentricus
11950	(L) 60% shale, 40% sand Cristellaria D, Robulus americanus, Globigerina spp., Cristellaria A, Eponides antillarum
11980	(L) Same Same fauna
12010	(L) Same Same fauna
12040	(L) Same Same fauna
12070	(L) Same Same fauna & Trochammina teasi
12100	(L) Same Same fauna
12130	(L) Same Same fauna
12160	(L) Same Same fauna
12190	(L) Same Same fauna
12220	(L) Same Same fauna

12250	(L) 70% shale, 30% sand Cristellaria A, Eggerella sp., Robulus sp.,
12280	(L) 80% shale, 20% sand Same fauna
12310	(L) Same Same fauna plus Uvigerina howei
12340	(L) 70% shale, 30% sand Cristellaria A, Globigerina sp.,
12370	(L) 80% shale, 20% sand Same fauna
12400	(L) Same Same fauna plus Siphonina davisi
12430	(L) Same Same fauna with Siphonina davisi missing
12460	(L) Same Same fauna
12490	(L) Same Same fauna
12520	(L) Same Same fauna
12550	(L) Same Same fauna slight increase plus Lenticulina jeffersonensis
12580-12610	(L) Same Same fauna plus Siphonina davisi
12700	(L) 80% shale, 20% sand Cristellaria A, Uvigerina peregrina, Globigerina spp., Cristellaria D, Eponides antillarum, Siphonina advena, Siphonina davisi, Discorbis bolivarensis
12730	(L) Same Same fauna
12760	(L) Same Same fauna plus Cristellaria D uncoiling
12790	(L) Same Same fauna
12820	(L) Same Same fauna

12850	(L) Same Same fauna
12880	(L) Same Same fauna
12910	(L) Same Same fauna
12940	(L) 80% shale, 20% sand Cristellaria A, Lenticulina jeffersonensis, Siphonina sp., Globigerina sp., Uvigerina howei, Discorbis nomata, Discorbis bolivarensis, Trochammina sp.,
12970	(L) 90% shale, 10% sand Same fauna
13030-13060	(L) 90% shale, 10% sand Globigerina sp., Uvigerina peregrina, Nonion sp., Robulus sp., Siphonina davisi
13060	(L) 90% shale, 10% sand plus cement Cristellaria A, Discorbis bolivarensis, Uvigerina howei, Eggerella sp., Globigerina sp., Robulus cf. lacerta, Uvigerina sp., Dentalina sp.,
13090	(L) 80% shale, 20% sand Same fauna plus Eponides ellisorae, Liebusella byramensis, Lenticulina sp., Textularia sp., Bulimina sp., Lenticulina hanseni, Reophax sp.,
13120	(L) 70% shale, 30% sand Same fauna plus Nodosaria vertebralis
13150	(L) 80% shale, 20% sand Same fauna
13180	(L) Same Same fauna
13210	(L) Same Same fauna
13240	(L) Same Same fauna
13270	(L) Same Same fauna
13300	(L) 60% shale, 40% sandstone Same fauna-very rare

13330	(L) 80% shale, 20% sand Same fauna plus Siphonina davisi
13360	(L) Same Same fauna
13390	(L) Same Same fauna-sparse
13420	(L) 70% shale, 30% sand Same fauna
13450	(L) Same Same fauna
13480-13510	(L) Same Same fauna
13510	(L) 80% shale, 20% sand Cristellaria A, Cristellaria sp., Globigerina sp.,
13540	(L) Same Same fauna
13570	(L) Same Same fauna
13600	(L) Same Same fauna
13630	(L) Same Same fauna
13660	(L) Same Same fauna
13690	(L) Same Same fauna
13720	(L) Same Same fauna plus Nonion sp.,
13750	(L) Same Same fauna
13780	(L) Same Same fauna
13810	(L) 90% shale, 10% sand Same fauna
13840	(L) Same Same fauna
13870	(L) Same Same fauna plus Siphonina davisi, Discorbis sp.

13900	(L) Same Same fauna plus Uvigerina peregrina, Eggerella sp.
13930	(L) Same Same fauna plus Liebusella byramensis, Bulimina ovata, Ellipsonodosaria emaciatum, Uvigerina howei,
13960	(L) Same Same fauna
13990	(L) Same Same fauna plus Eggerella 3, Textularia sp.,
14020	(L) Same Same fauna
14050	(L) Same Same fauna plus Bifarena vicksburgensis
14080	(L) Same Same fauna
14110	(L) Same Same fauna
14140	(L) Same Same fauna
14170	(L) 80% shale, 20% sand Discorbis bolivarensis, Lenticulina hanseni, Cristellaria A, Eponides ellisorae, Globigerina sp., Uvigerina howei, Dentalina sp., Siphonina davisi, Bulimina ovata
14200	(L) Same Same fauna
14230	(L) Same Same fauna
14260	(L) Same Same fauna
14290	(L) Same Same fauna
14320	(L) 70% shale, 30% sand Same fauna

14350	(L) Same Same fauna
14380	(L) Same Same fauna
14410	(L) Same Same fauna
14440	(L) 80% shale, 20% sand Same fauna
14470	(L) 70% shale, 30% sand Discorbis bolivarensis, Lenticulina hanseni, Globigerina sp., Eponides ellisorae, Uvigerina howei
14500	(L) Same Same fauna
14530	(L) 80% shale, 20% sand Same fauna plus Cristellaria A, Reophax sp.,
14560	(L) 80% shale, 20% sand Same fauna
14590	(L) Same Same fauna-increase plus Lenticulina jeffersonensis, Siphonina davisi with Uvigerina howei & Globigerina sp.-common
14620	(L) Same Same fauna plus Textularia sp., Liebusella byramensis,
14650	(L) Same Same fauna
14680	(L) Same Same fauna
14710	(L) 90% shale, 10% sand Same fauna
14740	(L) Same Same fauna-decrease
14770	(L) Same Same fauna
14800-14830	(L) Same Same fauna

14830	(L) 80% shale, 20% sand plus minor pyrite Robulus chambersi, Lenticulina sp., Discorbis bolivarensis, Lenticulina jeffersonensis, Lenticulina hanseni
14860	(L) Same Same fauna
14890	(L) 90% shale, 10% sand Same fauna plus Uvigerina howei
14920	(L) Same Same fauna
14950	(L) Same Same fauna
14980	(L) Same Same fauna plus Eggerella sp., Bulimina ovata, Liebusella sp.,
15010	(L) 80% shale, 20% sand Same fauna plus Eponides ellisorae, Siphonina davisi,
15040	(L) Same Same fauna
15070	(L) Same Same fauna
15100	(L) Same Same fauna
15130	(L) 90% shale, 10% sand Lenticulina jeffersonensis, Robulus chambersi, Discorbis bolivarensis, Uvigerina howei, Eponides ellisorae, Siphonina davisi, Reophax sp., Globigerina sp.,
15160	(L) 80% shale, 20% sand plus pyrite Same fauna
15190	(L) 90% shale, 10% sand Same fauna
15220	(L) Same Same fauna
15250	(L) Same Same fauna

15280	(L) 90% shale, 10% sand Same fauna
15310	(L) Same Same fauna
15340	(L) 80% shale, 20% sand Same fauna
15370	(L) Same Same fauna
15400-430	(L) Same Same fauna
15460	(L) Same Same fauna
15520	(L) 80% shale, 20% sand Cristellaria A, Bulimina ovata, Globigerina sp., Discorbis sp., Lenticulina jeffersonensis, Eponides ellisorae, Discorbis bolivarensis, Textularia sp., Uvigerina howei
15550	(L) Same Same fauna plus Reusella byramensis
15580	(L) Same Same fauna
15610	(L) Same Same fauna
16640	(L) Same Same fauna
16670	(L) Same Same fauna
16700	(L) 90% shale, 10% sand Liebusella byramensis, Uvigerina howei, Eggerella sp., Lenticulina jeffersonensis, Robulus sp., Nonion sp., Eponides ellisorae
15730	(L) 70% shale, 30% limey sandstone Same fauna
15760	(L) 80% shale, 20% sand Same fauna (sparse)
15790-820	Gap

15820-15850 (L) 80% shale, 20% sand
Same fauna plus Discorbis bolivarensis

16030	(L) 70% shale, 30% sand Cristellaria A, Globigerina sp., Siphonina sp., Reophax sp.,
16050-16150	Gap
16150	(L) 80% shale, 20% sand Cristellaria A, Robulus americanus, Robulus mayeri, Globigerina sp., Uvigerina howei, Siphonina sp., Dentalina sp.,
16180	(L) Same Same fauna
16210	(L) Same Same fauna
16240	(L) Same Same fauna
16270	(L) Same Same fauna
16300	(L) Same Same fauna-rare
16330	(L) 70% shale, 30% consolidated sand Same fauna
16360	(L) Same Same fauna
16390	(L) Same Same fauna
16420	(L) 90% shale, 10% sand Same fauna
16450	(L) Same Same fauna
16480	(L) Same Same fauna
16510	(L) Same Same fauna
16540	(L) Same Same fauna plus Eponides antillarum

16570	(L) 90% shale, 10% sand Bulimina ovata, Nonion sp., Robulus americanus, Cristellaria cr. R, Cristellaria A, Quinqueloculina sp., Globigerina sp.,
16600	(L) Same Same fauna plus Liebusella pozonensis
16630	(L) 80% shale, 20% sand Bathysiphon sp., Siphonina advena
16660	(L) 70% shale, 30% sand Same fauna
16690	(L) 80% shale, 20% sand Same fauna
16720	(L) Same Same fauna
16750	(L) Same Same fauna
16780	(L) Same Same fauna
16810	(L) Same Same fauna
16840	(L) Same Same fauna
16870	(L) Same Same fauna
16900	(L) Same Same fauna
16930	(L) 80% shale, 20% sand Cristellaria A, Globigerina sp., Robulus americanus,
16960	(L) Same Same fauna plus Globigerina sp.,
16990	(L) Same Same fauna
17020	(L) Same Same fauna

17050	(L) Same Same fauna
17080	(L) Same Same fauna
17110	(L) Same Same fauna
17140	(L) Same Same fauna
17170	(L) Same Same fauna
17200	(L) Same Same fauna
17230	(L) Same Same fauna
17260	(L) 80% burned shale, 20% sand Sparse fauna
17290	(L) Same Same fauna
17320	(L) Same Same fauna-sparse
17350	(L) Same Same fauna-sparse
17380	(L) Same with cement Same fauna-sparse
17410	(L) Same Same fauna
17470	(L) Same Same fauna
17500	(L) Same Same fauna-sparse
17530	(L) Same-small sample Same fauna-sparse
17560	(L) Same Same fauna

17590	(L) Same Same fauna
17620	(L) 80% shale, 20% sand Uvigerina peregrina,
17650	(L) Same Same fauna
17680	(L) Same Same fauna
17710	(L) Same Same fauna
17740	(L) Same Same fauna
17770	(L) Same Same fauna
17800	(L) Same Same fauna
17830	(L) Same Same fauna
17860	(L) Same Same fauna
17890	(L) Same Same fauna
17920	(L) 90% burned & fused mudstone fragments, 10% sand, No fauna
17950	(L) Same No fauna
17980	(L) Same No fauna
18010	(L) Same No fauna
18040	(L) Same No fauna
18070	(L) Same No fauna

18100	(L) Same No fauna
18130	(L) Same No fauna
18160	(L) Same No fauna
18190	(L) Same Globigerina sp.,
18220	(L) 90% fused & burned mudstone fragments, 10% sand No fauna
18250	(L) Same No fauna
18280	(L) Same No fauna
18310	(L) Same No fauna
18340	(L) Same No fauna
18370	(L) Same No fauna
18400	(L) Same No fauna
18430	(L) Same No fauna
18460-500	(L) Same No fauna
18500	(L) 90% shale, 10% sand Robulus sp., Cristellaria A, Trochammina sp., Eggerella sp.,
18520	(L) Same Same fauna (very rare)
18550	(L) 90% burned shale, 10% sand Eggerella sp.,
18580	(L) Same Same fauna
18610	(L) Same with lost circulation material Robulus sp.

18640	(L) Same No fossils
18670	(L) Same No fossils
18700	(L) Same No fossils
18730	(L) Same No fossils
18760	(L) Same No fossils
18790	(L) Same Robulus sp., Eggerella sp., Globigerina sp. Guttulina sp., Uvigerina howei,
18820	(L) Same Same fauna & Reophax sp., Cristellaria cf. R (small) Cyclammina cancellata,
18850	(L) 90% shale, 10% sand Robulus americanus, Cristellaria sp., Globigerina sp., Uvigerina howei, Cristellaria A
18910	(L) Same Same fauna plus Eggerella sp.,
18940	(L) Same Same fauna
18970	(L) Same Same fauna plus Quinqueloculina sp.,
19000	(L) 80% shale, 20% hard consolidated sand Same fauna-rare
19030	(L) Same Same fauna-very rare
19060	(L) Same Globigerina sp.,
19090	(L) 90% shale, burned from diamond bit, 10% sand Same fauna
19120	(L) Same Same fauna

19150	(L) Same No fauna
19180	(L) Same No fauna
19210	(L) Same No fauna
19240	(L) Same No fauna
19270	(L) Same No fauna

18728	(L) Same No fauna
18732	(L) Same No fauna
18979	(L) Same No fauna
18988	(L) Same No fauna
10 thru 8	Gap
19110	(L) Same No fauna
19115	(L) Same No fauna
5	Gap
19187	(L) Same No fauna
19190	(L) Same No fauna
19198	(L) Same No fauna
19308	(L) Same No fauna

19300	(L) 80% shale, 20% sand with abundant cement Robulus sp., very rare fauna
19330	(L) Same Uvigerina peregrina-sparse fauna
19360	(L) Same Globigerina sp.
19390	(L) Same Robulus americanus
19420	(L) Same No fauna
19450	(L) Same No fauna
19480	(L) Same No fauna
19510	(L) Same No fauna
19540	(L) Same No fauna
19570	(L) Same Globigerina sp., Bulimina cf. ovata, Cristellaria A,
19600	(L) 90% shale, 10% sand Robulus sp.-very sparse fauna
19630	(L) Same Same fauna
19660	(L) Same Globigerina sp.,
19690	(L) Same No fauna
19720	(L) Same No fauna
19750	(L) Same No fauna
19780	(L) 70% shale, 30% sand No fauna

19810	(L) Same No fauna
19840	(L) Same No fauna
19870	(L) Same No fauna
19900	(L) 80% shale, 20% sand with sandstone fragments No fauna
19930	(L) Same Globigerina sp.
19960	(L) Same Cibicides floridanus,
19990	(L) Same with mud additives No fauna
20020	(L) Same with cement No fauna
20050	(L) Same No fauna
20080	(L) Same No fauna
20110	(L) Same No fauna
20140	(L) Same No fauna
20170	(L) 60% shale, 40% sand No fauna
20200	(L) 80% shale, 20% sand(Shale burned with diamond bit) No fossils
20230	(L) Same No fossils
20260	(L) Same No fossils
20290	(L) Same No fauna
20320	(L) Same No fauna

20350	(L) 70% hard burned shale, 30% sand No fauna
20380	(L)Same No fauna
20410	(L) Same No fauna
20440	(L) Same Siphonina sp.
20470	(L) 80% burned shale, 20% sand No fauna
20500	(L) 70% burned shale, 30% sand No fauna
20530	(L) Same No fauna
20560	(L) Same No fauna
20590	(L) 90% shale, 10% sand plus mud additives -abundant No fauna
20620	(L) Same plus limey medium sandstone fragments No fauna
20650	(L) Same No fauna
20680	(L) Same No fauna
20710	(L) Same No fauna
20740	(L) Same No fauna
20770	(L) Same No fauna
20800	(L) Same No fauna
20830	(L) Same No fauna
20860	(L) Same No fauna

20890	(L) Same No fauna
20920	(L) Same No fauna
20950	(L) 70% shale, 30% sand No fauna
20980	(L) Same No fauna
21010	(L) Same No fauna
21040	(L) Same with sandstone fragments No fauna
21070	(L) Same No fauna
20070	(L)80% burned shale, 20% sand No fauna
20200	(L) Same Globigerina sp.-rare
20230	(L) Same plus mud additives No fauna
20260	(L) Same plus selenite gypsum-rare No fauna
20290	(L) Same plus cement & lime fragments No fauna
20320	(L) Same No fauna
20350	(L) Same No fauna
20380	(L) Same No fauna
20410	(L) Same with common mud additives No fauna
20440	(L) Same No fauna
20470	(L) Same No fauna

SIDETRACK HOLE

20500	(L) Burned shale No fauna
20530	(L) Same Same fauna
20560	(L) 70% shale, 30% sand & mud material No fauna
20590	(L) Same No fauna
20620	(L) 90% burned shale, 10% sand & mud material No fauna
20650	(L) Same No fauna
20680	(L) Same No fauna
20710	(L) Same No fauna
20740	(L) Same No fauna
20770	(L) Same No fauna
20800	(L) Same
20830	(L) 90% shale, 10% sand plus mud additives Orbulina sp., Cibicides 8, Uvigerina sp., Haplophragmoides sp., rare fauna
20860	(L) Same Buliminella curta, Cristellaria A
20890	(L) Same Robulus sp.,
20910	(L) Same No fauna

20950	(L) Same No fauna
20980	(L) Same No fauna
21010	(L) Same No fauna
21040	(L) Same No fauna
21070	(L) Same No fauna
21100	(L) Same No fauna
21130	(L) 80% shale, 20% sand No fauna
21160	(L) Same No fauna
21190	(L) Same No fauna
21220	(L) Same No fauna
21250	(L) Same No fauna
21280	(L) Same No fauna
21310	(L) Same No fauna
21340	(L) Same No fauna
21370	(L) Same No fauna
21400	(L) Same No fauna
21430	(L) Insufficient residue No fauna noted

21460		(L) 80% shale, 20% sand plus mud additives No fauna
21490		(L) Same No fauna
21520	-50	(L) Same No fauna

Superior Oil Company
Erath S. Field (Sec. 2-14S - 4E)

#1 Willis Hulin
Vermilion Parish, La.

SIDE WALL CORES

33	(L) 90% shale, 10% sand Rotalia beccarii
32	Gap
31	(L) Same No fauna
30-29	Gap
28	(L) Same No fauna
27-25	Gap
24	(L) Same No fauna
23	(L) Same No fauna
22	(L) Same No fauna
21	(L) Same Same fauna
20	(L) Same Same fauna
18529	(L) Same plus No fauna
18637	(L) Same No fauna
18640	(L) Same No fauna
18700	(L) Same No fauna
18702	(L) Same No fauna

Superior Oil Company
Erath S.Field (Sec.2-14S - 4E)

#1 Willis Hulin
Vermilion Parish, La.

SIDE WALL CORES

17560	(L) 100% shale No fossils
17750	(L) 100% shale Trochamina sp. (1)
17970	(L) 95% shale, 5% sand No fossils
18013	(L) 100% shale No fossils
18102	(L) 100% shale Globigerina sp.
18104	(L) 100% shale Siphonina sp.
18106	(L) 100% shale No fossils
18114	(L) 100% shale No fossils
18241	(L) 100% shale No fossils
18250	(L) 95% shale, 5% sand No fossils
18260	(L) 95% shale, 5% sand No fossils
18276	(L) 100% shale No fossils
18320	(L) 60% shale, 40% sand No fossils
18338	(LO 70% shale, 30% sand No fossils
18410	(L) 100% shale No fossils

REVIEW OF THE GEOPRESSURED-GEOTHERMAL WELL TEST RESULTS IN SOUTH LOUISIANA

by
Michael Byron Miller

ABSTRACT

Geopressured reservoirs (>0.7 psi/ft) capable of flowing methane-saturated brines at temperatures of 300°F are an alternative energy source. The DOE sponsored nine geopressured-geothermal test wells in Louisiana: six "wells of opportunity" (WOO) were abandoned hydrocarbon exploration wells re-entered to test geopressured reservoirs; three "design wells" were drilled specifically for long-term flow tests of selected geopressured-geothermal prospects. The WOO program provided short-term flow tests over a broad sample of geopressured reservoirs.

Maximum brine flow rates for the test wells range from 3,887 to 36,500 bbl/day. Flow rates of 50,000 bbl/day are expected with larger production tubing. Formation brine temperatures range from 234°F to 330°F. Brine salinity varies from 23,500 to 190,904 ppm TDS. Brine solution gas values are from 20 to 50 SCF/bbl. Gas composition is primarily methane (71 to 94 mol%) and CO_2 (2.5 to 23.5 mol%). CO_2 content increases with temperature, resulting in a decrease in methane. Several wells recovered minor amounts of liquid hydrocarbons during brine production, the origin of which is unknown. Recovered brines appear to be gas-saturated. Although undersaturated brines were reported from three wells, liquid hydrocarbons and CO_2 depress methane solubility, possibly to saturation levels.

Formation water expansion is the principal reservoir drive mechanism; rock compressibility and other factors contribute locally. Resource utilization is potentially feasible with the combined recovery of methane, hydraulic, and geothermal energy.

INTRODUCTION

The geopressured-geothermal resource consists of hot, high-pressure, methane-saturated brines. This is an attractive alternative energy source due to the energy potential of geothermal, geohydraulic, and methane solution gas recovery.

The DOE program began with regional studies to identify geopressured areas favorable for energy recovery, i.e., high geopressures (>0.7 psi/ft), shallow depth to geopressured reservoirs, low-salinity brines, and thick sand reservoirs. Flow testing of geopressured reservoirs began in 1977 with the Edna Delcambre #1 well, Vermilion Parish, Louisiana. This well, originally drilled for hydrocarbon production, was acquired by DOE before abandonment by the operator, under DOE's well of opportunity (WOO) program. The WOO program utilized abandoned hydrocarbon test wells to allow testing of the geopressured-geothermal resource at a relatively low cost in various geologic settings. The objectives were to obtain reliable, short-term test information on aquifer fluid properties, reservoir characteristics, fluid and reservoir behavior at moderate and high flow rates, and completion techniques. In Louisiana, six hydrocarbon production or exploration wells were acquired and successfully tested for geopressured-geothermal energy by DOE under the WOO program.

In addition, the DOE sponsored three design wells in Louisiana. The design well program provided funding to drill wells specifically to evaluate the geopressured-geothermal resource. Although at a much higher cost than WOO, design wells allowed the long-term testing of selected geopressured-geothermal prospects with complete control over the drilling, sampling, and testing procedure. This program provided a wealth of information about reservoir characterization, reservoir fluids, production rates, equipment design, and environmental factors (Westhusing 1981). Perhaps the most important accomplishment of the design well program was the ability to evaluate the long-term flow testing of geopressured-geothermal reservoirs. Such long-term producibility is essential to evaluate the economic feasiblity of the resource as an alternative energy source.

This paper summarizes the wells tested in Louisiana under the DOE geopressured-geothermal resource program. A historical outline, geologic setting, and significant results for each well are provided. A comparison and summary interpretation of the results to date is presented.

REGIONAL GEOLOGY

The northern Gulf of Mexico basin has been a major depocenter for terrigenous clastic sediments throughout the Cenozoic Era. Areas of major sandstone deposition shifted through time in response to paleogeography and especially the location of ancient river systems (figure 1). Basinward of the shelf margin that existed during the Early Cretaceous, prograding sediments were deposited on unstable basinal muds, initiating growth faulting. The oldest geopressured sandstones in the area occur basinward of this shelf margin (Bebout and Gutierrez 1981).

Normally pressured sediments typically exhibit a pressure-depth gradient of 0.465 psi/ft. This is equivalent to the normal hydrostatic fluid pressure exerted by a column of saline water. Abnormally pressured sediments have pressure-depth gradients that deviate from normal hydrostatic pressure. Geopressured sediments in the northern Gulf of Mexico basin have abnormally higher pressure-depth gradients than normal hydrostatic and are often referred to as "overpressured." These geopressured sediments can be further subdivided into two pressure-depth regimes: soft geopressure (0.465-0.70 psi/ft) and hard geopressure (>0.70 psi/ft).

Normally pressured sediments are typically massive or thick sandstones with thin shale layers. The top of geopressure generally occurs at the base of this thick sand sequence with a soft geopressure transition zone of interbedded sandstone and shale. This transition grades into a hard geopressure zone of thick shales with thin or isolated sandstones (Norwood and Holland 1974). Anomalously thick sandstones may occur in the geopressured section as a result of various depositional events (Bebout and Gutierrez 1981).

A variety of mechanisms to generate geopressured sediments have been proposed, including gravitational loading of sands isolated by rapid deposition, stratigraphy, and/or faulting; excess formation water liberated by clay mineral diagenesis (i.e., montmorillonite to illite); aquathermal pressuring due to temperature increase with burial (Barker 1972; Burst 1969; Dickinson 1953; Flanigan 1981). Virtually all of the mechanisms may operate simultaneously in the Gulf Coast to contribute to the formation of geopressured sediments. However,

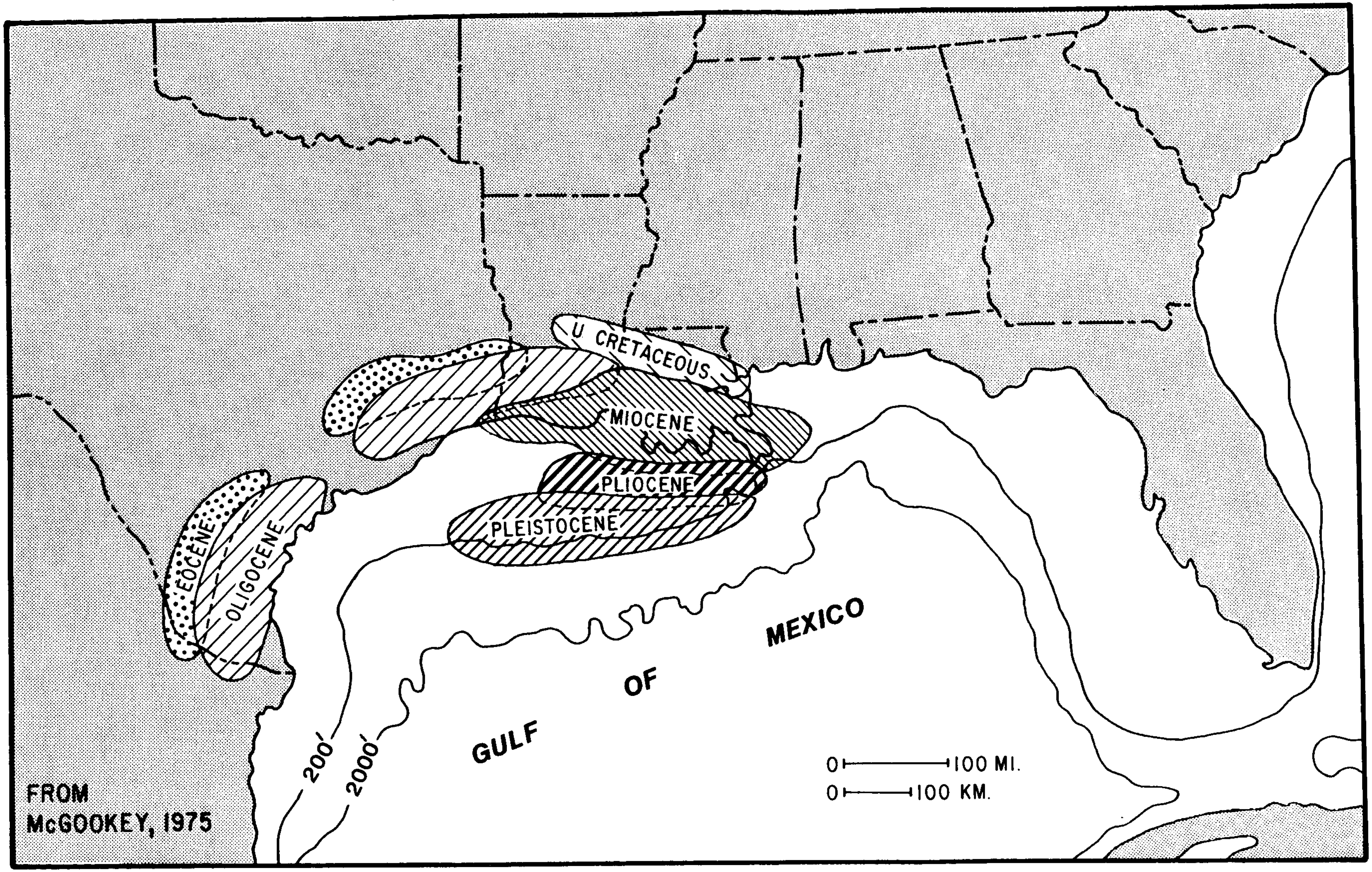

Figure 1. The location of major depocenters, northern Gulf of Mexico basin.

the common variable necessary for each of these mechanisms is a structurally and/or stratigraphically isolated reservoir to restrict the flow of fluids, thereby producing abnormal formation pressures. Ironically, a restricted reservoir is undesirable from a geopressured-geothermal energy recovery standpoint; only large reservoirs capable of high flow rates for extended periods are economically justified.

GEOPRESSURED-GEOTHERMAL WELL TESTS

The DOE-sponsored, geopressured-geothermal test wells in Louisiana are discussed below in chronological order (oldest to the most-recent test). The location of the test wells is shown in figure 2. A summary of the test results and conclusions follows.

OHRW-DOE #1 Edna Delcambre

The OHRW-DOE #1 Edna Delcambre was the first geopressured well tested under the WOO program. The well is in the Tigre Lagoon field, Sec. 8, T14S, R5E, Vermilion Parish, Louisiana (Rogers and Randolph 1979). Originally drilled to 14,314 ft T.D. by Coastal States, Inc., gas production was established in three sands of the Lower Miocene Epoch, Planulina sands (Planulina #6, #7, #8 sands) beginning at ~13,700 ft. The total cumulative production for the well was 9.9 BCF before the well was temporarily abandoned. DOE acquired and re-entered the well to test two shallower Planulina sands (Planulina #1 and #3 sands).

The well was drilled approximately 300 ft downdip from the crest of an anticlinal structure at the Planulina #1 sand horizon (figure 3). The well, as mapped, is approximately 120 ft structurally downdip and 1,100 ft laterally offset to a free gas/water level. The Planulina #3 sand test was penetrated in a similar structural position, but no information on the presence or location of free gas accumulations was given.

The Planulina #1 and #3 sands were tested in the summer of 1977. The #3 sand is 48 ft net sand, log porosity 26%, original formation pressure 11,012 psia, and temperature 238°F (Wieland 1977). The sand was perforated at 12,869 to 12,911 ft and flow tested for 24 days. The maximum flow rate was 10,333 BWPD; salinity 133,000 mg/l TDS.

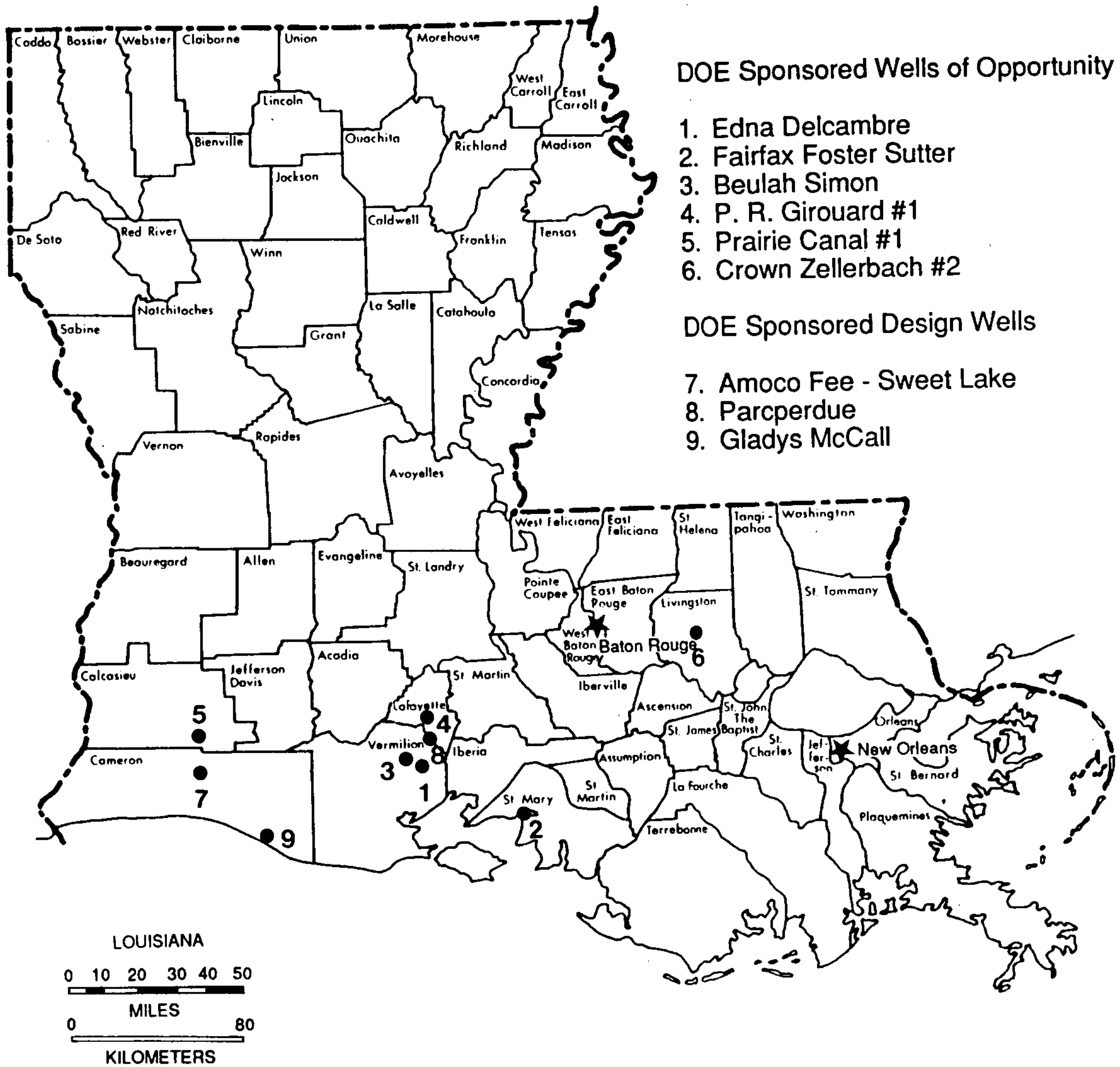

Figure 2. Location of U.S. Department of Energy-sponsored geopressured-geothermal test wells in Louisiana.

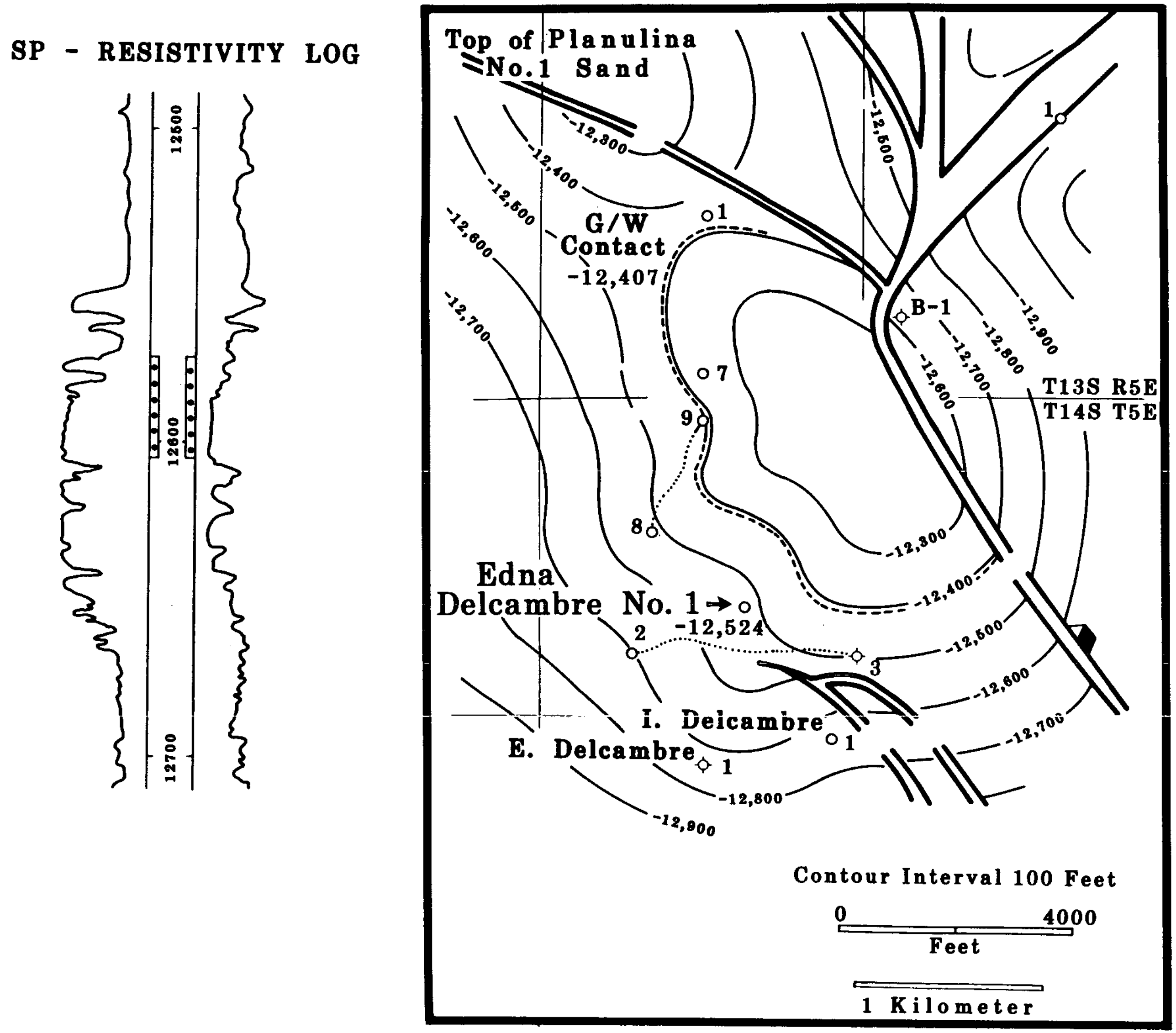

Figure 3. Structure map and log of the OHRW-DOE No. 1 Edna Delcambre test well (WOO).

The Planulina #1 sand was perforated at 12,573 ft to 12,605 ft and tested for 25 days after the Planulina #3 sand had been tested and isolated. The Planulina #1 sand has 30 ft net sand, log porosity 29%, original formation pressure 10,858 psia, temperature 234°F. Maximum flow rate was 12,653 BWPD; salinity 113,000 mg/l TDS. Pressure transient data indicated a barrier at 460 ft from the well. The geologic structure map indicates a fault may extend this close to the wellbore.

The #1 Delcambre well produced anomalously high amounts of solution gas. The Planulina #1 sand, in particular, initially produced approximately 20 SCF/bbl and suddenly increased to over 50 SCF/bbl after eight days of flow testing. Both sands, after rates stabilized, produced 50 to 60 SCF/bbl solution gas. However, recombination studies yielded brine saturation values of 22.8 to 25.4 SCF/bbl, indicating the well was yielding more gas than possible by gas solubility alone (Karkalits and Hankins 1979). Post-separator gas composition was similar for both sands, averaging 94.1 mol % methane, 1.6 mol % CO_2, and 4.3 mol % other gases. Since this was the first geopressured well tested, the excess gas recovery and the possibility of additional, unrecognized mechanisms for the liberation of geopressured gas created intense excitement.

A variety of mechanisms for producing excess gas were postulated (Rogers and Randolph 1979). These included free gas from coning down of a nearby gas cap; free gas present as a dispersed phase in the rock matrix; free gas exsolution and migration resulting from a decrease in pressure; free gas from other zones, flowing via channels between casing and wellbore due to a poor cement bond; and excess gas from the nearby #4 Delcambre well, which experienced an underground blowout, or the #4A Delcambre, drilled as a blowout relief well.

The first two mechanisms, gas coning from a nearby free gas cap versus a dispersed free gas phase, were evaluated with computer simulation models (Rogers and Randolph 1979). The dispersed gas model did not give a reasonable match to the production plots. The free gas cap hypothesis gave an approximate fit to the production data if the edge of the gas cap is only ~400 ft away. The geologic structure map indicates a free gas cap ~1,100 ft away, but the #4 and #4A wells are located 400 ft away and could be the source of the free gas.

The Coastal States #4 Delcambre was drilled 400 ft away from the #1 Delcambre and completed in the Planulina #8 sand. Cumulative production from this sand was 5.2 BCF. The #4 well suffered an underground blowout during workover operations. The #4A well was drilled directionally as a relief well to kill the blowout. The #4A well was completed in an upper Planulina sand, possibly the Planulina #1 sand, and produced 3.7 BCF after successfully killing the #4 blowout. The #4A well was finally junked and abandoned after killing a second blowout in the #4 well. The #4 was subsequently abandoned.

The production problems associated with the #4 and #4A wells, and the documented hydrocarbon flow between reservoirs make these wells a likely source for possible free gas in the tested geopressured zones. In addition, all the Planulina sands have proven hydrocarbon-productive in the Tigre Lagoon field (Rogers and Randolph 1979). Therefore, a free gas phase near the #1 Delcambre well is possible.

Gruy Federal-DOE #2 Fairfax Foster Sutter

The Gruy Federal-DOE #2 Fairfax Foster Sutter well is located in Sec. 6, T15S, R10E, St. Mary Parish, Louisiana, in the East Franklin gas field (Gruy 1979). This was the second geopressured-geothermal well tested under the DOE WOO program. The well was obtained after abandonment as a dry hole at 16,340 ft T.D. by Neuhoff Oil and Gas Company. The prospective geopressured section is the Marg Ascension (MA-6) sands of the Lower Miocene Epoch (figure 4). These sands are interpreted as regressive blanket sands deposited in an inner neritic (shallow marine) environment. The MA-6 sand is not hydrocarbon productive in the East Franklin field, but has produced over 119 BCF in the Garden City field approximately three miles south, which is separated by a syncline and fault from the East Franklin field. Structurally, the Fairfax Foster Sutter well penetrates the MA-6 horizon on the east flank of the East Franklin field anticlinal structure and is bounded by two east-west trending faults.

The MA-6 sand is 270 ft gross, 190 ft net sand. The perforated interval is 15,781 to 15,916 ft, but because of problems with setting the production packer, only the upper 58 ft of perforations were available for testing. Original formation pressure was 12,220 psia, formation temperature 270°F, and log-derived effective

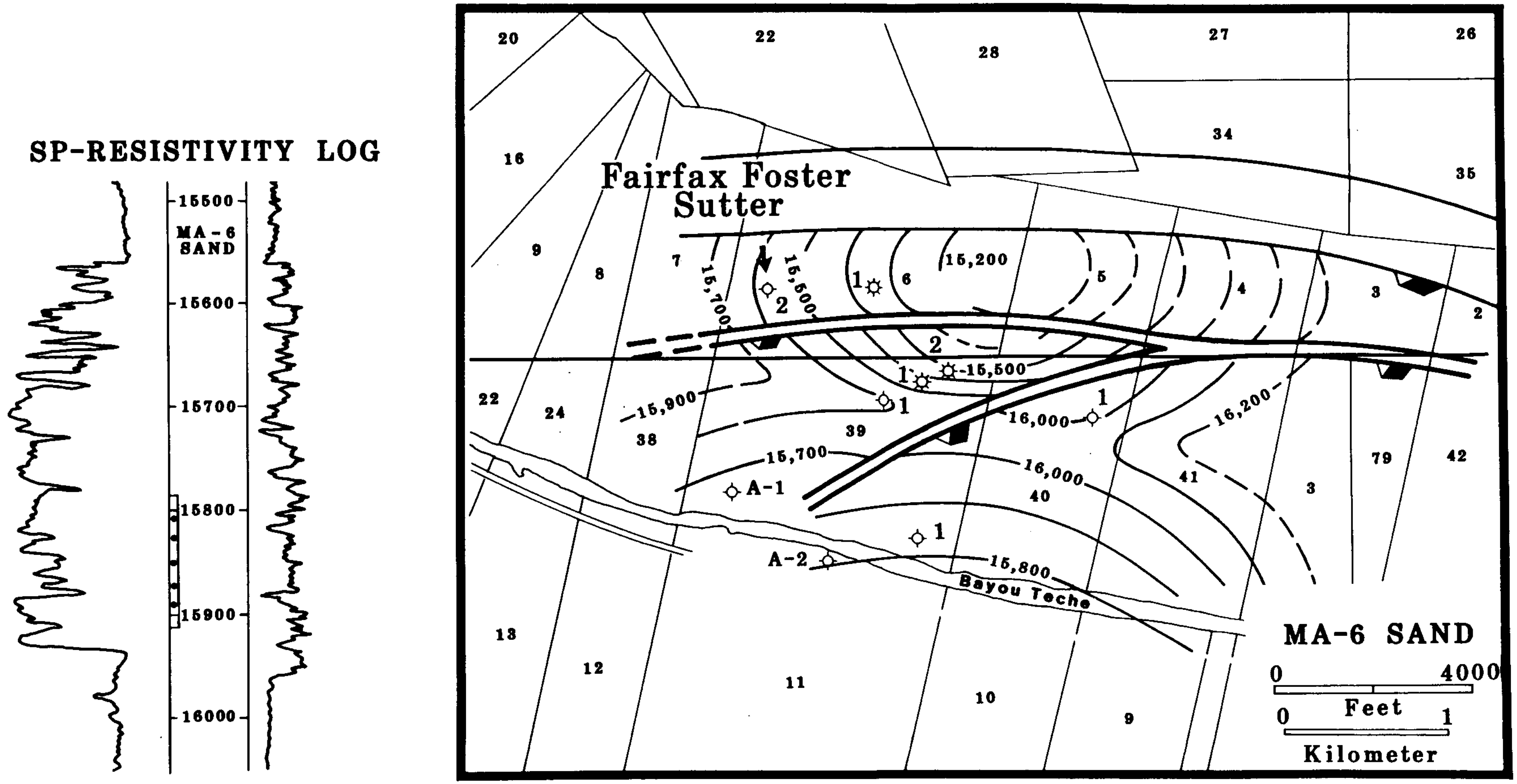

Figure 4. Structure map and log of the Gruy Federal-DOE No. 2 Fairfax Foster Sutter test well (WOO) (modified from Gruy 1979).

porosity averaged 19.3%.

Testing consisted of two flow tests and two buildup tests over 73 days. Pressure transient analysis indicated an effective permeability of 14.3 md. Measured salinity averaged 190,904 mg/l TDS. The maximum flow rate was 7,747 BWPD. This rate could not be sustained, presumably due to the low permeability. Barriers identified by the pressure data confirm the geologic interpretation, placing the well approximately 900 ft and equidistant from two parallel faults. There was no indication of aquifer limits from the test data. Solution gas content showed little variance and averaged 22.8 SCF/bbl. This is near the estimated saturation value of 24.9 SCF/bbl based on recombination tests. Separator gas composition was 89.6 mol% methane, 7.9 mol% CO_2 and approximately 4-7 ppm H_2S. A high concentration of magnesium and calcium salts caused severe scaling problems.

Gruy Federal-DOE #2 Beulah Simon

The Gruy Federal-DOE #2 Beulah Simon well is located in Sec. 26, T11S, R2E, Vermilion Parish, Louisiana (Gruy 1980). This, the third well tested under the WOO program, was offered to DOE by Southport Exploration after the well was abandoned as a dry hole at 15,265 ft T.D. The well was completed in a geopressured Oligocene-age Camerina A sand (Upper Frio) and tested from September to December 1979. Structurally, the well is positioned near the crest of a fault wedge trap in a downdip, synclinal position between hydrocarbon-producing fields (figure 5). The Camerina A section produces gas and condensate in many structures on trend but has only minor production in adjacent Cossinade field.

Beulah Simon #2 penetrated 266 ft net sand in the Camerina A section. The well was perforated at 14,674 ft to 14,770 ft. Original formation pressure at 14,722 ft (i.e., the perforation midpoint) was 13,015 psia, formation temperature 266°F, measured salinity 103,925 ppm TDS. Log-derived porosity varies from 14.5% at the top of the sand section to 22.4% at the base, averaging 17.4%.

The well was tested for 62 days with an average flow rate of 11,000 BWPD maintained throughout the test. The brine is saturated with gas at a value of 24 SCF/bbl. Content of the produced gas is 88.9 mol%

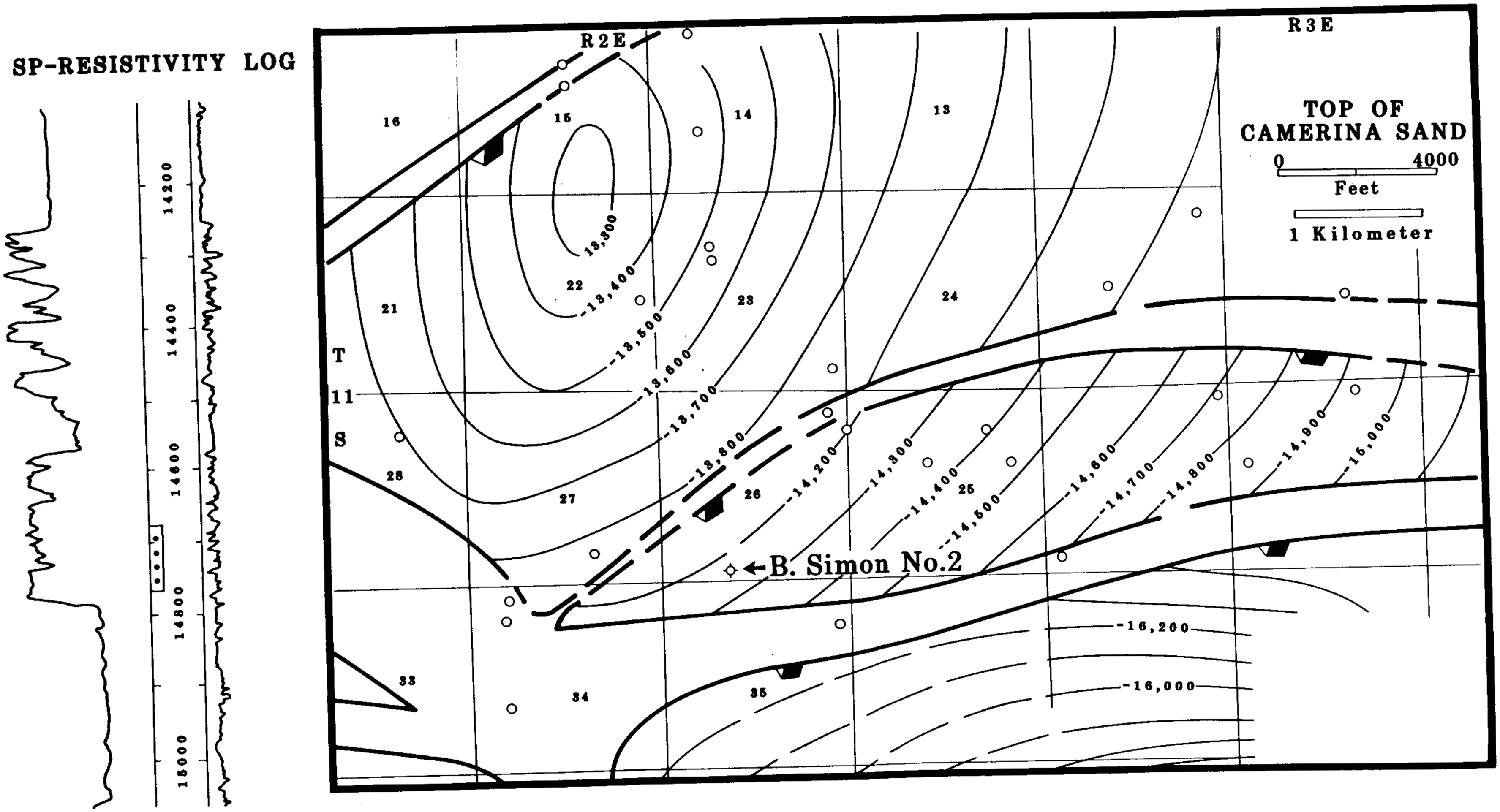

Figure 5. Structure map and log of the Gruy Federal-DOE No. 2 Beulah Simon test well (WOO) (modified from Gruy 1980).

methane, 7.7 mol% CO_2. Effective water permeability is 11.6 md. Pressure transient data identified two permeability barriers (probable faults) at 556 ft and 731 ft from the wellbore. Flow periods were too short to determine the volume of water in the aquifer.

Eaton Operating-DOE #1 P.R. Girouard

The Eaton Operating-DOE #1 P.R. Girouard, a WOO, is located in Cade field, Sec. 10, T11S, R5E, Lafayette Parish, Louisiana (Eaton 1981). Wainoco originally drilled the well to 15,700 ft T.D. for a hydrocarbon prospect and abandoned the well as noncommercial after testing one zone at 12,300 ft. The prospective geopressured sand section is the Marg Tex of the Upper Oligocene Epoch (Upper Frio), interpreted as a lenticular sand body deposited in a barrier bar or strand plain environment (figure 6). Structurally, the well penetrates this horizon in a southwest dipping, downthrown fault block on the southern flank of Cade field. The north bounding fault is approximately 1,200 ft from the wellbore. Fault displacement varies from 100 to 300 ft across the field.

The Marg Tex #1 sand in the P.R. Girouard well is 107 ft gross, 91 ft net sand. Sonic-derived average porosity is 26%. The sand was perforated at 14,744 ft to 14,819 ft. Original formation pressure was 13,203 psia, temperature 274°F, measured salinity 23,500 ppm.

A total of five flow tests were conducted over 15 days. Cumulative production was 41,930 bbl, maximum flow rate 15,000 BWPD and the drawdown permeability 200 to 240 md. The solution gas-to-water ratio was 40 SCF/bbl. Recombination studies yielded a brine saturation value of 44.5 SCF/bbl, indicating the brine is slightly undersaturated. Post-separator gas composition is 91.3 mol% methane, 6.0 mol% CO_2, 2.5 mol% heavy hydrocarbons and 0.2 mol% other. Pressure transient analysis indicated a permeability barrier near the wellbore, restricting the flow angle to less than 50 . This was interpreted as indicating a lenticular sand body geometry. Maximum distance explored was 1,540 ft. It was concluded the well could not sustain flow rates over 10,000 BWPD due to the well's position relative to the lenticular sand body geometry, not because of reservoir sand quality.

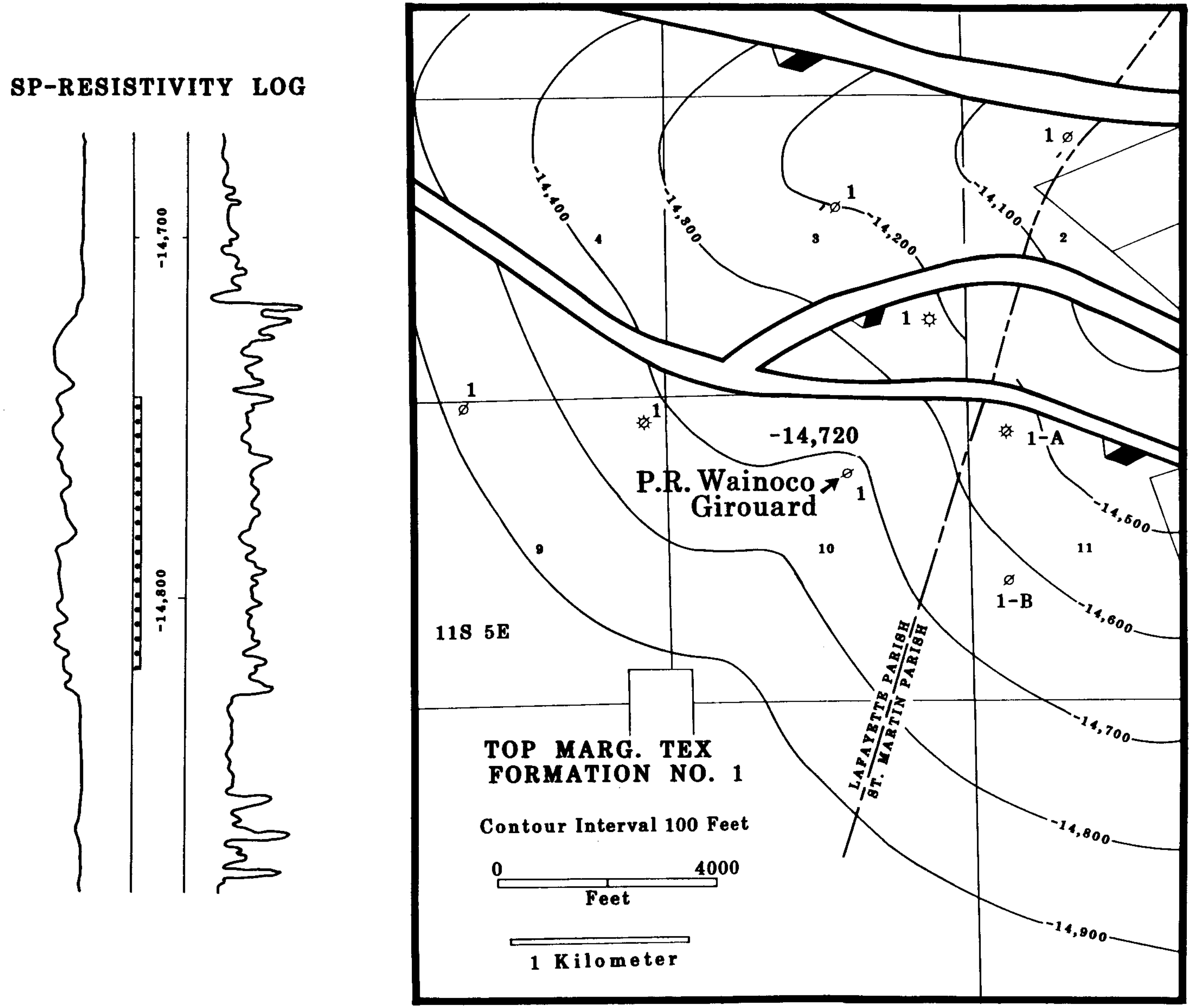

Figure 6. Structure map and log of the Eaton Operating-DOE No. 2 P. R. Girouard test well (WOO) (modified from Eaton 1981).

Eaton Operating-DOE #1 Prairie Canal

The Eaton Operating-DOE #1 Prairie Canal well was tested as a WOO in February and March 1981 (Eaton 1982a). The well is located in Sec. 21, T11S, R8W, Calcasieu Parish, Louisiana. The well was originally drilled to 15,636 ft T.D. and abandoned as a dry hole by Houston Oil and Minerals. The geopressured zone of interest is in the Hackberry section of the Oligocene Epoch (Frio Formation). Hackberry sands in this area occur in a southward thickening sedimentary wedge of deep-water fauna and are interpreted as turbidite deposits. Structurally, the well is positioned near the crest of a southwest-dipping fault trap at the Hackberry horizon (figure 7). A small trapping fault immediately north of the well and a large expansion fault approximately four miles south of the well are the only faults revealed by seismic data.

Initially, a sand was perforated and completed at 14,976 ft to 15,024 ft for flow testing. However, a large amount of sand, shale, gravel, and rocks was produced early in the flow test, and the zone was abandoned. A second sand was perforated at 14,782 ft to 14,820 ft for testing. Log analysis indicated 25 ft gross sand (14 ft net) with a sonic-derived porosity of 22.5%. Original formation pressure was 12,942 psia, formation temperature 294°F, measured salinity 43,400 mg/l TDS.

Four pressure drawdown and three pressure buildup tests were performed within 12 days. Total brine produced was 36,505 bbl. Highest sustained flow rate was 7,100 bbl per day; highest flowing surface temperature was 250°F. Measured solution gas values ranged between 41 and 50 SCF/bbl. A disagreement among investigators concerning the gas saturation value of the brine (43.3 versus 49.7 SCF/bbl) places the brine at or very near saturation. Flare gas content consists of 88.4 mol% methane, 8.4 mol% CO_2, 12-24 ppm H_2S.

Pressure transient analysis detected two permeability barriers restricting the flow angle to 40°. The maximum distance tested was 4,741 ft. This equals an explored brine volume of 22.4 MMbbl or an approximate reservoir area of 885 acres. Reservoir brine permeability is 90 md.

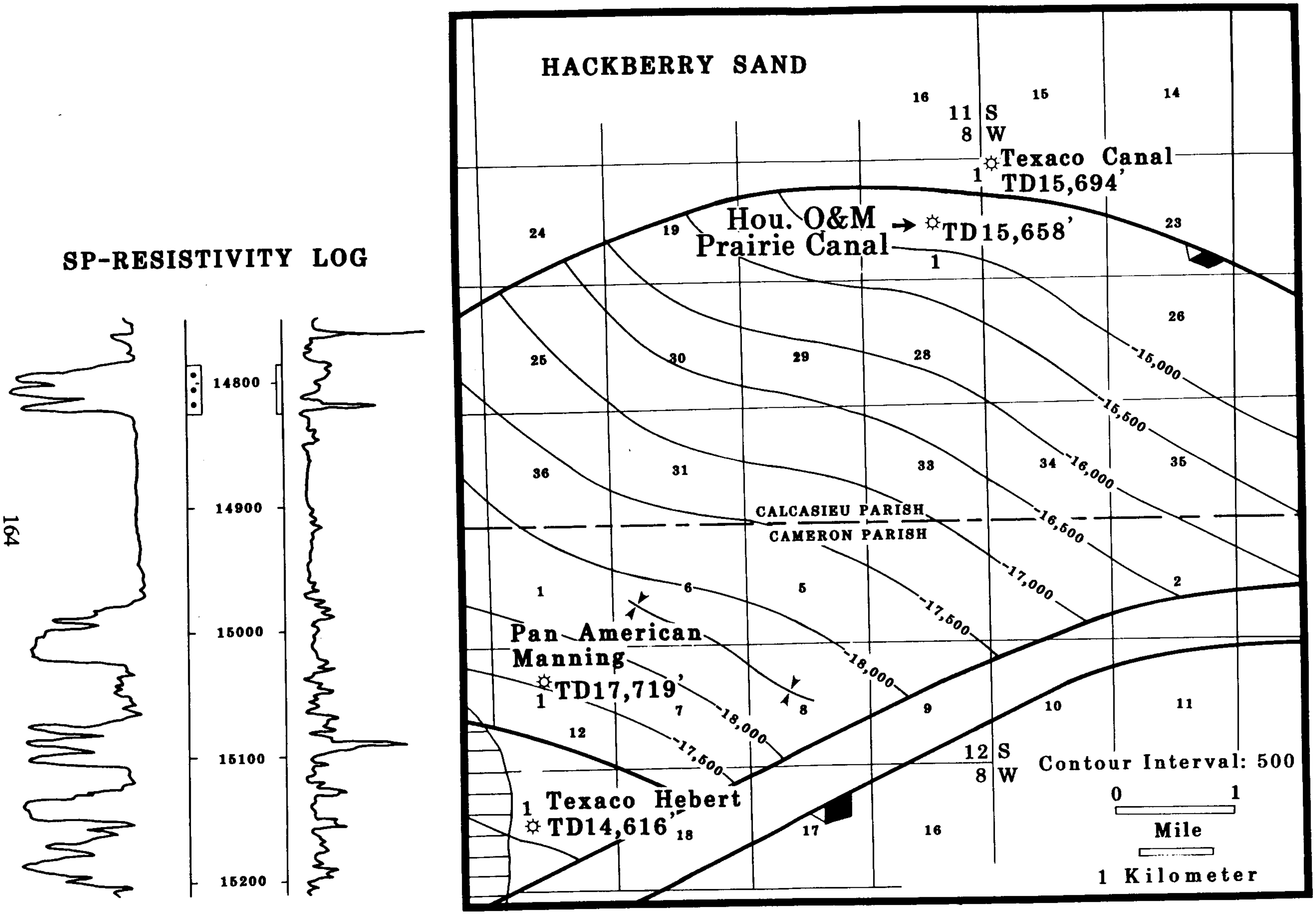

Figure 7. Structure map and log of the Eaton Operatin-DOE No. 1 Prairie Canal test well (WOO) (modified from Eaton 1982a).

Eaton Operating-DOE #2 Crown Zellerbach

The #2 Crown Zellerbach well was acquired by DOE as a WOO after Martin Exploration Co. abandoned the well as a dry hole at 17,000 ft T.D. (Eaton 1982b). The well is located in Sec. 19, T6S, R5E, Livingston Parish, Louisiana. The prospective geopressured section is the Lower Tuscaloosa sands of the Upper Cretaceous. These sands were deposited in highly constructive deltaic systems downdip of the Edwards Reef trend in a fluvial-to-shallow marine environment. A seismic-based structure map places the well between two subparallel-trending faults on the north flank of a faulted anticlinal structure (figure 8). Approximate fault displacements are 900 ft on the north bounding fault and 450 ft on the south bounding fault.

Flow testing was conducted on two sands. A lower sand (sand A) was tested initially for 12 days, then an upper sand (sand B) was perforated and fluids from both zones comingled for two days of flow testing. Sand A is 36 ft gross, 35-ft net sand, log-derived average porosity 17%. This sand was perforated at 16,720 ft to 16,750 ft with 8 HPF. Original formation pressure was 10,114 psia, temperature 330°F, measured salinity 31,700 mg/l TDS. The highest flow rate achieved was 3,887 BWPD. Pressure transient analysis indicated a reservoir permeability of 14.1 md, a permeability barrier at 197 ft and an increase in sand thickness away from the wellbore. Solids production was high at 20 to 190 lb/1,000 BW. Corrosion and scaling were slight. Measured gas in solution was 32.0 SCF/bbl. Flare-line gas content was 71.0 mol% methane, 23.5 mol% CO_2, and 5.0 mol% heavier hydrocarbons. The methane content is low, and the CO_2 content is high relative to the other geopressured test wells.

Sand B was perforated at 16,462 ft to 16,490 ft with 4 HPF. Sand B has 28 ft gross, 23-ft net sand with average log porosity of 13.7%. Original formation pressure was estimated at 10,007 psia, formation temperature 330°F to 324°F.

A two-day flow test was conducted with comingled production from sand A and sand B. Maximum flow rate was 3,000 BWPD, post-separator salinity 29,900 ppm. Solution gas ratio, gas content, and other fluid values showed little change. Solids production with the comingled test was low (7 to 23 lbs/1,000 BW) versus the high solids production associated with the first zone. There was no apparent explanation for the low solids

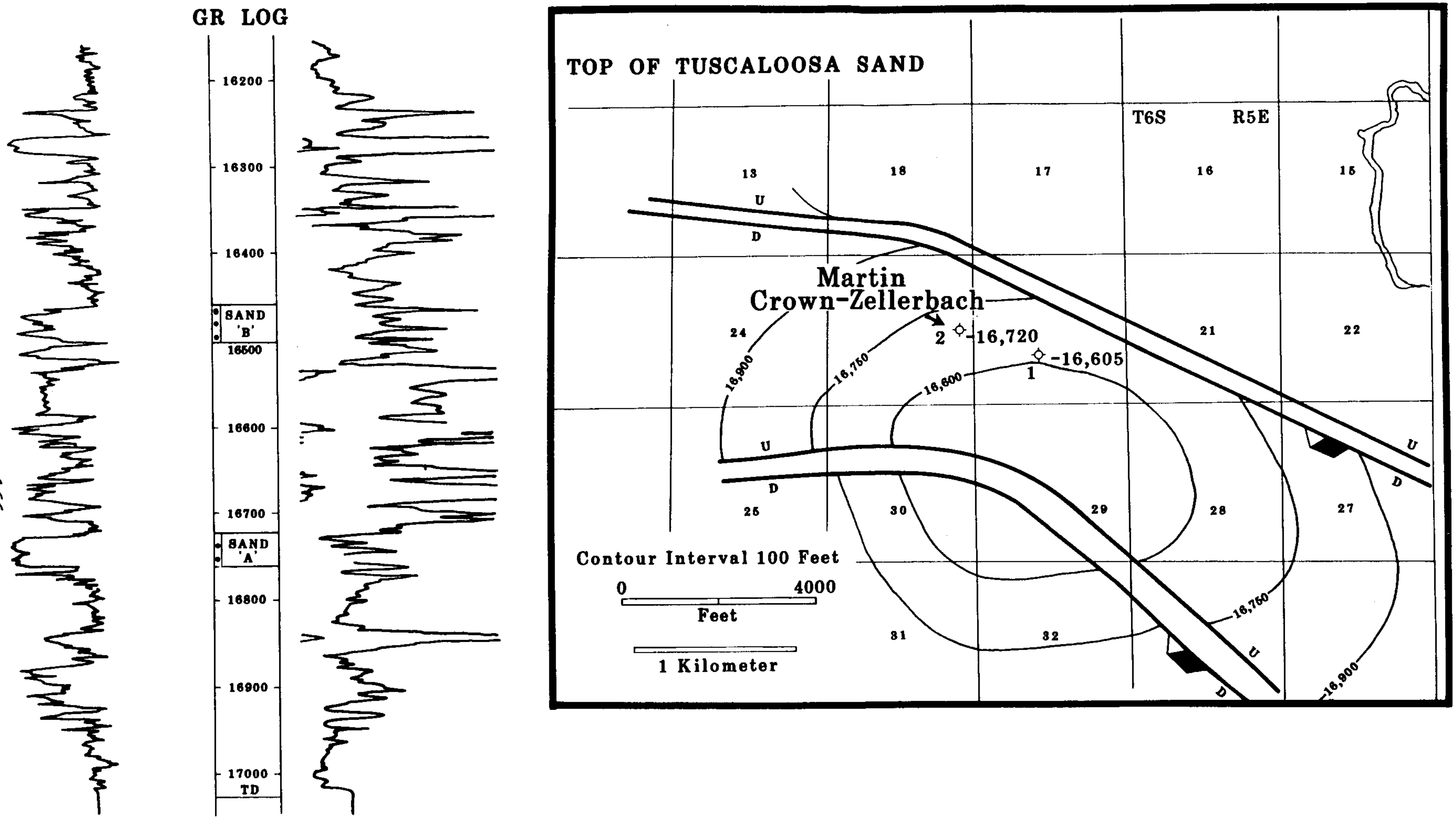

Figure 8. Structure map and log of the Eaton Operating-DOE No. 2 Crown Zellerbach test well (WOO) (modified from Eaton 1982b).

production. The combined flow of both zones was still incapable of sustaining high production rates.

Liquid hydrocarbons were recovered during testing at an average rate of 5.3 liters/MCF. This is a very high production rate for liquid hydrocarbons in the WOO program. Chemical analysis of the recovered liquids indicate the C7 compounds exclusive of toluene are 70-85% cyclic hydrocarbons. This differs from normal crude oil, which usually contains only a small fraction of cyclic compounds. This suggests that the recovered liquid hydrocarbons may have been in solution in the brine and not from a free oil phase.

Extrapolated laboratory data indicated a brine gas saturation value of 55.7 SCF/bbl at reservoir conditions. The recovered gas solubility value of 32.0 SCF/bbl suggests the brine is very undersaturated. However, the combined effects from the relatively high CO_2 and liquid hydrocarbons present in this well may suppress the methane solubility to the extent that the recovered gas solubility values are saturated. This is supported by results from the Koelemay well, Texas, that a volume fraction of $5x10^{-4}$ of produced oil added to NaCl brine increased the bubble point for methane from 9,585 $\pm$35 psi to >10,995 psi at 260°F (Eaton 1982b).

Magma Gulf-Technadril-DOE #1 Amoco Fee

The Magma Gulf-Technadril-DOE #1 Amoco Fee, popularly known as "Sweet Lake," is the first design well tested in Louisiana (Hoffman 1983). The well, located in Sec. 13, T12S, R8W, Cameron Parish, Louisiana, was drilled to 15,740 ft to test the Miogypsinoides section of the Oligocene Epoch (Upper Frio) in a graben structure bounded by east-west-trending faults (figure 9). The east side of the graben is fault bounded, but no structural boundaries are known to the west and northwest. The reservoir dips to the northwest, providing a potentially large geopressured reservoir.

The Miogypsinoides sand was deposited in an outer shelf environment. Approximately 380-ft gross sand is present in the Miogypsinoides sequence in the Amoco Fee #1 well. Conventional core analysis indicates 14 to 24% porosity and air permeability of 4 to 3,670 md (~400 md water permeability). The sand is cemented by quartz overgrowths, and clays are present as fine hairs lining pore throats. Rock mechanics testing suggests rock compaction will have a minimal impact on reservoir pressure maintenance. Geochemical analysis of well

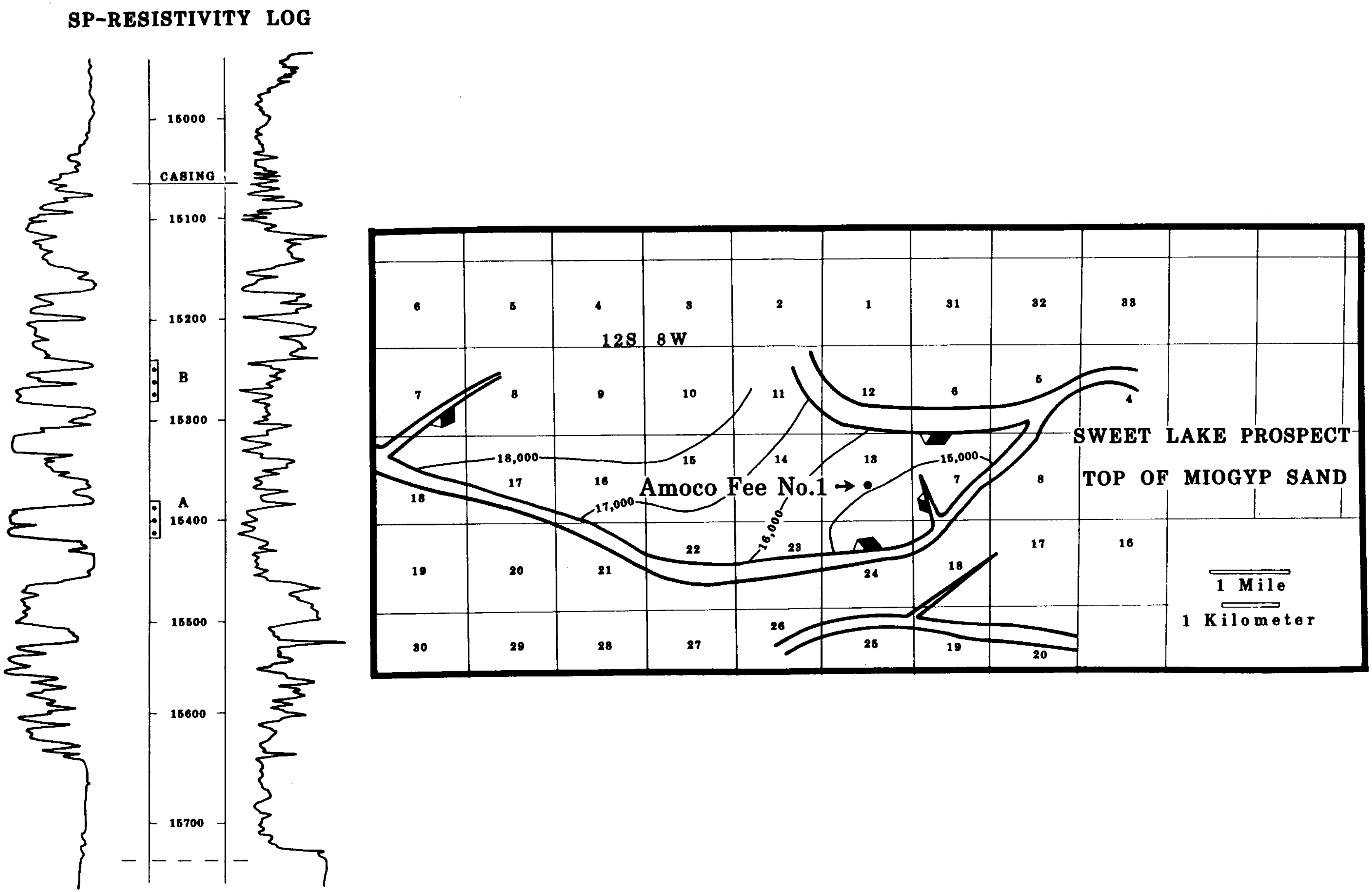

Figure 9. Structure map and log of the Magma Gulf-Technadrill-DOE No. 1. Amoco Fee test well (design well) (modified from Hoffman 1983).

cuttings samples indicates that shales are immature and could not have produced petrogenic methane locally.

Two zones were flow tested. The first zone, perforated at 15,387 ft to 15,414 ft, began testing June 19, 1981, and ended February 10, 1982, when the disposal well sanded up. Cumulative production was 1.2 MMBW + 24 MMCFG. Production-derived reservoir permeability was 339 md, salinity 160,000 ppm TDS, temperature 298°F. Maximum flow rate achieved was 34,000 BWPD, but the average flow rate was 6,824 BWPD. Recovered solution gas was 88.7 mol% methane, 8.6 mol% CO_2, and 2.6 mol% other gases. Measured brine solution gas values were 25-28 SCF/bbl. Recombination studies yielded a solution gas saturation value of 34 SCF/bbl indicating the brine is undersaturated. However, experimental gas saturation curves and analyses by the Institute of Gas Technology indicate that the produced brine is saturated at the produced values of 25-28 SCF/bbl. Therefore, it is uncertain whether the brine is saturated.

The second zone, perforated at 15,245 ft to 15,280 ft, was flow tested for three months. Cumulative production was 349,000 BW at an average flow rate of 2,684 BWPD. Brine chemistry and gas composition were similar for both zones.

Pressure transient analysis identified two production barriers at 452 ft and 1,753 ft from the wellbore. These barriers were interpreted as possible pinchouts, thinning, a permeability decrease, or minor faulting, but not as the major sealing graben faults. A flow angle of 25° was indicated with the reservoir open in one direction for at least four miles. This agrees with the structural interpretation of a graben, fault bounded to the east. The low sustained flow rates are due to the restricted 25° flow angle.

Dow-DOE #1 L.R. Sweezy

The Dow-DOE #1 L.R. Sweezy is a design well located in Parcperdue field, Sec. 26, T11S, R4E, Vermilion Parish, Louisiana (Hamilton and Stanley 1983). Dow Chemical Co. proposed drilling the well in a small, restricted, well-defined fault block. The objective was to produce a small, geopressured reservoir to near depletion to determine the production characteristics of the geopressured resource. The well was drilled to 13,600 ft T.D. and completed July 1, 1981.

The objective sand is in the Cibicides Jeffersonensis (Cib. Jeff.) section of the Upper Oligocene Epoch. Although the Cib. Jeff. section has produced both gas and oil elsewhere in the field, Parcperdue field is mainly gas productive with most of the production from older Camerina-age sands.

The Cib. Jeff. sand is a ~50-ft sand body interpreted as a lenticular offshore barrier bar feature overlaid by ~1,300 ft of marine shale and underlaid by ~3,000 ft of marine shale (figure 10). Analysis of 120 ft of conventional core indicated that the sand could be divided into two zones. The lower zone (13,391 to 13,424 ft) is 28% porosity with 20 md fluid permeability. This low permeability is due to high amounts of detrital clays in the pore throats. The upper zone (13,343 to 13,391 ft) is 30% porosity with 100 to 1,000 md fluid permeability. The higher permeability is the result of a larger grain size and the development of secondary porosity. A gravel-pack completion was performed on this well due to some unconsolidated sand layers in the conventional core. This is the only test well to utilize a gravel-pack completion. An analysis of shale samples indicates that the bounding shales are immature, capable of having produced only a small amount of biogenic methane.

Structurally, the well was drilled in a triangular shaped fault block completely bounded by faults. The well is downdip of a structural crest in this fault block, tested wet in the Cib. Jeff. sand by a previous well (Phillips #1 Denais). Structural control for the interpretation is considered excellent, and includes well logs, existing seismic lines, and a 3-D seismic survey acquired under contract to DOE. The bounding faults have displacements of 150 ft to over 500 ft and, with the adjacent marine shales, should provide excellent seals.

Eleven drawdown and buildup tests were conducted. Cumulative production was 1.9 MMBL + 31.5 MMCFG. Original formation pressure was 11,410 psi at 13,395 ft, formation temperature 237 °F. Solution gas values for the produced brine averaged 20 SCF/bbl, brine salinity 99,700 mg/lTDS. PVT analysis indicated a gas saturation value of 30 SCF/bbl, therefore the brine is undersaturated. Gas composition was methane 94%, ethane 2.5%, CO_2 2.5%, other 1%. Persistent sand production limited flow rates to <10,000 BPD. The well was plugged and abandoned after massive sanding in February, 1983, and was deemed irreparable.

Permeability at the original reservoir conditions was ~1 darcy. Calculated absolute open flow rate is

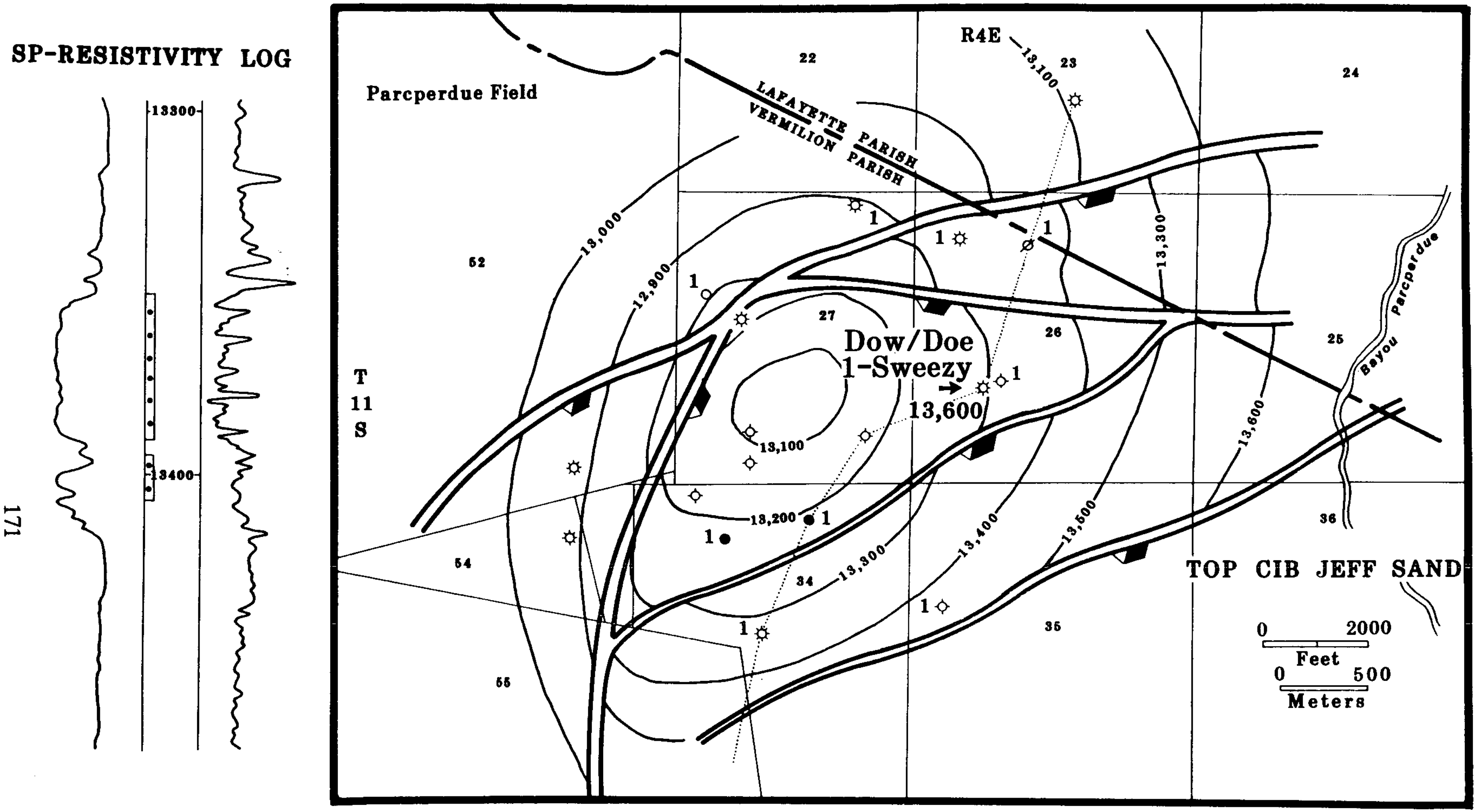

Figure 10. Structure map and log of the Dow-DOE No. 1 L. R. Sweezy test well (design well) (modified from Hamilton and Stanley 1983).

40,000 BPD. Total water in place was 97 MMBL. Total depletion performance is estimated as >3,800 bbl/psi. Estimated contributions from shale dewatering (22 bbl/psi) and edge influx (184 bbl/psi) were minimal compared to total performance. The ultimate predicted recovery for this reservoir is 11 MMBL + 184 MMCFG over 3.7 years for abandonment at bubble point (8,550 psi) and a flow rate of 8,500 BPD.

Highly aromatic liquid hydrocarbon condensates were noticed early during production testing. Liquid hydrocarbon production increased over the test period with heavy oil production occurring about one month before the well was abandoned. Estimated condensate ratios were 15 ml/MCF. These aromatic condensates were distinctly different from natural gas well condensates producing from the same reservoirs but fault separated from the L. R. Sweezy well. Dow researchers hypothesized that the produced geopressured brine was still in contact with a liquid petroleum phase to allow the equilibration and partitioning of hydrocarbon compounds. Aromatic hydrocarbon compounds are generally more soluble in water than aliphatic compounds with an equal number of carbon atoms (i.e., benzene C_6H_6 vs. hexane C_6H_{14}). This probably accounts for the high concentration of aromatic hydrocarbons in the brine.

Reservoir rock compressibility was discovered to be the principal drive mechanism. Of the total available aquifer drive energy, 89.7% is due to rock compaction and 10.3% from in-situ water expansion. The unusually high rock compressibility of this reservoir was much greater than anticipated and varied as a function of pressure. Rock compressibility is estimated to account for 94% of the total available energy. However, formation compaction may alter the final flow performance of the reservoir and therefore the final recovery.

Technadril-Fenix and Sisson-DOE #1 Gladys McCall

The Gladys McCall prospect was drilled as a design well in 1981 (Technadril 1986). The Technadril-Fenix and Sisson-DOE #1 Gladys McCall, T.D. 16,510 ft, is located in Cameron Parish, Louisiana, Sec. 27, T15S, R5W. A comprehensive summary has also been provided by John (1988).

Approximately 1,150-ft net sand is present in the Cristelleria A section of the Lower Miocene Epoch in the #1 Gladys McCall well (figure 11). These sands are interpreted as distributary channel sands deposited

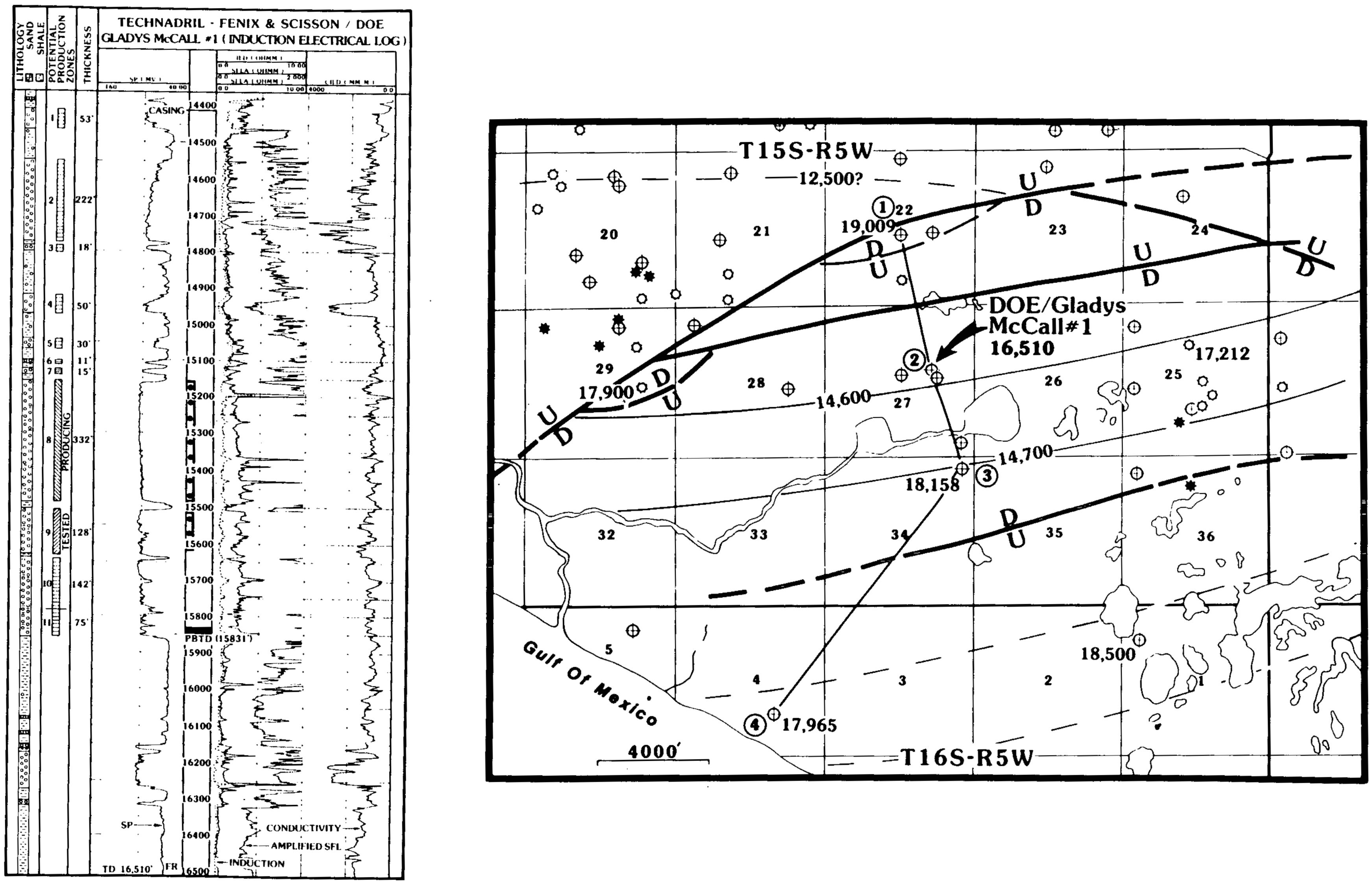

Figure 11. Structure map and log of the Technadrill-Fenix and Sisson-DOE No. 1 Gladys McCall test well (design well) (modified from John 1988).

in a shelf environment. Core analysis indicates that the sand is mainly fine grained, well consolidated, and silica cemented.

The structure at the Cristelleria A horizon is interpreted as south-to-southeast dip bounded to the north by northeast-trending, south-dipping faults. The structure is poorly defined due to sparse well control and limited seismic data. Additional seismic data has been obtained in an effort to clarify the structural setting.

Two zones were flow tested. The first zone, perforated at 15,508 ft to 15,636 ft, produced 119,000 BW + 3.4 MMCFG. Average porosity was 24%, permeability 90 md, temperature 298°F, original formation pressure 12,936 psi, measured salinity 95,500 ppm TDS. The dissolved gas content was 32 SCF/STB.

Long-term flow testing was performed on the second zone, perforated at 15,158 ft to 15,490 ft. This zone was flow tested from December 1983 to October 1987. Average porosity was 22%, permeability 130 md, temperature 288°F, original formation pressure 12,821 psi, measured salinity 94,000 ppm TDS, and dissolved gas content 31 SCF/STB. Gas composition, similar for both zones, was 85.9 mol% methane, 10.6 mol% CO_2, and 3.5 mol% other gases. Cumulative production totaled 27 MMBW + 676 MMCFG without a significant decline in bottom-hole pressure.

The well was flow tested at various rates from 5,000 to 36,500 BWPD, averaging 20,000 BWPD. The well is considered capable of producing 19,000 BWPD at a constant pressure. The flow rate is limited by frictional pressure loss in the 5-inch tubing. The well may be capable of producing 50,000 BWPD or more with larger diameter tubing.

An accumulation of oil was noted in the brine after the well had produced 6.6 MMBW. The oil concentration in the brine was 24-28 ppm after discovery and decreased to 3-4 ppm. Trace amounts of oil were recovered during periods of high flow, but no oil was recovered during low rates of flow or immediately after the well had been shut in. The oil was light amber in color, very waxy (65% paraffin), 32.9 API gravity, pour point 90°F, flash point 330°F, and would hardly burn. It was interpreted to be from the adjacent shales, possibly expulsed during the pressure drawdown.

The Gladys McCall geopressured-geothermal test is the most successful test to date in terms of sustained flow duration, sustained flow rate, and cumulative production. The well performed much better than was predicted by engineering and reservoir modeling studies. Research is continuing to define the reservoir structure and monitor surface subsidence and environmental impact. Coring of the reservoir is planned before abandonment of the well to investigate changes from pre-production conditions.

SUMMARY OF RESULTS AND DISCUSSION

The DOE-sponsored, geopressured-geothermal research projects have provided a wealth of data characterizing the reservoir properties, fluid composition, flow behavior, and engineering challenges of this resource. The WOO program provided a low-cost means of evaluating geopressured reservoirs of various ages in various geographic locations. However, because these wells were originally drilled for hydrocarbon exploration prospects, they are often located in restricted structural positions---a poor location for geothermal test wells. Therefore, high flow-rate capability was not a research objective of the WOO program. The design well program allowed for the long-term testing of selected geopressured-geothermal prospects. This provided data on the sustained high-volume deliverability of the geopressured-geothermal reservoirs essential for the practical application and utilization of the resource.

Nine geopressured-geothermal wells (six wells of opportunity and three design wells) have been tested under DOE sponsorship in south Louisiana. Tested formations range from Lower Cretaceous to Lower Miocene age and 12,573 ft to 16,720 ft in depth. Test well locations are illustrated in figure 2. Test results are provided in table 1.

Formation brine temperatures varied from 234°F to 330°F. A temperature vs. depth plot of the nine test wells shows temperature gradients of 1.3 to 1.7°F/100 for the geopressured formations tested (figure 12). This agrees with regional geothermal gradients in the northern Gulf of Mexico basin.

Maximum brine flow rates range from 3,887 BPD to 36,500 BPD. The wide range is due to the generally restricted nature of the reservoirs tested in the WOO program, the diversity of reservoir properties, tubing restrictions, and sand production problems. Sustained flow rates for extended periods of time were acquired

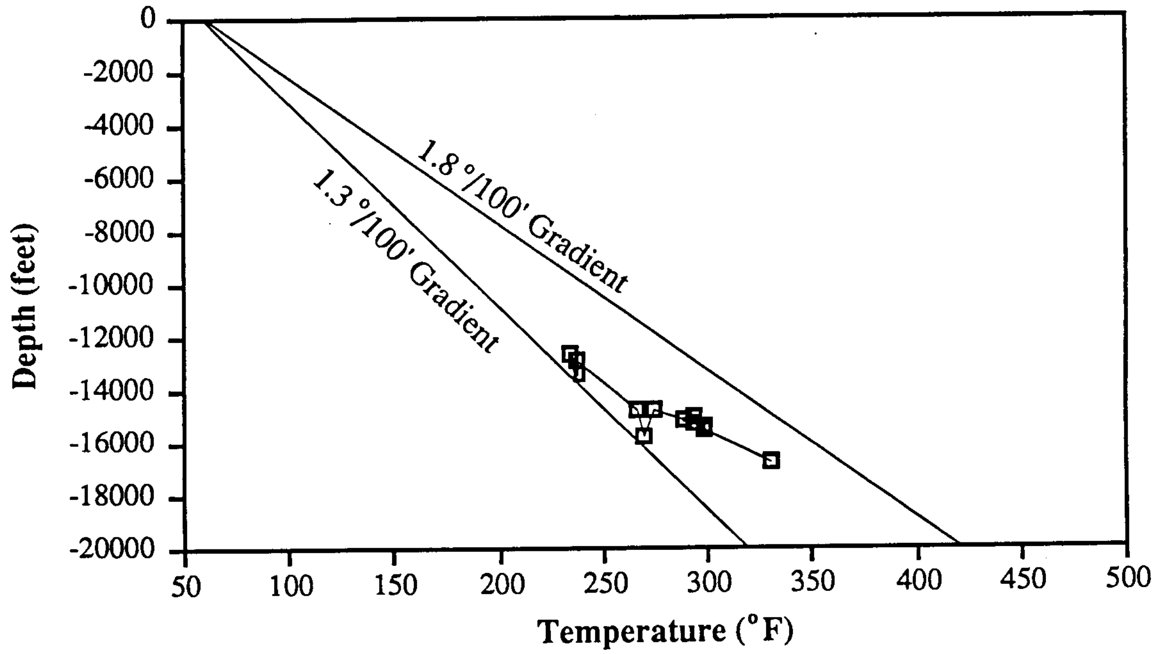

Figure 12. Temperature-depth plot of tested geopressured-geothermal reservoirs.

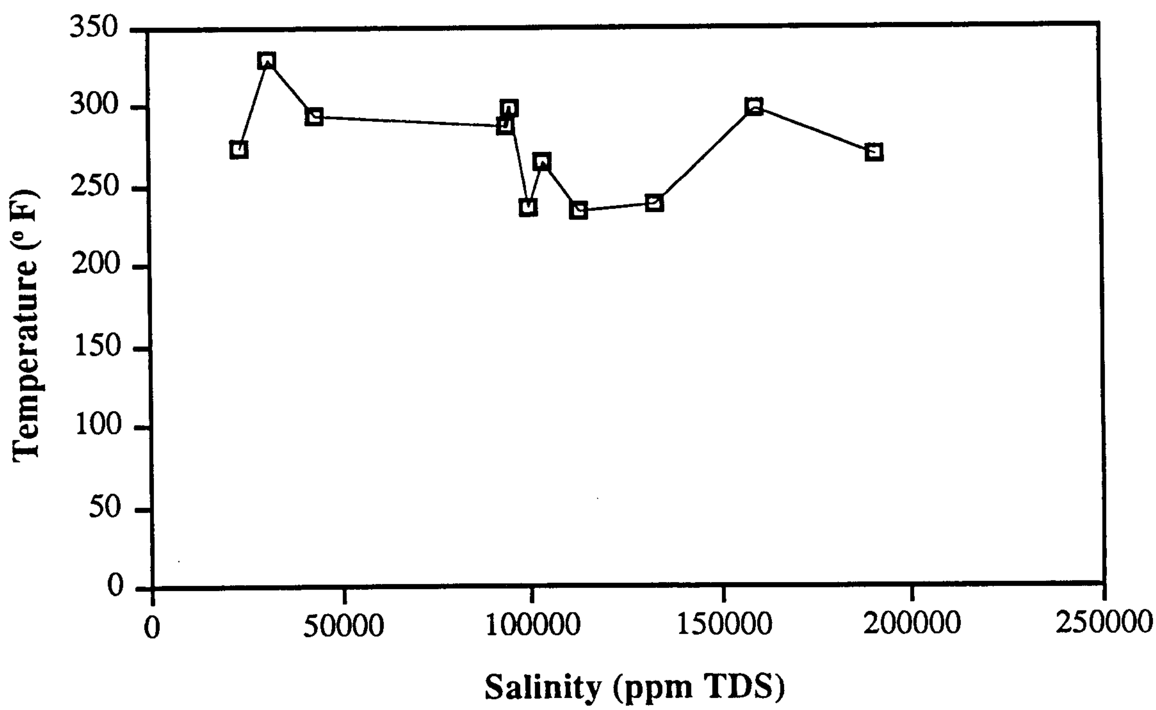

Figure 13. Salinity-temperature plot of tested geopressured-geothermal reservoirs.

Table 1. Summary of test results from the DOE-sponsored geopressured-geothermal test wells.

Well Name	Depth (ft)	Pressure (psi)	Temperature (°F)	Salinity (ppm TDS)	Dissolved Gas (SCF/bbl)	Gas Saturation (SCF/bbl)	Flow Rate (BPD)	Methane (mol%)	CO_2 (mol%)	Other Gases (mol%)	Porosity (%)	Permeability (mD)
Delcambre 3sd	-12,869	11,012	238	133,300		24.0	10,333	92.8	1.1	6.1	26.0	44.0
Delcambre 1sd	-12,573	10,858	234	113,000		24.0	12,653	95.4	2.0	2.6	29.0	364.0
F.F. Sutter	-15,781	12,220	270	190,904	22.8	24.9	7,747	89.6	7.9	2.5	19.3	14.3
Buelah Simon	-14,722	13,015	266	103,925	24.0	24.0	11,000	88.9	7.7	3.4	17.4	11.6
P.R. Giroud	-14,744	13,203	274	23,500	40.0	44.5	15,000	91.3	6.0	2.7	26.0	220.0
P. Canal	-14,976	12,942	294	43,400	45.0	47.0	7,100	88.4	8.4	3.2	22.5	90.0
C. Zellerbach	-16,720	10,144	330	31,700	32.0	55.7	3,887	71.0	23.5	5.5	17.0	14.1
Sweet Lake A	-15,387	11,974	298	160,000	26.5	34.0	34,000	88.7	8.6	2.6	20.0	400.0
Sweet Lake B	-15,250	11,794	293									
Parcperdue	-13,395	11,410	237	99,700	20.0	30.0	10,000	94.0	2.5	3.5	29.4	500.0
Gladys McCall A	-15,508	12,936	298	95,500	32.0	30.4	36,500	86.9	9.5	3.6	24.0	90.0
Gladys McCall B	-15,158	12,821	288	94,000	31.0	30.4	36,000	85.9	10.6	3.5	22.0	130.0

only for the three design wells. Of these, the Gladys McCall well provided the highest sustained flow rate, 19,000 BPD. A theoretical unrestricted flow rate of 50,000 BPD has been calculated for the Gladys McCall well given a larger production tubing string. The Amoco Fee well could only sustain a 6,824 BPD average flow rate because of a restricted reservoir. The Parcperdue design well was held at a flow rate below 10,000BPD due to sand production problems.

Salinity values exhibited a wide variation, from a low of 23,500 ppm TDS to 190,904 ppm TDS. Typically, salinity increases with depth in normal hydrostatic pressured sediments, reaching a maximum just above the geopressured zone (Bebout and Gutierrez 1981). In geopressured sediments, salinity values may be highly variable. A plot of temperature vs. salinity shows no distinct trend among the geopressured-geothermal test wells (figure 13). Factors that influence the salinity of formation fluid include aquifer size; the nature, spacing, and movement of fluid along bounding growth faults; fluid explusion from adjacent shale beds; and the proximity of salt intrusions.

The CO_2 content of recovered solution gas shows a dramatic increase with increasing temperature (figure 14). This increase coincides with a decrease in methane content. Figure 15 further illustrates the increase in CO_2 and a corresponding decrease in methane content with an increase in temperature, whereas the content of other minor gases remains relatively constant. This relationship agrees with experimental and field data showing that CO_2 content of formation waters in the Tertiary Gulf Coast increases with temperature, CO_2 being liberated from the thermal cracking of kerogen. As CO_2 concentrations exceed 10 mol% of total gas in solution, methane solubility is suppressed (Price et al. 1981).

Measured gas in solution values ranged from 20 SCF/bbl in the Delcambre and Parcperdue wells to 50 SCF/bbl in the Prairie Canal well. A plot of gas in solution versus salinity shows a general decrease in solution gas values with an increase in salinity (figure 16). This agrees with laboratory studies of methane solubility which indicate a decrease in solubility with an increase in salinity (Price et al. 1981).

Gas saturation values for produced brines are listed in table 1. Gas saturation values for the test wells range from 22 to 55.7 SCF/bbl. Most of the test wells contained solution gas at values that approximate

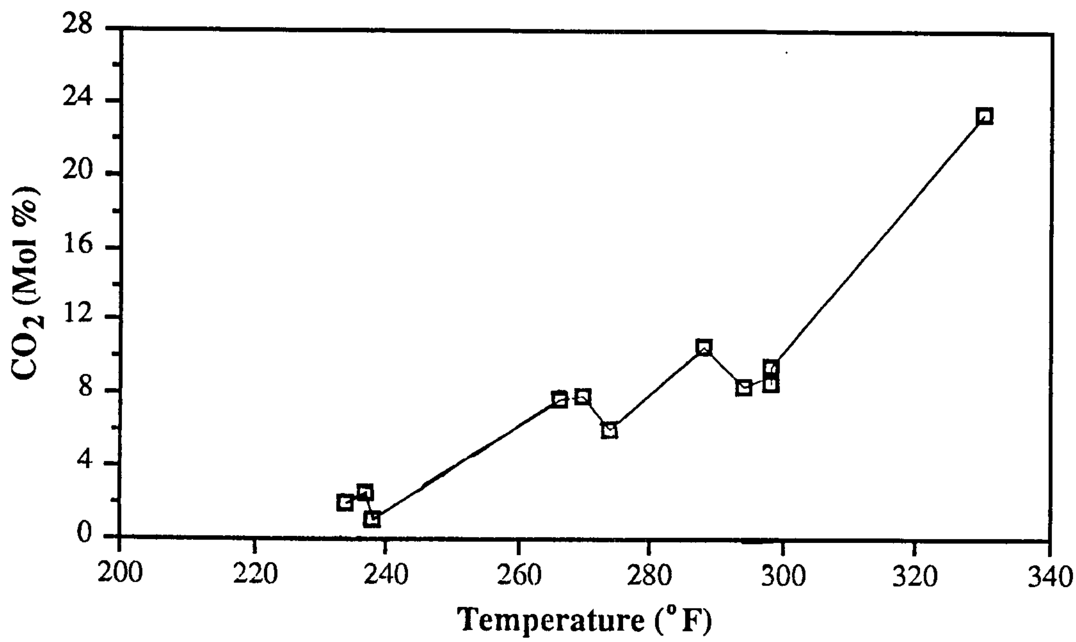

Figure 14. Temperature vs. CO_2 content of recovered solution gas.

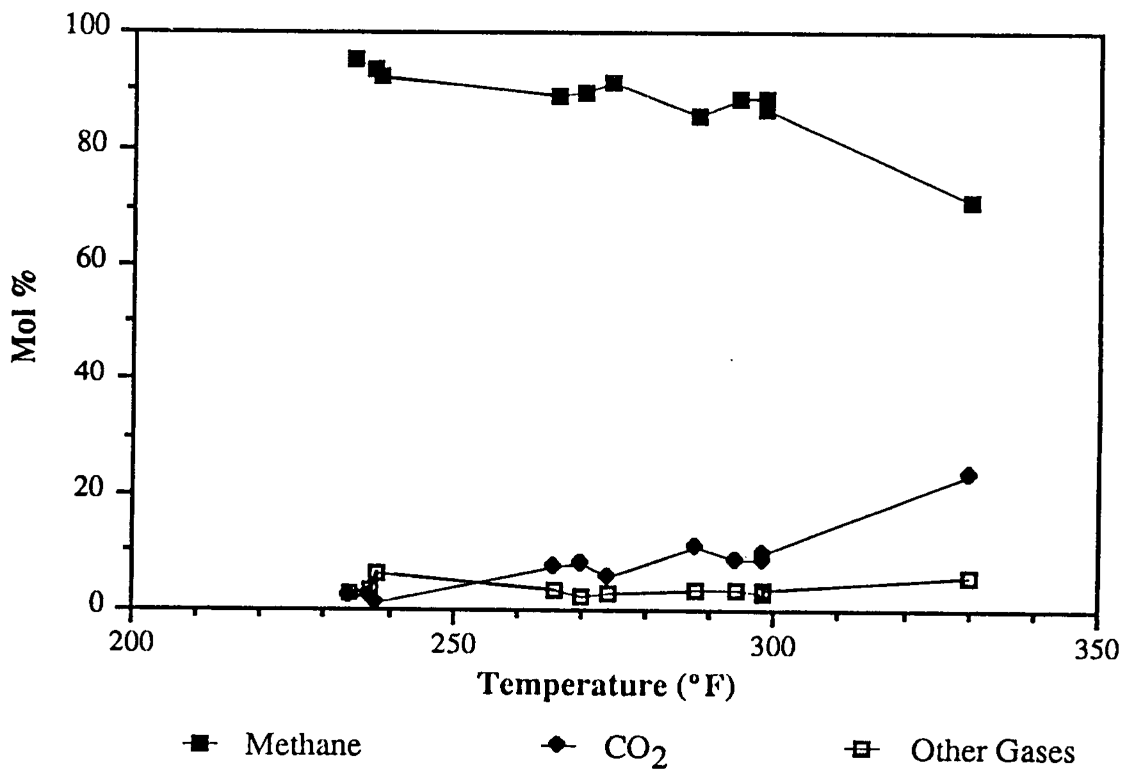

Figure 15. Temperature vs. composition of recovered solution gas from geopressured-geothermal reservoirs.

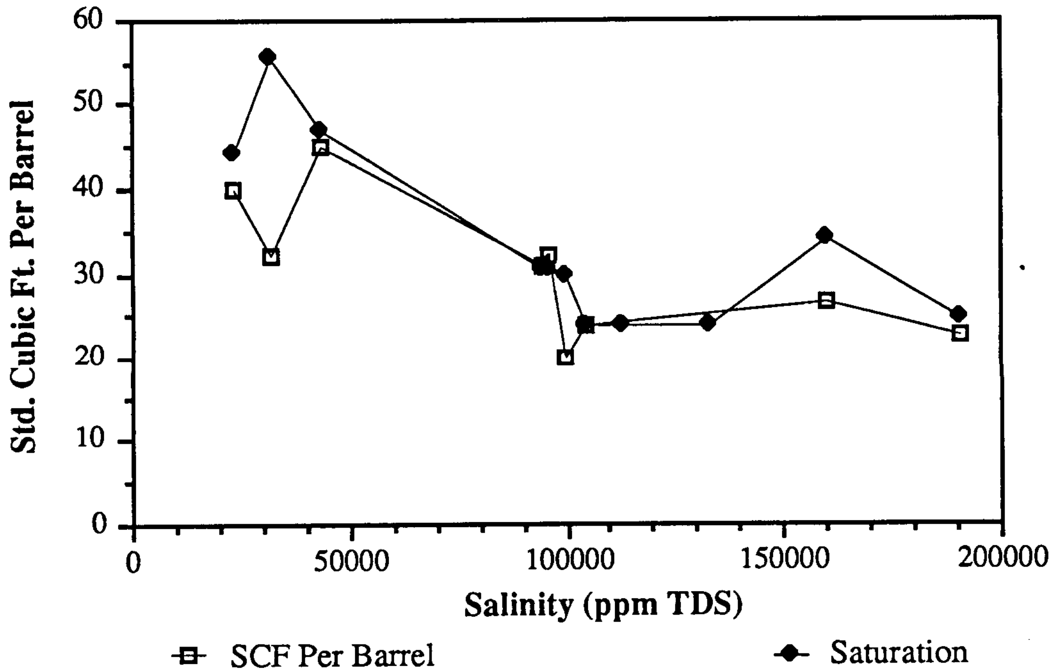

Figure 16. Measured gas in solution vs. salinity for tested geopressured-geothermal reservoirs.

saturation. Only three wells had brines that were considered undersaturated: the Parcperdue, P. R. Girouard, and the Crown Zellerbach wells. The Zellerbach well exhibited the widest divergence with a solution gas value of 32 SCF/bbl vs. a saturation value of 55.7 SCF/bbl. However, each of these wells reported the presence of heavy hydrocarbons, which may affect methane solubility. The investigators at the Zellerbach well claim the combined effects of liquid hydrocarbons and the high CO_2 values may have altered the methane solubility to the extent that the observed gas in solution values are at saturation levels. These investigators cited a previous study which indicated that adding a volume fraction as small as $5x10^{-4}$ of produced oil to NaCl brine increased the bubble point for methane from 9,585 35 psia to >10,995 psia at 260 °F (Eaton 1982b). This mechanism, whereby minute amounts of liquid hydrocarbons could alter the solubility of methane in NaCl brine, may explain the discrepancies between the observed solution gas values and the gas saturation values for many of the geopressured-geothermal test wells.

Liquid hydrocarbons were observed in several of the test wells. Small amounts of condensible hydrocarbon liquids (CHLs) were recovered from the Zellerbach, Prairie Canal, Parcperdue, Amoco Fee, and Gladys McCall wells. Production of CHLs generally varied during flow testing with production rates from 15 ml/MCF at Parcperdue to 5 l/MCF at the Zellerbach well. The CHLs recovered were similar for each well, even though the test wells represented a broad spectrum of reservoirs and geographic locations. The CHLs sampled are largely aromatic compounds, typically benzene, toluene, ethylbenzene, xylenes, and up to 90 additional compounds. These compounds differ markedly from natural gas well condensates, which are typically aliphatic compounds. The origin of the CHLs is unknown, but the similarity of the CHLs recovered on essentially a basinwide scale suggests a common geochemical process for their production (Keeley and Meriwether 1985).

Liquid hydrocarbons, present as a heavy oil fraction, were noted from the Parcperdue and Gladys McCall wells. Only a small amount of oil was recovered from the Parcperdue well one month before a sand failure forced its abandonment. This sample was described as a heavy, dark, highly paraffinic oil. Oil production was first noted at the Gladys McCall well only after the cumulative production of 6.6 MMBW.

This oil was light amber in color, very waxy, 32.9 degree API gravity, and would hardly burn (Technadril et al. 1986). After discovery, the oil concentration in the brine was 24-28 ppm and decreased to 3-4 ppm. No oil production was noted for a period of time after the well had been shut in. The origin of the heavy oil recovered from the Parcperdue and Gladys McCall wells is not known. Possible mechanisms cited are remobilization of dead or irreducible oil in the formation, oil coning from thin layers, soluble hydrocarbons in the brine, and oil from adjacent shales during periods of pressure drawdown (Hamilton and Stanley 1983; John 1988).

Generally, in-situ formation water expansion is the principal drive mechanism for the tested geopressured-geothermal reservoirs. Rock compaction, originally anticipated to be a major contributing factor, is relatively minor and generally on the order seen in normally pressured reservoir rocks (McDonald and Peters 1981). However, there are two important exceptions: the Parcperdue and the Gladys McCall wells.

Rock compressibility was found to be much greater than anticipated at the Parcperdue design well, contributing approximately 94% of the totalreservoir drive energy. Inconsistent results from pressure transient analysis and additional modeling led to the realization that reservoir compressibility was much greater than anticipated and varied as a function of pressure. The high reservoir compressibility increased the expected ultimate recovery several times (Hamilton and Stanley 1983). Rock compressibility was not identified as a significant reservoir drive mechanism in the previous geopressured test wells. Reservoir rock mechanics testing at the Amoco Fee well indicated only a minimal contribution to pressure maintenance from rock compaction (Hoffman 1983). Clearly, rock compaction can be an effective, yet reservoir-dependent, drive mechanism.

The sustained production flow rate and cumulative production from the highly successful Gladys McCall well far surpassed predictions based on reservoir engineering and modeling studies. The principal drive mechanism to account for this production is still unknown. Possible contributing factors are recharge from a remote reservoir and/or fluid flow across growth faults, crossflow recharge from overlaying and underlaying sands and shales, and presence of a remote gas cap to increase the effective compressibility of the reservoir fluid (Technadril et al. 1986).

CONCLUSIONS

The DOE design well and well of opportunity programs have provided the first practical data on the geopressured-geothermal resource in the northern Gulf of Mexico basin.

1. The geopressured-geothermal resource has proven capable of producing gas-saturated brines at temperatures near 300°F at flow rates of 20,000 BPD for periods of several years. Theoretical production flow rates approaching 50,000 BPD are possible with sufficient size tubing.

2. Salinity is highly variable in geopressured sediments, ranging from 23,500 to 190,904 ppm TDS. The mechanisms that control formation fluid salinity are not fully understood.

3. The CO_2 content of recovered solution gas is 2.5 to 23.5 mol%. The CO_2 content increases with temperature and results in a corresponding decrease in dissolved methane content.

4. Measured gas in solution ranges from 20 to 50 SCF/bbl, with methane the principal component.

5. Gas-saturated brines were recovered from all but three of the test wells. The three wells with undersaturated brines also reported the presence of small amounts of heavy hydrocarbons. Minor amounts of oil in brine raises the bubble point of methane significantly, therefore observed solution gas values for the three wells also may be at saturation levels.

6. Liquid hydrocarbons, present in several test wells, are insignificant as an energy resource. The origin of the liquid hydrocarbons is unknown.

7. In-situ formation water expansion is the principal reservoir drive mechanism. However, reservoir rock compressibility provides up to 94% of the total drive energy at the Parcperdue test well and additional drive mechanisms are possible.

Efficient recovery of solution gas is possible with current separator technology. Brine temperatures, although low (~300°F), can provide energy with current low temperature binary cycle converters (Lombard and Wallace 1987). Conversion of the hydraulic pressure energy via pressure turbines has also been demonstrated to be a contributing energy source (Swanson et al. 1986). However, with current technology and economic conditions, the geopressured-geothermal resource is potentially feasible only in multi-use applications where a combination of on-site electricity generation, geothermal, and natural gas utilization is necessary to compete with present and forseeable energy costs.

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