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SUBSURFACE AND SEISMIC INVESTIGATION

OF THE GEOPRESSURED-GEOTHERMAL
POTENTIAL OF THE ABBEVILLE AREA
OF SOUTH LOUISIANA

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MASTER

MHP

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ABSTRACT

SUBSURFACE AND SEISMIC INVESTIGATION OF THE
GEOPRESSURED-GEOTHERMAL POTENTIAL OF
SOUTH LOUISIANA
PART I: THE ABBEVILLE AREA

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The structure investigated is a basin roughly bounded by the Abbeville Dome on the West, the Erath Dome on the Southeast and the Grosse Isle Dome on the Northeast and whose center is located at approximately Section 31 T14S R4E. The geopressured sands investigated are below approximately 12,800 feet (3,901 M) in the center of the basin and consist of two groups of rather thin, discontinuous, marly sands. These two groups, rather arbitrarily defined, are termed the upper and lower geopressured sands and the following map types and analyses have been derived from subsurface data of each: structure, temperature, pressure, salinity and net sand maps; and porosity, permeability and methane content analyses.

The parameters of special interest are as follows:

<u>NUMBER OF WELLS</u>	<u>UPPER GEOPRESSURED ZONE</u>	<u>LOWER GEOPRESSURED ZONE</u>
Averaged	35	27
Averaged Uncorrected		
Temperature	213°F	230°F
Average Pressure	11,308 psi	12,663 psi
Average Salinity	102,590 ppm	93,948 ppm
Average Porosity	25.5	23.6
Average Permeability	110 md	95 md
Calculated Sand Volumes	.921mi ³ (1.482km ³)	1.023mi ³ (1.646km ³)
Calculated Fluid Volumes	.235mi ³ (.378km ³)	.241mi ³ (.388km ³)
Estimated Methane	22.9 cu.ft./bbl	27.3cu.ft./bbl

Seismic data proved to be very important in the evaluation of this prospect. Well control is sparse within the basin but quite adequate on the surrounding domes. Four CDP seismic lines were purchased and reprocessed and structural maps from four horizons were prepared from them. These maps confirmed that the major faults found over the domes do in fact extend into the basin. The general basin structure and shape is also confirmed as is the shape of an unconformity surface which appears to mark the top of geopressure in the area. Perhaps the most important result of the seismic data is the proof that the rocks below the unconformity, i.e. in

the geopressured region of interest, are highly and complexly faulted. An indication that this might be the case can be seen over the Grosse Isle structure where sufficient well control penetrates the uplifted unconformity to establish copious faulting; however, in the basin itself the seismic data were necessary to establish the degree of faulting.

INTRODUCTION

Within the past 10 years much attention has been focused on the feasibility of exploiting the abnormally pressured zones of the Gulf Coast for the production of natural gas and geopressured-geothermal energy. Estimates of the amount of recoverable methane in solution within geopressured aquifers varies widely. Bernard (1978) gave estimates of 60 trillion mcf while Hawkins (1977) estimates the amount of methane which could feasibly be recovered from the Gulf Coast region at 57 billion mcf. The current rate of consumption of natural gas within the United States is .02 trillion mcf per year (Bernard 1978). Thus it is conceivable that there is enough methane in solution within the geopressured reservoirs of the Gulf Coast to last 3000 years at the present rate of consumption. Even the more pessimistic estimate of methane in solution, 13.6 billion mcf in Louisiana alone, may justify continued research and development of the geopressured-geothermal resources of the Gulf Coast (Hawkins 1977).

Regional studies show the existence of geopressured-geothermal zones extending from Mexico to the Mississippi coast. The major depositional trends of south Louisiana make it an excellent area for research in geopressured-geothermal production. The major geopressured areas lie within a region

A 2

extending from approximately 100 miles inland out to the continental shelf (Bernard, 1978). The recent discoveries within the Tuscaloosa trend in Louisiana testify to the oil industry's technological ability to extract natural gas from abnormally high pressured sediments.

The focus of the present study is the geological feasibility of geopressured-geothermal production southeast of the Abbeville field and the city of Abbeville, Vermilion Parish in south Louisiana (Fig. 1). It was previously known that east of Abbeville a basin existed which contained geopressured-geothermal sands. The city of Abbeville became interested in this resource as a possible energy source for an industrial park and proposed to us and to the Department of Energy (DOE) that a study be conducted to investigate the reservoir. We were then contracted by DOE (Contract #ET-78-S-05-6064) to arrive at the best estimates of the following parameters for the geopressured sands in the Abbeville area: 1) structure, 2) temperature, 3) pressure, 4) salinity, 5) porosity, 6) permeability, 7) reservoir volume, and 8) total dissolved methane. Reservoir analysis was accomplished by the use of wire line surveys (electric logs) and computer analyses based on standard relationships found in Schlumberger manuals. Seismic analysis proved to be an invaluable tool in establishing the structure of the area.

FIGURE 1
LOCATION MAP

DETECTION OF GEOPRESSURES

As mentioned previously, the oil industry has the capability of bringing abnormally pressured reservoirs into production. However, technological capability alone will not necessarily bring about the desired results. Of vital necessity in controlling abnormal pressure is the ability to detect its presence before drilling into these zones. Close scrutiny of drilling progress, wire line surveys and a suitable knowledge of geological environment of the area are of primary importance in detection of abnormal pressures. Many on-the-spot judgements by geologists and engineers can result in profitable returns. However, well "blow outs" do occur when abnormal pressure is not adequately prepared for.

Regional studies have shown that abnormal pressures frequently occur at the base of the main sand series or within a major shale sequence (Dickinson, 1953). This is by no means universal, since abnormal pressures can occur within the main sand series if the right conditions prevail. Adding to the problem is an abundance of faults. In some cases the geopressured zone is confined to a stratigraphic horizon and if the horizon is faulted, the geopressure will in turn change levels. It is also possible for the pressure to migrate up a fault.

Much progress has been made in the detection of geopressured zones at the well site. Mud logging apparatus can detect high background gas as drilling progresses. Analysis of shale density can reveal a deviation from the normal density of shales to lower density which usually indicates the presence of an abnormally pressured zone. This deviation in density along with high gas content in the mud and reduction of mud weight can indicate abnormal pressures. Also noticeable on wire line surveys is a markedly lowered resistivity-increased conductivity along with the lower densities in geopressured zones.

Forgotson (1969) states that an increase in the rate of drilling penetration of shales on the order of 200% above the normal rate is an indication of the proximity, either vertically or horizontally of abnormal pressures. This increased rate results from the lower density and lower cohesiveness of sediments which hold highly pressured fluids.

Observation of geothermal gradients has also been used to detect the presence of abnormal pressures. This method involves recording temperatures in the borehole. In an ideal situation geothermal gradients will be linear; however, owing to differences in rock properties, fluid content etc., this ideal situation is seldom realized. If enough measurements of temperature are taken a "least squares fit" line in normally pressured zones would show this linear geothermal gradient.

Close to abnormally pressured zones there is a noticeable increase in temperatures.

GEOLOGIC SETTING

The study area lies within the lower Miocene Abbeville-Planulina trend of south Louisiana. The area is just north of what Jam et al. (1969) have termed the "hot belt" of south Louisiana (Fig. 2). It lies within what Ocamb (1961) calls the "growth" fault trend. In addition to growth faults in this area, there are faults that do not exhibit predominant growth characteristics and are associated with salt and shale movement. To the northeast and southeast as well as the east is the Five Islands Salt Dome trend.

The major structural features of the study area are these domes. They are: the Abbeville dome in the northwest portion, the Grosse Isle structure in the northeastern portion, and Erath dome to the southeast.

The stratigraphic interval of importance in this study is the lower Miocene Abbeville-Planulina section and the deeper sediments of the Anahuac (Oligocene) faunal assemblage. It is within these sediments that the greatest pressures are encountered.

FIGURE 2

TEMPERATURES IN SOUTH LOUISIANA AT A DEPTH
OF 10,000 FEET (3,048 METERS)
MODIFIED AFTER JAM ET AL. (1969)

DEVELOPMENT OF ABNORMAL FORMATION PRESSURES IN GULF COAST LOUISIANA

Many factors can cause abnormally high formation pressures. A combination of factors may exist in some areas. To place possible causes in correct perspective, it is essential to comprehend the significance of petrologic and geochemical parameters, and how they relate to the structural, stratigraphic and tectonic history of an area.

PRESSURE CONCEPTS:

Fertl and Timko (1975) state that "hydrostatic pressure is pressure due to unit weight and vertical height of a fluid column. Size and shape of this fluid column have no effect on hydrostatic pressure". A "hydraulic head" is described by hydrologists in terms of the height of a column of fresh water, with a density of 1 gram per milliliter (g/ml), above a specified datum. This is equivalent to a pressure of 0.432 pounds per square inch (psi) for every foot of water column. However, hydrostatic pressure gradient is affected by concentration of dissolved solids in the fluid column and different or varying temperature gradients. Petroleum engineers in the Gulf Coast region describe hydraulic head in terms of water having a dissolved solid content of 80,000 mg/l and a density of 1.055

g/ml, which exerts a pressure of about 0.465 pounds per square inch for every foot of fluid column (Jones, 1967).

Overburden pressure, as defined by Fertl and Timko (1975) is "the combined weight of the formation matrix (rock) and fluids (water, hydrocarbons) overlying and exerting a total pressure on the formation of interest." Fertl and Timko (1975) also state that the "average Gulf Coast Tertiary deposits exert an overburden pressure gradient of 1.0 psi/ft. of depth. This corresponds to the force exerted by a formation with an average bulk density of 2.31 g/cc."

The formation pressure is a certain degree of pressure acting upon the fluids confined in the pores of the reservoir rock (Levorsen, 1967). This is equivalent to a pressure gradient of 0.465 pounds per square inch per foot of depth (Jones, 1967). Normal formation pressure is equal to the hydrostatic head of water from surface to subsurface formations.

Abnormal pressures are characterized by any departure from the normal formation pressure trend. Dickinson (1953) defines abnormal pressure as "any pressure which exceeds the hydrostatic pressure of a column of water (extending from the stratum tapped by the well to the land surface) containing 80,000 mg/l total solids." He also states that abnormal pressures are caused by the weight of the overburden in the Gulf Coast region.

"Compression of argillaceous beds during the early stages of sedimentation and the synchronous expulsion of fluids give rise to progressive compaction as additional sediments are added to the overburden. As compaction proceeds the expulsion of fluids becomes more difficult because of decreasing permeability, so that the pressure in the clay will be partly transmitted to the fluids, and thereby to the fluids in any sand body completely enclosed in the compacting mass, even though the sand body itself may not be compressible. So long as the sediments remain plastic these pressures [the pressure in the sand and the shale] will ultimately become practically identical and will be determined by the pressure gradient of the contained fluids, that is, the geostatic pressure gradient of the overburden.

The pressures in fluids within sediments are dominated by two factors, the compression due to compaction on the one hand, and the resistance to expulsion on the other..."

However, in order for geopressure to occur, Dickinson (1967) states that a "reservoir containing high pressure must be effectively isolated from any other porous formation which contains normal hydrostatic pressure, otherwise the pressure would be dissipated." The reservoir would have to be porous yet sealed off in all directions (Dickinson, 1967).

Three important seals are: lensing, faulting, and osmosis. In Figure 3 the lensing and faulting seals are illustrated. Figure 3(a) indicates that a sand body in a basically shaly series is commonly lenticular and erratic, i.e. faulting is not necessarily a requirement for the preservation of abnormal pressure. However, faults do play an important role in reservoir seals as seen on Figures 3(b) and 3(c). The downdip seal of some reservoirs can be due to the change from

SMALL RESERVOIR SEALED BY PINCHOUT
(a)

LARGE RESERVOIR SEALED UPDIP BY FAULTING DOWN AGAINST THICK SHALE SERIES, SEALED DOWNDIP BY REGIONAL FACIES CHANGE.

(b)

RELATIVE POSITION OF FAULT SEALS IN UPTHROWN AND DOWNTROWN BLOCKS.

(c)

FIGURE 3

TYPES OF RESERVOIR SEALS NECESSARY
TO PRESERVE ABNORMAL PRESSURES
(DICKINSON, 1963)

A.12

shallow-water facies to deep-water facies. This is especially true in the reservoirs situated in ancient deltaic environments where facies may change from fore-delta to pro-delta, i.e. from sand to shale (Coleman and Ho, 1967). Another effective seal is created by osmosis. An osmotic seal can arise when two solutions of different concentrations are separated by a semi-permeable membrane (Fertl and Timko, 1975).

A number of studies indicate that fine-grained, clayey sediments have membrane characteristics that are responsible for concentration of dissolved solids, as well as osmotic pressures.

Upon the compaction of the clay material, a stage in the process is reached at which the clay begins to impede the flow of water. In the northern Gulf of Mexico Basin the clay beds that form these semipermeable membranes, according to Jones (1967),

"are soft and plastic and where they are greater than a few feet thick they should be highly efficient -- that is, as effective in filtering out salt ions as a perfect semipermeable membrane. The great contrasts in water salinity above and below them in normal hydrostatic aquifer systems, and the great pressures they are able to confine in the geopressured systems, give evidence of this high efficiency. But field and laboratory tests will be necessary before quantitative evaluation of this important aspect of the ground-water hydrology can be made. The writer believes that osmotic flow is a dominant factor in the hydrology of regional aquifers systems in the northern Gulf Basin -- both normally and abnormally pressured."

CAUSES FOR ABNORMAL PRESSURES

A. COMPACTION

The load pressure exerted by a column of average rock is approximately one pound per square inch per foot height. (The average natural specific gravity, with all pores filled with water, of the typical sedimentary basin sediment is about 2.1 for sandstone, 2.3 for shale, and 2.4 for limestone.) Therefore by using a specific gravity of 2.3 as an average for basin sediments and multiplying it by 0.43 pounds per square inch per foot, one obtains approximately 1.0 pound per square inch per foot, or 100 pounds per square inch per 100 feet of depth. This load pressure, which is more than twice the average hydrostatic pressure gradient of water, is called lithostatic pressure or overburden pressure (Levorsen, 1967).

The primary difference between lithostatic and fluid pressure is that lithostatic pressure is transmitted through the mineral particles in close contact, i.e. the rock itself, whereas fluid pressure is transmitted through the fluid that fills the pores in the rock. The mineral particles in the lithostatic pressure are in contact and acting as supports. Lithostatic pressure normally acts on the rock particles while hydrostatic pressure is applied to the pore fluids. When the lithostatic pressure becomes great enough to deform the mineral grains thereby reducing the pore space, the lithostatic pressure is transmitted to the fluid pressure. It is believed that in

the initial stages of a rapidly filling basin, the increasing weight of the overburden enables the grains, especially in the shales and clays, to come into contact during compaction. Figure 4 shows the relation of porosity and compaction of shales to depth of burial. It can be seen that enormous quantities of water and possibly hydrocarbons still remain in shales at depths of greater than 20,000 feet (6095 meters). This would then result in a force on the contained fluids, most of which are squeezed out of the sediments (Levorsen, 1967).

B. TECTONIC ACTIVITIES

The structural evolution of the Gulf Coast "geosyncline" has played an important role in development of formation pressure. Fertl and Timko (1975) state that "abnormally high pressures may result from faulting, folding, lateral sliding and slipping, squeezing caused by down-dropping fault blocks, diapiric salt or shale intrusions, earthquakes, etc."

Thorsen (1963) believes that the growth fault is "probably the most distinctive feature of south Louisiana geology." Ocamb (1961) defines growth faults as "those (normal) faults which have a substantial increase in throw with depth and across which, from the upthrown to the downthrown block, there is a great thickening of correlative section." Regional growth faults are developed by intersecting arcuate faults whose

FIGURE 4
RELATION OF POROSITY AND COMPACTION
OF SHALES TO DEPTH OF BURIAL
(DICKINSON, 1963)

A 16
throw may be the same for many miles. The fault may then split, so that each fault shares a part of the total displacement. The average fault plane dip is approximately 50° at shallow depths, and generally decreases with depth (Jones, 1967).

The mechanics of growth faults and their causes have not been explained adequately. One possible factor in the development of growth faults might be diapiric movements of salt from a deeply buried "mother salt" bed as well as large scale movement of "diapiric shale" (Jones, 1967).

C. OSMOSIS

As stated previously, an osmotic pressure can arise when two solutions of different concentrations are separated by a semipermeable membrane. Fertl and Timko (1975) state that "regardless of the mechanism by which the semipermeable membrane operates, the final result is the same. Osmotic flow will continue until the chemical potential of the diffusing component is equal on both sides of the membrane."

The clays in a sedimentary basin act as semipermeable membranes. This, in effect, permits osmotic pressures to develop across the bedding whenever there is a discernible contrast in the concentrations of the dissolved solids, usually salts, on either side of the clay layer. This process is one of the primary sources of reservoir fluid pressure, and is more than likely the cause for the numerous fluid potential gradient anomalies observed in underground aquifers (Levorsen, 1967).

D. AQUATHERMAL PRESSURING

The Gulf Coast "geosyncline" has been an area of continuous and substantial deposition. If a potential high pressure zone is isolated from any other porous formation at a shallow depth it will tend to have uncompacted shales and generally low salinity formation waters.

Upon burial of a non-isolated system, the salinity increases; the temperature increases; the shales become more compact and the overburden pressure increases. However, according to Barker (1972), "the isolated system becomes one of constant density because a fixed mass of material is trapped in an essentially constant volume." Therefore when a closed system is subjected to a given rise in temperature, the pressure will increase more than that in the open system. Barker (1972) also states that "the pressure generated aquathermally depends on how much the depth of burial increases after the volume becomes isolated, as well as on the geothermal gradient." The shales become less compacted in a high pressure zone in contrast with other shales at the same elevation. At high pressured depths the under-compacted shales will contain a greater percentage of water, which in turn will be of lower salinity (Barker, 1972).

E. SECONDARY PRECIPITATION OR CEMENTATION

The original minerals in many reservoir rocks have been partially dissolved and recrystallized. As a result of this

process secondary minerals have developed. Leverson (1967)^{A 18} states that "where there has been more deposition than solution, a decrease in porosity has resulted, which in a sealed or in a confined space means an increase in fluid pressure. Where solution is greater than deposition, on the other hand, an increase in pore space results, and there is a decrease in fluid pressure. The differences are probably only temporary and soon equalized."

Dickinson (1964) noted that with increased compaction due to increased deposition of overburden the contacts of sand grains within isolated sand bodies become areas of silica precipitation. The net result is a decrease in porosity and expulsion of fluids with a rise in fluid pressure.

F. DIAGENESIS OF CLAYEY SEDIMENTS

Changes in the mineral composition of sedimentary deposits of the Gulf Coast basin often result in hydrodynamic forces. The diagenetic alteration of montmorillonite to illite is probably the single most important chemical alteration. Montmorillonite commonly makes up 40 to 65% of the clay at shallow depth.

Powers (1967) conducted extensive x-ray diffraction tests of cuttings from deep wells in Texas and Louisiana. His results suggest that there exists a relationship between the depth at which geopressures are encountered and the depth at which montmorillonite is altered to illite.

Fertl and Timko (1975) reported that in some regions ^{A 19} a "marked temperature-dependent alteration of clay minerals with depth goes largely montmorillonite (swelling lattice) to illite (nonswelling lattice)."

Burst (1969) offered a simple dehydration model -- "the three stage water escape model", for the conversion of montmorillonite to illite (Figure 5). However, recent studies show that montmorillonite undergoes significant chemical changes in the conversion to illite (Hower et al., 1976).

Those mineralogical changes which are believed to occur are: (1) decomposition of mica, (2) decomposition of potassium feldspar, (3) removal of kaolin, (4) formation of quartz, and (5) the formation of chlorite or chlorite interlayers. Hower et al. (1976) put forth the generalized conversion of montmorillonite to illite as: montmorillonite + K-feldspar + mica = illite + chlorite + quartz. The analysis of the actual chemical conversion and mineralogical changes is beyond the scope of this study.

Alteration of montmorillonite to illite normally begins at a depth of approximately 6500 feet (2000 meters) and continues to a depth of about 12,000 feet (3700 meters) (Hower et al., 1976). The abnormal pressures in the Gulf Coast region tend to fall within this depth range. It has been suggested that the last layers of bound water expand considerably in volume when released during the alteration. This

FIGURE 5
MARINE SHALE BULK COMPOSITION
DURING DEHYDRATION
(BURST, 1969)

expansion to normal free water density increases the pore fluid^{A21} pressures in the reservoirs into which the water has been forced (Powers, 1967).

Jones (1967) states that "the progressive decrease in the salinity of water with depth in geopressured aquifers is due mainly from the influx of fresh water produced by alteration of montmorillonite to illite." Water released by clay dehydration is fresh water, and its volume may equal 10 - 15% of the bulk volume of the clayey sediments.

STRATIGRAPHY

GENERAL

In Vermilion Parish, the deeper subsurface deposits are documented from numerous oil and gas test wells with an average depth of approximately 12,000 feet (3,660 meters). The deeper wells are located on the east and west side of a structural syncline, and are situated in the Abbeville, Grosse Isle, and Erath fields. The deepest test is 18,241 feet (5,560 meters) deep.

The oldest strata encountered in the area are the Frio and Anahuac Formation of Upper Oligocene or Lower Miocene age. The exact age of the Frio and Anahuac Formations has been disputed for many years, but for the purpose of this study their age is assumed to be Oligocene. The Oligocene section is divided into, from oldest to youngest, the Vicksburg Group, Frio Formation, and Anahuac Formation. However, in the study area, the oldest bed investigated is designated as the Camerina "A". Refer to Figure 6.

The Miocene Grand Gulf Group contains the most important deposits in the study area. These deposits include the primary oil and gas producing sands as well as being geopressed and geothermal. Therefore, they will be discussed in detail (Fig. 6).

SYSTEM	GEOLOGIC COLUMN			
	Series	Group	Formation	Diagnostic Benthonic Fossils or Assemblages
QUATER-NARY	Recent			
	Pleisto-cene			TRIMOSIA "A" GLOBOROTALIA CRISTELLARIA "N"
TERTIARY	Plio-cene			BULIMINELLA CURTA TEXTULARIA "X"
	MIOCENE	GRAND GULF	FLEMING	ROBULUS "E"
				BIGENERINA FLORIDANA BUCCELLA MANSFIELDI BIGENERINA DIRECTA TEXTULARIA STAPPERI
				BIGENERINA HUMBLEI AMPHISTEGINA "B"
				OPERCULINOIDES ROBULUS CHAMBERSI SIPHONINA DAVISI PLANULINA PALMERAE ABBEVILLE ASSEMBLAGE
	?		ANAHUAC	DISCORBIS GRAVELLI (DISCORBIS) ZONE HETEROSTEGINA (HETEROSTEGINA) ZONE MARGINULINA HOWEI (MARGINULINA) ZONE
	?		FRIO (SUBSURFACE)	CAMERINA "A" CIBICIDES HAZZARDI

FIGURE 6

GEOLOGIC COLUMN
(MODIFIED, RAINWATER, 1964)

ANAHUAC FORMATION

In 1944 the Houston members of the American Association of Petroleum Geologists Geologic Names and Correlations Committee formally named the Anahuac Formation. The name was introduced to replace the older term "Middle Oligocene" (Murray, 1961).

Ellisor (1944) described and defined the Anahuac. The formation is not exposed in the Louisiana-Texas Gulf Coastal Plain; therefore, a well was used in the Anahuac field in Chambers County, Texas and this was chosen for the type section. Ellisor described the section as "dark, greenish gray, slightly micaceous calcareous shale with very fine partings of sand. Lenses of sand and calcareous sand are interlaminated with the shale." There are three subdivisions of the Anahuac established in Texas by Ellisor (1944) and these can be recognized in southwest Louisiana. They are based primarily on microfaunal content and are from bottom to top the Marginulina zone, the Heterostegina zone, and the Discorbis zone, i.e. the lower, middle, and upper Anahuac respectively (Ellisor, 1944).

Stuckey (1964) states that "the Anahuac represents a large transgression of the sea which overlapped all of the subsurface Frio which includes the post-Vicksburg marine transgression".

The deepest subsurface mapping horizon, the Discorbis gravelli, is found in the upper Anahuac, i.e., the Discorbis zone. The Heterostegina zone is also important because it contains the "lower" geopressured, limey, Heterostegina sands.

MIOCENE

The lower and upper boundaries of the Miocene are not precisely defined. The formations of this age outcrop in an almost continuous belt which varies in width from a few miles to more than 75 miles (120 kilometers). It extends from central peninsular Florida to Mexico which is approximately 1200 miles (1,935 kilometers). The Miocene underlies about 200,000 square miles (322,500 square kilometers) of the northern Gulf of Mexico Region. The thickest Miocene section occurs at the southern end of the Mississippi Embayment, just offshore southeastern Louisiana. In the central and western Gulf Coast all the terrigenous clastic sediments were deposited in coastal and shallow nearshore marine environments. The Miocene of this region of the Gulf Coast continental shelf is composed of sand, silt, and shale. The sands are for the most part fine grained in the "updip" alluvial deposits. However, coarse quartz and chert are found in parts of the section. The "middip" belt consists of alternating sand and shale beds which accumulated in lagoonal, strand line, and deltaic environments (Rainwater, (1967)).

Rainwater (1967) concludes that the majority of the sediments were deposited at or near sea level in deltaic depocenters. The coastal and offshore Louisiana area was subsiding during deposition as indicated by the great thickness, approxi-

mately 20,000 feet (6,095 meters), of the deposits. During the^{A26} early part of the Mississippi delta building episode the depocenters were mainly in southwestern Louisiana and the adjacent continental shelf (Rainwater, 1964).

The more extensive transgressions occurred during times when the supply of sediments transported to the Gulf Coast was small. The continental shelf was widest during the transgressive periods (Rainwater, 1964).

According to Rainwater (1964) the primary factor controlling the rate of sedimentation is believed to have been climatic change, from wet during regressive phases to dry during transgressive phases. The fluctuations occurred at time intervals which were too short to have resulted from uplift and peneplanation of the hinterland (Rainwater, 1964).

The sedimentation rate was slow during the transgressive phases, so it seems that conditions should have been appropriate for accumulation of marls and limestones. However, these rock types are very rare in the Miocene of the area. This may indicate that fine grained sediments were transported to the region during the transgressive stage (Rainwater, 1964).

The Gulf Coast subsurface Miocene has been divided or "zoned" by the use of benthonic Foraminifera as illustrated in Figure 6. The geologic column used in this study is a modified form of Rainwater's classification chart. This chart divides the Miocene into nine divisions, from A (youngest) to I (oldest).

MIOCENE DIVISION A (Top of Bigenerina cf. floridana to top of Buccella mansfieldi)

Bigenerina cf. floridana marks the top of the Upper Miocene.

The section is approximately 600 feet (180 meters) thick in northcentral Vermilion Parish and is composed of massive sand bodies and alternating sand, silt and shale which were deposited in the neritic environment of the inner continental shelf zone (Rainwater, 1964).

MIOCENE DIVISION B (Top of Buccella mansfieldi to top of Bigenerina directa)

This zone is composed of alternating sand and shale. The Bigenerina directa interval is approximately 600 feet (180 meters) thick and was deposited in coastal and neritic facies. Most of the sediment was deposited very close to the strandline, which was constantly shifting (Rainwater, 1964).

MIOCENE DIVISION C (Top of Bigenerina directa to top of Textularia stapperi)

This zone is composed mostly of upper deltaic sand, shale and silt, overlain by neritic shale. The section increases in thickness seaward where sedimentation took place in deltaic depocenters (Rainwater, 1964).

MIOCENE DIVISION D (Top of Textularia stapperi to top of Bigenerina humblei)

The Bigenerina humblei zone is considered middle Miocene and is approximately 1,400 feet (425 meters) thick. It is

composed of neritic sands and shales. The upper section is marked by a major shale break. The sediments were deposited on the middle continental shelf (Rainwater, 1964).

MIOCENE DIVISION E (Top of Biginerina humblei to top of Amphistegina shale)

The Amphistegina marker is the first mapping horizon for the subsurface structure maps. The top of the Amphistegina is at approximately 8,500 feet (2,590 meters) in the Grosse Isle Field and is considered early middle Miocene. Division E is composed of alternating neritic massive sand, silt and shale and is from 2,000 to 2,300 feet (610 to 700 meters) thick. Some sand bodies as thick as 100 feet (30 meters) are discernible and are separated by thinner beds of shale. The massive sands were deposited on the middle of the continental shelf (Rainwater, 1964).

MIOCENE DIVISION F (Top of Amphistegina shale to top of Operculinoides)

The Amphistegina shale marks the top of this section. Below this shale exists a widespread marine section, approximately 200 to 400 feet (60 to 120 meters) below the Amphistegina shale, containing the distinctive Foraminifera Robulus macomberi. This is considered a better stratigraphic "marker" than Amphistegina. At the base of this section the top occurrence of the Foraminifera Operculinoides is found.

This section is composed of alternating layers of sand, shale, and silt which were deposited in transitional and neritic

A 29

environments. Rainwater (1964) states that "this was mainly a regressive period during which the shoreline was farther south than it was during some younger regressive periods. Pea size gravel which was deposited in alluvial environments are in the regressive beds of southwestern and south central Louisiana."

MIOCENE DIVISION G (Top of Operculinoides to top of Robulus Chambersi)

This division is composed of deltaic sand interbedded with neritic and lagoonal shale. The thickest section is located in southwestern Louisiana where depocenters were located (Rainwater, 1964). The Robulus chambersi horizon is approximately 250 feet (75 meters) below the Amphistegina in the Grosse Isle Field.

MIOCENE DIVISION H (Top of Robulus Chambersi to top of Siphonina davisii)

The Siphonina davisii is the second marker used in mapping the study area. The top of this marker is at approximately 11,350 feet (3,460 meters) in the Grosse Isle Field, i.e. 2,850 feet (870 meters) below the Amphistegina marker. Siphonina davisii is considered a diagnostic faunal marker for lowermost Miocene. This division is composed mostly of neritic shale and silt, with some lagoonal sand and clay in the upper portion.

MIOCENE DIVISION I (Top of Siphonina davisii to Oligocene Anahuac Formation)

Rainwater (1964) states that the lowest division "marks the beginning of major regressive periods following the widespread Late Oligocene Anahuac Transgression."

Within this division there are two zones, the "Planulina" and the "Abbeville" (Goheen, 1959). The Planulina zone overlies the Abbeville and is encountered at a depth of approximately 12,750 feet (3,885 meters) in the Grosse Isle Field. The Abbeville is found at about 13,000 feet (3,960 meters). The zone consists largely of massive shale beds which were deposited in an outer continental shelf to inner continental slope environment. The Planulina section most likely represents a transitional zone between the overlying shallow water sediments and the underlying bathyal shales of the Abbeville (Goheen, 1959).

The exact age of the Planulina and Abbeville is questionable. Goheen (1959) believes that the zones belong in the Anahuac Formation. Limes and Stipes (1959) have assigned them to the lowermost Miocene. We have adapted their age assignment in this paper.

STRUCTURE

One hundred-sixty-nine wells were incorporated in subsurface structural mapping. Three structural horizons were mapped throughout the entire study area; the fourth structure map was confined to the Grosse Isle area due to the inability to correlate the marker used into the other areas. The major faults were projected into these unmapped areas. (Plates 2, 3, 4 and 5)

Three domes are the main structural features of the study area. They are: Abbeville dome in the northwest, Grosse Isle dome in the northeast and Erath dome in the southeast. Two major depositional basins can be seen, one between the Abbeville structure and the Grosse Isle and Erath structures. The other essentially parallels the east flanks of the domal structures of Grosse Isle and Erath.

Three structural cross sections were completed. (Plates 6, 7 and 8) Cross sections A-A' and B-B' run north-south and correspond to the regional dip of the Gulf Coastal Plain. Cross section C-C' runs from the west to east and is parallel to the strike of the Gulf Coastal sedimentary basin.

AMPHISTEGINA B

The shallowest mapping horizon within the study area is

the Amphestegina B micropaleontologic marker (Plate 2). At this elevation exist five major fault systems. These are Faults A, B, C, D, and E. The secondary faults being Faults A₁, A₂, B₁, and D₁.

The anticlinal feature of Abbeville field is, as a result of fault systems A and B, broken up into 6 major fault closures and numerous anticlinal noses. The largest fault in the Abbeville area is Fault A, which exhibits approximately 1,000 feet (300 meters) of throw along its western extension at this horizon. Two grabens exist. One was formed between the large down-to-the-south Fault A and the down-to-the-north Fault B. The other is between the down-to-the-east Fault B₁ and the down to the west Fault B₂. To the east of Fault B₁ the general trend of the dip of the beds is to the southeast.

A single basinal feature can be seen in the eastern portion of the study area. The deepest portion of the basin is at approximately 9,000 feet (2,740 meters) under the city of Erath. An extension of this basin trends west and southwest approximately through the junction of the four townships and ranges.

South and southwest of the basin, the domal feature of Erath is readily visible. Fault C, which strikes essentially east-west across the northern portion of the dome, divides the dome into two distinct fault closures within each fault block.

North of the basin, the anticlinal feature at Grosse Isle is of low relief and lacks any resemblance to an area of domal uplift. The southward plunging synclinal trough west of Grosse Isle was observed in both the subsurface and seismic investigation.

SIPHONINA DAVISI

The Siphonina davis mapping horizon is approximately 2,500 feet (762 meters) below the Amphistegina B horizon (Plate 3). All of the primary and secondary faults existing at the Amphistegina B horizon are present at this deeper horizon. At this horizon all of these faults have migrated down their dip and several new faults are present. The most obvious development is that at this depth Fault A extends eastward and has connected with the westward extension of Fault E. This connection has been labeled Fault A-E.

Abbeville field is still broken into numerous fault closures. However, at this depth the tightening of contours gives it the appearance of a domal structure. The two grabens narrow as the respective bounding faults migrate toward each other. Fault F can be seen at this horizon. Again the beds south of Faults A and B dip toward the east-southeast. Fault G is also seen at this depth.

At this horizon the basin has been effectively divided

into two separate basins by the merging of the Grosse Isle structure and a small high north of the Erath dome. The central portion of the eastern basin is situated slightly west of the city of Erath, while the central portion of the western basin is situated approximately 2 miles (3.22 kilometers) northeast of the junction of the four townships and ranges. The greatest depth of the eastern basin is approximately 12,100 feet (3,688 meters) and the greatest depth of the western basin is approximately 12,200 feet (3,718 meters).

Erath dome has become exceptionally well pronounced at this depth, as have two smaller structural highs. The small anticlinal feature now seen in the southeastern corner of the study area is an extension of Tigre Lagoon field to the southeast. The crest of Erath dome can be seen in section 16-13S-4E. The smaller anticlinal structure mentioned earlier north of Erath dome is bounded by Fault D on the south. Minor faulting associated with Fault D and the now apparent Fault H can also be seen. Fault D₃ apparently formed in direct response to the stress exerted between Faults O and H.

North of the two basins, the Grosse Isle area is now starting to take on the appearance of a relatively large domal feature. Closure can be seen along Fault A-E.

TOP OF GEOPRESSURE

The top of the geopressure mapping horizon is approxi-

mately 1,500 feet (457 meters) below the Siphonina davis horizon (Plate 4). Appreciable growth along Fault A is noticeable from 1,000 feet (300 meters) at the Amphistegina B horizon to nearly 2,000 feet (610 meters). Again the major faults are present in their down dip positions. At this depth two new fault systems, Faults I and J, are present.

In the Abbeville area the characteristic domal features are seen again. The graben created by Faults A and Fault B seen on the previous horizons is no longer present. There is present, however, a last remnant of the graben created by Faults B₁ and B₂. The steepness of the dome is seen in the elevation differences between the crest, 10,800 feet (3,292 meters) in section 68-12S-3E, and the western basin depth of 13,700 feet (4,176 meters). South of the Abbeville dome there appears to be a small structural high. This was also observed in the seismic investigations.

It should be pointed out that the top of the Geopressure marker does not correspond to the same stratigraphic marker through the study area. This is readily seen in the Erath area where, starting at about the Goldking Harrington well in section 47-12S-4E, the top of the geopressure switches stratigraphic markers going southward. The top of the geopressure on the downthrown side of Fault H is within the Planulina-palmera section. Thus the top of the geopressure on the downthrown side of Fault H is stratigraphically and structurally higher than

the top of the geopressure on the upthrown side. The top of the geopressure was found to correspond to the top of the Abbeville shale sequence in the areas outside of the Erath dome.

It is the opinion of the authors that a local unconformity is present along the upthrown side of Fault H extending northward to the Goldking Harrington Well. Dobie (1979) stated the same opinion.

Fault H with depth shows considerable growth on the order of 4,000 feet (1,220 meters) (see cross-section A-A'). The result of the top of the geopressure being higher on the downthrown side is a hydrodynamic gradient in a northwesterly direction away from Fault H. The hydrocarbon accumulation in the northwest fault block was forced nearly to the spill point (near to capacity of the trap) by this pressure difference (Dobie, 1979).

The two basins are still essentially separate. The eastern basin has migrated westward and its deepest point is approximately 13,900 feet (4,237 meters). The western basin has migrated southeasterly somewhat with its central portion being at the junction of the four townships and ranges. Its deepest point is approximately 13,700 feet (4,176 meters). Southward of the western basin can be seen the northern portion of another synclinal feature. This feature is better seen on the seismic interpretations. North of the basins two faults, Fault J and Fault I, now appear. Fault I has joined with Fault

A in the west and Fault E in the east, and cuts the northern portion of the Grosse Isle dome. Faults J, J₁ and J₂, which are smaller faults, are seen on the south nose of the Grosse Isle structure. West of the Grosse Isle structure is the north-south synclinal trough which extends southward into the western basin. At this horizon it is cut by numerous faults.

In the eastern portion of the study area can be seen again the western edge of the structural high associated with the Jefferson Island salt dome.

DISCORBIS GRAVELLI

The Discorbis gravelli marker in the Grosse Isle area is approximately 1,300 feet (396 meters) below the top of the geopressure marker. This map was constructed to show that extensive faulting exists at the deeper horizons. The inability to correlate this marker into the remaining portions of the study area restricted this mapping horizon to the Grosse Isle area. The major faults of the study area were projected to their down dip migrated positions (Plate 5).

In the Grosse Isle area, Fault I has shown a great deal of growth. At the previous horizons the throw was approximately 200-300 feet (60-90 meters), while at the Discorbis gravelli horizon the throw approaches 1,000 feet (300 meters). Fault E₁ has merged into Fault E. Fault systems J and Fault K attest to the complexity of the faulting with increased depth.

Fault J₂ split from Fault J at this horizon. Fault K, which strikes roughly north-south, can now be seen. It is not certain that Fault J extends westward and joins with Fault A, however, seismic profile Teledyne 4-A indicates that Fault J does extend in a northeasterly direction.

GEOPHYSICAL INTERPRETATIONS

This portion of the report presents a geological interpretation of the subsurface structures of the research area based primarily on four reprocessed and wave migrated seismic sections. The four seismic lines are as follows: Arco 431-4, Arco 431-6, Arco 431-9, and Teledyne 4-A. Their locations can be seen on the seismic structure maps. In order to understand fully the seismic structure maps, each individual line will be discussed before any explanation of the maps is offered. The four mapping horizons, from shallowest to deepest, are: the Amphistegina B, Siphonina davisii, an unconformity, and Discorbis gravelli. It is essential to realize that the four seismic mapping horizons are approximately equivalents of the subsurface structure map horizons. It was not possible to correlate the individual mapping sands directly with distinct reflecting horizon with the data available for the study.

ARCO 431-4

The Arco 431-4 seismic line runs in a north-south direction about 3 miles (5 kilometers) west of the City of Abbeville (Plate 9). The first seismic interval under investigation is approximately equivalent to Amphistegina B as Plate 4 illus-

trates. The seismic characteristic of this reflector interval varies from medium amplitude reflections near the fault plane to a continuous, medium to high amplitude basinward. At this elevation one can see the gentle southward dip of the reflector horizon toward the basinal feature. Approximately at shot point 111 and 2.07 seconds the down-to-the-north Fault B exists with about 200 feet (60 meters) of throw. Directly north of this, the down-to-the-south Fault A is found at about shot point 123 and 2.15 seconds with a throw of approximately 175 feet (53 meters). Within the graben between the two faults the seismic characteristic of the interval under investigation has a variable amplitude and is discontinuous.

The next reflection interval is about 6 seconds below the Amphestigina B zone. This horizon is approximately equivalent to the Siphonina davisii. At this level the general structure is still the same, i.e. the reflector horizon has a southward dip. However, the seismic reflection varies from low amplitude in the north to medium-high amplitude in the south. There is a discernible thickening of the reflection interval towards the Gulf which may be part of the regional thickening of sediments basinward. At this seismic interval only Fault A is seen with a throw of approximately 300 feet (90 meters). The seismic characteristics to the north of this fault are comprised of variable amplitude, discontinuous reflections.

About 2 seconds below the Siphonina davisii horizon is the next reflection interval of interest. This is considered

approximately equivalent to the unconformity level. Again the general structural trend is similar to the above horizons.

Fault A is the only fault existing at this reflection horizon and it has a throw of about 1,000 feet (300 meters). To the north of Fault A the majority of the reflectors have variable amplitudes and are rarely continuous for any length.

The last reflection interval that was used for a mapping horizon is approximately equivalent to the Discorbis gravelli zone. At this depth the seismic characteristic shows low amplitude reflections dipping southward. These deeper horizons do not appear to have the same definition and resolution in the reflector intervals as do the horizons above. Sheriff (1976) states that "wavelengths generally increase with depth because: (1) velocity increases, and (2) frequency becomes lower. Because the wavelength limits resolving power, deep features have to be much larger than shallow features to produce the same expression." Therefore, minor features are not as easily detected at this depth as they would have been at shallower levels where the resolution and quality of the data are better.

As one can see (Plate 9), this seismic interval has numerous faults. The faults do not cut beyond or above the unconformity horizon, with the exception of Fault A. At this depth the seismic resolution has dropped. Therefore, the faults at this level will only be detected if they have a large enough displacement. This implies that any small faults, throws of

75 to 150 feet (23 to 46 meters), are unlikely to be seen. It is almost certain that at this depth there are more faults than those shown in the seismic section.

ARCO 431-6

This seismic line, the Arco 431-6, runs in a east-west direction approximately 2.5 miles (4 kilometers) south of the city of Abbeville (Plate 10).

The Amphistegina B seismic characteristics show medium to high amplitude, continuous reflections. No faults were detected at this horizon. The general structure at this depth is a gentle anticline, with the highest point at about shot point 80.

The approximate equivalent of Siphonina davisii is about 6 seconds below the Amphistegina B seismic horizon. At this level the reflector interval is fairly continuous and has variable amplitude reflections. Again, the general structure is that of an anticline with a down-to-the-east fault cutting the reflection horizon at about shot point 134. The fault, labeled Fault Z, has a throw of approximately 300 feet (90 meters).

The approximate unconformity reflection horizon is the next interval of interest. It is about 2 seconds below the Siphonina davisii seismic reflector horizon. The seismic characteristic of this level consists of continuous, low amplitude reflections. At this depth additional faults can

be seen. In addition to Fault Z there are two more important faults, Faults B_1 and S_1 . Fault B_1 has a throw of about 800 feet (240 meters). Fault S_1 is a down-to-the-northwest fault with a throw of about 200 feet (60 meters). Faults T and T_3 form a small graben.

The deepest reflector horizon of interest in the seismic section is approximately 2 seconds below the unconformity horizon. This level is about equivalent to the Discorbis gravelli zone. The seismic characteristics are similar to those of the unconformity horizon. Also, the general structure is the same as for the above horizons with the exception that displacements of the strata, as a result of the faults, are greater. For example, Fault B_1 has a throw of about 900 feet (275 meters) at this depth in contrast to 800 feet (240 meters) of throw on the horizon above. Once again there are probably more faults present at this depth, but the quality and resolution of the seismic data are not adequate to detect any but the larger faults.

ARCO 431-9

The Arco 431-9 seismic line runs in a northwest-southeast direction with the end of the section, shot point 75, about 1 mile (1.6 kilometers) south of the city of Abbeville (Plate 11).

this study is the Teledyne 4-A. This line runs in a north-south direction approximately 2 miles (3.2 kilometers) east of the city of Abbeville.

The Amphistegina B is a variable amplitude, continuous reflection horizon. No faults were discovered at this depth throughout the entire length of the line. The reflection horizon shows that a basin exists, with the deepest portion at about shot point 392. From this shot point southward the seismic interval indicates a gentle anticline (see Plate 12).

Approximately 6 seconds below the Amphistegina B level is the Siphonina davisii. This reflection horizon has a similar seismic characteristic to that of the Amphistegina B level. At this elevation two down-to-the-south faults were discovered, Faults C and A-E. Fault C has a throw of approximately 900 feet (275 meters). The general synclinal shape is still discernible at this horizon; however, the anticlinal shape has now been disrupted by Fault C.

The approximate equivalent of the unconformity reflection horizon is about 2 seconds below the Siphonina davisii level. At this depth the seismic characteristics are perceivably different from those of the above horizons. The reflection amplitude is variable and the reflection horizon is discontinuous across the synclinal portion of the seismic section. Fault I is a down-to-the-south growth fault with a throw of perhaps 100 feet (30 meters). As one can see on Plate 12,

Fault A-E is a smaller fault that, with depth, runs into the major and older Fault I. To the far south Fault C exhibits a very large throw of about 1,500 feet (450 meters). As one can see on Plate 12, there is a thickening of the strata to the south of this fault. Obviously deposition was contemporaneous with faulting.

The approximate equivalent to the Discorbis gravelli is about 2 seconds below the unconformity horizon. Both Fault C and I are present at this elevation, with the throws increasing to 2,500 feet (760 meters) and 900 feet (275 meters) respectively. At this depth one must remember that the resolution and quality of the data will cause difficulty in detecting structural features such as faults. Therefore, even though there are numerous faults cutting this reflector horizon, it is conceivable that there are more faults than are depicted in the seismic section.

One structural feature found in this seismic line that may be related to the formation of some of the faults in its vicinity is the structure situated on the upthrown portion of fault plane I. There are no distinct or continuous seismic reflections in this mass and the reflection amplitudes are variable. However, surrounding the structure the reflection horizons are continuous and of uniform amplitude. This could be a possible salt or residual shale mass. There are no wells at this time that have penetrated to that depth so that the

composition of the feature is not shown. Many local geologists believe it to be a salt structure.

To the south of Fault C a very distinct anticlinal structure is present. As one can see on Plate 12, the structure has been erosionally truncated at approximately 3.2 seconds. Mitchum et al. (1977) states that "erosional truncation implies the deposition of strata and their subsequent removal along an unconformity surface." One should note that the approximate unconformity reflection horizon is simply a reflector interval that does not necessarily follow the unconformity level throughout the seismic data.

Rather standard processing of the data was performed to yield these sections and processing is one area which holds promise of improvement of data quality at the depths of geopressured-geothermal reservoirs. Application of state of the art processing techniques aimed at optimizing resolution at the depth of interest should yield appreciable improvements.

SEISMIC STRUCTURE MAPS

Having discussed the seismic sections, it is now possible to incorporate the four seismic lines into seismic structure maps of the region. The four mapping horizons are, from shallowest to deepest, the approximate seismic equivalents of: Amphistegina B, Siphonina davisii, unconformity, and Discorbis gravelli. It should be noted that the seismic interpretations were used in conjunction with the known subsurface geology in the contouring of these structure maps. One can get a general idea as to what may exist at increasing distances from the seismic lines, but in order to have a complete structure map one must rely on the subsurface geology interpretations in the areas with no seismic control. For example, some of the faults in a given horizon are present not because they were seismically interpreted, but because the geological subsurface interpretations require them and/or they are necessary to make reasonable contours. Therefore, any faults located outside the seismic line's control will be indicated by a dashed line. The major growth faults in this region are associated with the Abbeville, Grosse Isle, and Erath structures. Many of the minor faults are bifurcations of the major fault systems. The major faults that are seen in most of the mapping horizons are: Faults A, A₁, A-E, I, C, and H.

AMPHISTEGINA B

The first seismic mapping horizon, Amphistegina B, contains four faults which are all related to the Abbeville structure (Plate 13). Between Faults A and B exists a graben. To the south of Fault B and east of Fault B₁ a southerly plunging anticlinal nose is present. Subsurface geology suggests that an anticlinal nose also exists between Fault B₁ and B₂. Past the southern limit of both faults the nose has a greater dip and swings southeast exhibiting a gentlier dip (Sec. 15, T13S, R3E).

The dominating feature at this mapping horizon is the basin or syncline situated at approximately the junction of T13S-R3E, T13S-R4E, T12S-R3E, and T12S-R4E. The northern portion is a pronounced trough with a local structural high to the east. To the southwest of the basinal feature a structural ridge along the first 31 shot points of seismic section Arco 431-6 was detected. This ridge separates the northern basinal area from a southern syncline that becomes deeper as one proceeds southward. Another regional high, the Erath structure, is found to the east of this southern syncline.

SIPHONINA DAVISI

The Siphonina davis is the second seismic mapping horizon.

The overall general structure of the study area is similar to the Amphistegina B horizon. However, the throw of the existing faults has increased. At this elevation two new faults were discovered, Fault A-E and C (Plate 14). Fault H is not detected by the Teledyne 4-A seismic section, however, there is evidence for its existence in the subsurface geology.

In contrast to the Amphistegina B mapping horizon, Fault B₂ has merged into Fault B₁ so that only the latter is present at this level. Similarly, Fault B has migrated northward into Fault A. South of Fault A and west of Fault B a local fault closure is present. This small domal feature has developed southward, along Fault B₁, into a uniform dipping anticlinal nose. Past Fault B₁ the axis of the structure swings southeast and its dip decreases (Sec. 15, T13S-R3E).

To the west of Fault B₁ the strata dips uniformly to the southeast toward the basin. To the north of the basin the same trough as in the Amphistegina B horizon is present. However, at shot point 380 on the Teledyne 4-A seismic line, Fault A-E cuts off the northern limit of this feature. A fault closure has developed up against Fault A-E where the local structural high previously existed in the Amphistegina B horizon in the Grosse Isle Field.

At the Siphonina davisii level the structural basin appears to have extended southward past the Arco 431-6 seismic line. In contrast to the Amphistegina B mapping horizon there now

exist Faults C and H in the southeast corner of the study area. These two faults have essentially broken up the previous structure into a couple of fault closures. A saddle (Sec. 47, T12S-R4E) separates the Erath and Grosse Isle structures.

UNCONFORMITY

The unconformity is not continuous across the entire area of study. The seismic mapping horizons were chosen as close as possible to the subsurface mapping levels. The seismic unconformity mapping horizon corresponds approximately to that of the geologically mapped geopressured horizon. The subsurface geopressure structure map is based not on a distinct SP "kick" of the induction log, but on the resistivity curve and mud weights. Therefore, the subsurface geopressure map is not completely controlled by stratigraphy. The seismic structure map is based on the discontinuity between strata. This in effect confines the seismic mapping horizon to stratigraphic zones. Both the seismic and subsurface structure maps are fairly close in elevation within the basin. However, when approaching the local structural highs, i.e., Abbeville, Erath, and Grosse Isle structures, the geopressure does not follow the same beds as it did in the basin. In contrast, the seismic mapping horizon is confined to the same strata over the domes as within the basin. For example, when the

large down to the south growth fault in the Erath Field was encountered, the seismic mapping horizon was displaced downward by 1,500 feet (460 meters). Obviously, from the seismic, this is not the unconformity, but the stratigraphic equivalent to that of the horizon within the basin. It can now be seen that within the structurally high areas the seismic and sub-surface maps for this level differ.

The general structure of the study area is similar to the above horizons. At the unconformity mapping horizon Faults A and B₁, with larger throws, still exist. To the west of Fault B₁ and south of A the structural nose, observed in the two shallower horizons, is not as pronounced. At the southern limits of the Arco 431-4 seismic section a local high exists.

At this elevation four more faults have developed. Fault T and S₁ form a horst along Arco 431-9. North of the central basin Fault I and J disrupt the trough previously discussed in the upper horizons. Both Erath and Grosse Isle structures are similar to the above horizons.

DISCORBIS GRAVELLI

The Discorbis gravelli is the deepest mapping horizon in this study. At this depth the quality of the seismic data and its resolution is good enough to detect large features, but it is likely that many smaller features have been overlooked.

At this elevation there exists a rough resemblance in structure to that of the three shallower horizons. The Discorbis gravelli zone is broken up by numerous primary and secondary faults. The faults existing in the unconformity mapping interval are also found at this depth, but they have migrated in the direction of their dip and have increased in throw.

In the west part of the study area the nose has been cut by faults along its axis. The local high that was detected in the unconformity horizon at the southern portion of Arco 431-4 seismic section has now been replaced by Fault P and a local low.

The central basin has migrated eastward, but its general location has not changed greatly (T13S-R3E, T13S-R4E, T12S-R3E, T13S-R4E). However, as seen on Plate 16, the basin is repeatedly broken by secondary faults. The extent of the faulting may be greater than what is depicted. It is difficult to judge the degree of structural damage the faults have done to the central basin, but it is obvious that at this depth the homogeneity of the study area has been greatly disrupted.

GEOLOGIC HISTORY AND SEDIMENTATION

By late Oligocene the study area was located on what was then the continental shelf. In Early Anahuac time water depths were approximately 120 - 300 feet (37 - 90 meters) covering the study area. The sea began to retreat during Heterostegina time (Late Anahuac) and the approximate depth of the sea was then 40 - 120 feet (12 - 37 meters) (Rainwater, 1964). Sediments during this time were mainly shale with some sand and marly sediments.

Two major depositional centers can be seen on the net sand map of the lower geopressured sands (Plate 18). The lower geopressured sands are in the Heterostegina assemblage. The thinning of the lower sands north of Grosse Isle is in response to the large growth Fault I (Plate 5). The thinning of sands on top of the Erath structure attests to its having been actively uplifted during this time.

The Abbeville dome, a structurally high area, experienced uplift during Late Anahuac time. This can be verified by the thinning of Heterostegina sands over the dome. Low density shales, presumably overlying salt, are responsible for the uplift at Abbeville. However, no salt has been drilled to date in the area. Whether the structure is diapiric or not is also still uncertain.

It is suspected that Faults I and Fault A may actually be one, with the Fault I portion being the older. This fault could be responsible for initiating movement of the low density shales and salt in the Grosse Isle area prior to and during Anahuac time, and then later initiating uplift in the Abbeville area. The secondary faulting in the Grosse Isle area appears to predate the secondary faulting in the Abbeville area. Undoubtedly the secondary faulting seen on the Abbeville structure is in response to continued uplift of the Abbeville dome during post-Anahuac time.

Transgression occurred during the Early Miocene, with the Abbeville shale sequence being deposited. The Upper geopressed sands are within the Abbeville section (Plate 17). Again two depositional centers are present. There is a structurally high area in Grosse Isle just as during the Anahuac. The uplift in Abbeville appears to have slowed somewhat as there is less thinning of sands on the dome than during earlier time. Stuckey (1964) found that the updip limit of the Abbeville section is approximately 3 miles (4.8 kilometers) north of the northern boundary of the study area (Fig. 7 & Fig. 8).

By the end of Abbeville time it appears a major escarpment existed in response to Fault H. A noticeable unconformity can be seen with little Planulina palmera sands being deposited on the upthrown side and an enormous amount of Planulina palmera sands deposited on the downthrown side (cross

FIGURE 7
SOUTH LOUISIANA EMBAYMENTS
(STUCKEY, 1964)

FIGURE 8

DIP SECTION, B-B',
LAFAYETTE-VERMILION PARISH, LOUISIANA
(STUCKEY, 1964)

The approximate equivalents to the Amphistegina B seismic reflection horizon at this level consist of variable amplitude, continuous reflections. There is no observable structural feature at this depth, just a bed dipping uniformly gulfward.

The Siphonina davisii equivalent horizon for this particular line is about 6 seconds below the Amphistegina B reflector level. The seismic characteristics are similar to the above horizon. There are no perceptible faults existing at this depth.

However, at the approximate equivalent of the unconformity level, there are two faults, Faults S_1 and G. Fault S_1 is interpreted to be the same fault as mentioned in the Arco 431-6 seismic line. The throw of Fault G is approximately 300 feet (90 meters) and this fault dips to the southeast. As one can see on Plate 11 the two faults form a horst. The seismic reflections have variable amplitude and are not discontinuous across the seismic section.

The deepest reflection horizon, the Discorbis gravelli, has the same structural features and seismic characteristics. However, the throws of the two faults have increased. Again, it is important to remember that at this depth there could exist additional faults other than the ones illustrated.

TELEDYNE 4-A

The fourth seismic section used in the investigation of

section A-A'). The Abbeville section was not seen on the down-thrown side of Fault H because of the estimated 4,500 feet (1,370 meters) of growth.

Abbeville dome continued to be uplifted while the Erath structure became inactive, and regression of the sea occurred. Siphonina davisii time marks the commencement of deposition of the massive sand series that is so common to the Middle Miocene throughout south Louisiana. Predominantly deltaic and delta fringe deposits were laid down during this time span. Continued uplift of the Abbeville dome can be seen from the complexity of faulting on the dome at the Amphistegina B horizon. Minor regressions and transgressions continued until the present geological environments were attained.

RESERVOIR INVESTIGATIONS

TEMPERATURE MAPS

The construction of temperature maps entailed the use of the bottom hole temperatures read directly from the well log. This temperature was considered the most accurate since it was the first temperature recorded as the wire-line survey was being run. A linear gradient was then assumed as the temperature for a given depth was extrapolated from the bottom hole temperature (Schlumberger, 1978). Since assuming a linear gradient is erroneous, the result is a temperature value below what would actually be encountered.

The amount of error will now be discussed. Due to the fact that only one temperature log was available throughout the entire study area, the assumption of linear gradients was necessary. A temperature log was run in the Phillips Petroleum Company, Juanita Unit #1 well located in section 41-13S-4E in Erath field. Using the bottom hole temperature, the extrapolated temperature of the upper geopressured sands in the Juanita well was 212°F (100°C) at a depth of 12,350 feet (3,764 meters). The temperature recorded from the temperature log for the same depth was 238°F (114°C). The extrapolated temperature of the lower geopressured sands at a depth of 12,900 feet (3,930 meters) was 220°F (104.4°C while the recorded

temperature from the temperature log was 250°F (121°C).

From this observation it can safely be assumed that the extrapolated temperatures are 20 - 30 degrees Fahrenheit (-6.7° to -1.1°C) lower than would actually be observed. This discrepancy of temperatures is a result of inadequate temperature recording devices run with the standard electric log. It should be noted, however, that the logs used in this study are relatively old, averaging in the mid 1950's. Undoubtedly present day logging techniques are more accurate. For consistency the extrapolated temperatures of the wells were used in mapping the temperature data.

Two isothermal maps of sand occurrences were completed, one at the top of the upper geopressured sands and the other at the top of the lower geopressured sands. One isotherm map at the 14,000 foot (4,267 meters) datum point was included to show the relation of structural highs to temperature highs on a single depth datum.

The lack of adequate control dictated that changes be made in the normal procedure of mapping isothermal points. Thirty-five wells encountered the upper geopressured sands while only 27 wells were drilled to a depth where the lower geopressured sands were seen. These numbers may seem sufficient, however it is easily seen that the locations of these wells are restricted to the Grosse Isle, Abbeville and Erath areas. From the lack of well control, it is evident that there is

insufficient data from the basins and also that single wells undoubtedly are confined to separate fault blocks. For this reason the locations of faults were not incorporated and the entire study area was isothermally mapped as a single entity.

It should be mentioned that since temperatures are related to depths the faults would displace contours and thus actual temperature maps with sufficient well control would differ somewhat. This difference however is compensated for by the ability to contour across fault blocks without recognition of the faults and assurance that contour configuration is more accurate. One can see that where steep temperature gradients occur faults exist.

From the two temperature maps of the geopressed sands it is seen that all of the structurally high areas show a decrease in temperature (Plates 19 & 20). Likewise the basinal areas show an increase in temperature. The temperatures where no well control is present were contoured by extrapolation.

The maximum temperature to be expected in the western basinal area of the upper geopressed sands is 250°F (121°C). Adding $20 - 30^{\circ}\text{F}$ (-6.7 to -1.1°C) to this value one would expect temperature of 280°F (137.8°C). The steep thermal gradients between the structurally high areas and the basin areas, approximately 70°F (21.1°C), attest to the steepness of the structural configuration within the study area.

The maximum temperature to be expected in the western basin, which is the proposed site for possible testing, in the lower geopressured sands is 290°F (143.3°C) (Plate 20). Again adding $20 - 30^{\circ}\text{F}$ (-6.7 to -1.1°C) the temperature could exceed 300°F (148.9°C). Also seen again is evidence of steep dip between the structurally high areas and the basins.

The average temperature of the upper geopressured sands is about 213°F (100.6°C) while the average temperature of the lower geopressured sands is approximately 230°F (110°C). Both values do not include the correction factor.

In mapping temperatures along a single depth point the temperature gradients do not respond to depth since only one depth is used. Therefore any anomalies would be in response to factors other than structural depth.

The isotherm map at the 14,000 foot (7,260 meters) datum clearly shows the structural highs of Abbeville, Grosse Isle and Erath as temperature highs (Plate 2). Also there are two distinct basinal fairways. It is reasoned that the structural highs are deep seated diapiric salt or low density shale, which have a higher coefficient of thermal conductivity than the surrounding sediments. Thus the thermal highs correspond to these domal features. Such a mapping procedure can prove invaluable in structural delineation of a relatively unexplored area.

Kharaka et al. (1978) found that the temperature gradients for the Lafayette area are lower than the temperature gradients in the Houston-Galveston and Corpus Christi areas and other areas of south Texas (Fig. 9).

PRESSURE MAPS

Maximum expected pressure values were determined from the mud weight used during the drilling of that interval which corresponds to the two geopressured sands. The equation used was $\text{psi/ft} = \text{lb/gal}/19.27$ (Schlumberger, 1978). The mud weight which is recorded as pounds per gallon was simply substituted into the above equation. The resulting value of psi/ft was then multiplied by the depth to the zone in question in the respective well. Thus a final pressure value of pounds per square inch (psi) was obtained.

A quick review of what purpose drilling mud plays in the drilling of a well is essential in the understanding of what is meant by maximum expected pressure. Aside from the extracting of drilled material by circulation of drilling mud, and reduction of friction, a maintenance of a pressure gradient sufficient to enable drilling to proceed is the primary function of drilling muds. Mud weight is maintained so that the pressure exerted within the borehole is greater than that exerted by the formation being drilled. The mud weight is always somewhat greater than that actually required to balance

FIGURE 9

DEPTH/TEMPERATURE PLOT FOR SELECTED
AREAS IN COASTAL TEXAS AND LOUISIANA
(KHARAKA ET AL., 1978)

out the formation pressures. Care must be taken so that the pressure exerted by the mud upon the formation is not so great as to fracture the formation. In such a case a loss of drilling fluid would occur, and other possible dangerous situations could develop. This delicate overbalance in pressure is maintained to prevent any unexpected buildup of pressure that can result in a blowout. For this reason the pressure maps have been labeled maximum expected pressure maps.

In the exploitation of abnormally pressured reservoirs, pressure expectations are essential. Observed pressure measurements are normally carried out during the actual drilling of wells, so that a more accurate mud program can be instituted.

The procedure which was used in determining the maximum expected pressures can prove indispensable in the formulation of drilling mud programs. A comparison of maximum expected pressure to actual pressure observed was available with the aid of pressure vs depth plot provided by Phillips Petroleum of Houston (Fig. 10). The plot is of the Juanita well, the same well in which the temperature log was run.

The maximum expected pressure was found to be 11,023 psi at a depth of 12,350 feet (3,764 meters). The pressure observed from the pressure vs depth plot at the same depth is approximately 10,000 psi. Unfortunately no reasonable guide can be assumed as to how much the maximum expected pressure

FIGURE 10

PRESSURE VS DEPTH PLOT
 PHILLIPS NO. 1 JUANITA, SECTION 41, T13S, R4E
 (PHILLIPS PETROLEUM COMPANY, HOUSTON TEXAS)

exceeds the observed pressure throughout the study area.

Mapping of the pressure data was carried out in the same manner as was the temperature data in regard to the recognition of faults.

As would be expected the structural highs are marked by areas of less pressure while the basins show the greatest pressures (Plates 22 & 23). The greatest maximum expected pressure found within the upper geopressured sands is 14,000 psi and appears to be concentrated in the southwestern portion of the study area. The basinal area, east of the city of Abbeville, has maximum expected pressures of 13,000 psi. The least amount of pressure within the upper geopressured sands is on the Abbeville high which is structurally the highest point at this horizon.

The greatest maximum expected pressure within the lower geopressured sands was found to be 15,000 psi (Plate 23). At this horizon the least pressure can be found upon the Erath dome and is recorded at 11,000 psi. This could indicate that the domal feature at Erath is structurally higher or at least as high as the Abbeville dome at this horizon. It could, however, indicate a lack of data in the Abbeville area.

Average maximum expected pressure within the upper geopressured sands was found to be 11,308 psi. The average maximum expected pressure within the lower geopressured sands was found to be 12,663 psi. The average mud weight for the

upper geopressured sands was 16.66 lb/gal while the average mud weight for the lower geopressured sands was 17.38 lb/gal. These mud weights correspond to average pressure gradients of approximately .865 psi/ft and .902 psi/ft respectively.

Figure 11 shows the results of Kharaka et al., (1978) work in finding on average bottom hole pressure from the Lafayette, Louisiana area.

SALINITY ANALYSIS

If geopressured geothermal waters are to be produced a detailed chemical analysis of the formation waters is of great importance. The production must be carried out as environmentally safe as possible. Economically the presence of certain mineral constituents within the produced waters has a direct bearing on the amount of producible hydrocarbon present. Sodium chloride (NaCl) is by far the most important mineral constituent of formation waters in Gulf Coast geopressured zones.

The solubility of methane within geopressured waters decreases substantially as the salinity content of the formation water increases (Kharaka et al., 1978). The presence of salinity differences can easily be detected on the resistivity curve on induction wire line surveys. Saline waters are less resistive than fresh water. Of course the degree of

FIGURE 11

DISTRIBUTION OF ORIGINAL BOTTOM-HOLE
PRESSURES FROM THE LAFAYETTE AREA, LOUISIANA
(KHARAKA ET AL., 1978)

difference is relative in that the less saline the water the greater the resistivity.

Hydrocarbons by their nature are highly resistive and it is this difference that distinguishes potentially productive areas from those that appear to be not so productive. Hydrocarbons in solution are not directly detectable on the electric log, however by their presence, the salinity of the waters will be lowered and thus the characteristic resistivities of fresh water are noticeable.

Salinities are also important in the disposal of the water used in geopressured geothermal production. Since the volume of water needed to make the use of geopressured geothermal energy economically profitable is so great (40,000 - 50,000 bbl/day; Bernard, 1978) the salinity content must be carefully incorporated into any disposal plans. Overland transportation of this water by way of canals etc., could result in the pollution of farm land and/or fishing grounds. It would seem the most reliable disposal would be in subsurface aquifers which are not in connection with reservoirs used by municipalities for drinking purposes or irrigation.

High salinities also will pose problems in the operation of machinery in the production of geopressured geothermal energy. High salinities and temperatures increase the corrosivity of geopressured-geothermal waters.

Kharaka et al., (1978) stated that "there is no single regional salinity pattern but that different fields have different salinity patterns." He also stated that in his studies of the Gulf Coast, the Lafayette, Louisiana area generally had the highest salinities in abnormally pressured waters. He found the salinities in the Lafayette area, which includes the study area, to range from approximately 19,000 (20 gm/L) to 235,000 parts per million (275 gm/L).

SALINITY MAPS

The most accurate way to determine the salinity content of formation waters is to produce the waters and perform direct chemical analysis upon the produced waters. It is obvious that an oil company will not, if it can help it, produce a well solely for water. So then any analysis would be restricted to economically producing wells which may be a considerable distance from a proposed geopressured-geothermal well. This situation in itself may cause more discrepancy in projections.

Since produced water data was not available, an alternative method of arriving at salinity was used. Through the use of a computer program developed by Bateman and Konen (1977) salinities were derived from the electric log. The program was modified to serve the required purposes of this

study and to fit the computer at the University of Southwestern Louisiana. A copy of the entire program is reproduced in the appendix.

The basic product of the program is the determination of formation water resistivity (R_w) and then, from this, the salinities are derived. The essential input data were obtained or derived from the well logs. This data consisted of: resistivity of the mud filtrate (R_{mf}); temperature of the mud filtrate (T_{mf}); temperature of the formation (T_{fm}); and the spontaneous potential (SP). From this input, values of R_w were obtained and the salinities were then computed with fixed variables found within the program. The other input data were used in pressure computations discussed earlier. Porosity and permeability computations which will be discussed later.

A discussion of the accuracy of the salinity values is pertinent. Since the temperature of the formation plays such a vital role in the computation of salinities, it is the most serious flaw in the procedure when temperatures from linearly derived gradients are below actual formation temperatures. Studies indicate that the higher temperatures, when depth dependent, correspond to less salinity. Under normal conditions water is squeezed out of shales with increasing depth, thus resulting in a freshening effect along with increased temperature. In abnormally pressured sections this

is not always the case, thus high salinities and high temperatures prevail.

During the course of this study, Schlumberger of Lafayette was contacted concerning the procedures that they use in computation of salinities. The procedure used by Schlumberger incorporates the same techniques provided by Bateman and Konen. This is not to say that Schlumberger makes use of inadequate procedures in the service that they offer, but to emphasize that this is the best possible procedure with the available tools.

The salinity values were then mapped using the same procedures in regard to faulting as previously noted. The two salinity maps of the geopressured sands are in Plates 24 and 25.

Noticeable on the two maps is the presence of low salinity areas on the structural highs. This is by no means a set geological rule, since salinities are a function of hydrocarbon accumulations. Low salinities correspond to hydrocarbon accumulation and/or fresh water. In the case of stratigraphically trapped petroleum low salinities would also be present.

The maximum salinity that would be expected in the upper geopressured sands is 200,000 ppm (235 gm/L) within the basinal areas. The maximum salinity that would be expected within the lower geopressured sands is 200,000 ppm (235 gm/L) in the western basin and 250,000 ppm (300 gm/L) in the eastern basin.

A local anomaly of low salinities can be seen on the lower geopressured sand map (Plate 25), south of the Abbeville structure. This should not be interpreted as a possible area for hydrocarbon exploration, for such isolated anomalies undoubtedly are widespread.

Average salinity for the wells that penetrated the upper geopressured sands was 102,590 ppm (110 gm/L) while the average salinity for the wells which penetrated the lower geopressured sands was 93,948 ppm (100 gm/L). As would be expected the lower sands are somewhat less saline.

POROSITY ($\emptyset$) AND PERMEABILITY (K) ANALYSIS

POROSITY ($\emptyset$)

No porosity reading wire line surveys such as sonic logs or neutron density logs were available within the study area. For this reason the procedure that was used to determine porosities is one that was used for many years by engineers, geologists and log analysts before new porosity reading tools were developed (Hitt, 1978). This procedure is still used today when old electric logs are the source of data.

Porosities were found by the use of Archies equation $S_w = \sqrt{R_o/R_t}$ (Pirson, 1963). In this equation S_w = water

saturation, R_t = Resistivity of the formation and R_o = Resistivity of a porous rock at 100% connate water saturation. S_w is also equal to $F \cdot R_w$ where F = Formation Resistivity Factor and R_w = Resistivity of the water as mentioned earlier. An assumption of 100% water saturation was made for S_w and the R_t value was determined from the deepest induction curve on the log which read into the zone of question.

The above relationships allow the solution for F from the assumed S_w and the determined values of R_w and R_t . Once the F values were obtained porosity ($\emptyset$) values were found by substitution of F into the Humble equation (Pirson, 1963) for soft sediments; $F = 0.62/\emptyset^{2.15}$ and solving for $\emptyset$.

Through the courtesy of Texaco, Phillips Petroleum, Chevron and Continental Oil Co., sidewall analyses were available on some of the wells. Of the 35 wells which penetrated the upper geopressured sands only 14 sidewall core data were available. Since the zones which this study is appraising were in many cases were not exploitable by the well operators only 10 of these 14 wells were cored within 100 feet (30 meters) of the upper geopressured zone. Only 5 of the 14 wells were cored within 100 feet (30 meters) of the lower geopressured zone.

The average porosity of the upper geopressured sands was found by the computations to be 25.5%. The average porosity from the sidewall data in the same zone was 23.5%.

A total difference of 2% most certainly is negligible. However, there are some erroneous $\emptyset$ values, e.g., the 18.9% $\emptyset$ of the Joe Stansbury well, section 16-12S-4E. This is more than likely the effect of assuming 100% water saturation, which in reality is not so.

The average calculated porosity of the lower geopressed sands was 23.6%, while the average $\emptyset$ from the 5 sidewall core analyses was just under 24%.

Mapping of porosity data was attempted first by hand and then with the aid of a computer contouring package. It is the author's opinion that both attempts tended to contour the study area in such a way as to overly bias the contouring in favor of the location of well control. Both attempts revealed increasing $\emptyset$ within the basins away from the areas of well control. It is felt that porosity differences between the structural highs and the structural lows is not significant.

PERMEABILITY (K)

Estimations of permeability values were carried out statistically with aid of a program developed by Ogbe and Bassiouni (1978). They found that formation resistivity factor (F) and permeability (K) were related by the equation $F = AK^{-B}$, where K is measured in millidarcies (md) and A and B are coefficients which can be determined from a regression curve in the plotting of the K and F data (Fig. 12).

FORMATION RESISTIVITY FACTOR (F) vs PERMEABILITY (K)

FIGURE 12

FORMATION RESISTIVITY FACTOR (F) VS PERMEABILITY (K)
 "LEAST SQUARES FIT"
 LOWER GEOPRESSURED SANDS, ABBEVILLE AREA

The direct permeability measurements of the sidewall core data were used for the K data. The coefficients A and B are considered suitable for the entire reservoir so that K values can be derived from the electric log with the above equation.

The coefficients of the upper geopressured sands were $A = 20.29$ and $B = .148$, while the coefficients of the lower geopressured sands were $A = 25.79$ and $B = .1585$. The goodness of fit criteria for the least squares fit line through the K and F data was nearly 85%.

Unfortunately the comparisons of the log derived permeabilities and those obtained from the sidewall core analysis differed greatly on an individual well basis. It is of the author's opinion that it is the very nature of permeability itself that has caused the discrepancy. Permeability is dependent upon many geologic factors such as : effective porosity (that $\emptyset$ which is connected), angularity of rock grains, compaction, cementation, etc. Since these factors vary widely, thus permeability itself varies widely. The difference in the manner which the two K values were found probably allows for some difference. Sidewall coring may fracture the formation, thus increasing permeability.

The average permeability of the upper geopressured sands encountered was found to be 110 md, while the average permeability of the lower geopressured sands were 95 md. Those

values of K felt to be in error were disregarded in the averages.

It is felt that the factor of having suitable permeability throughout the reservoir is probably the greatest obstacle to effective economical production from geopressured-geothermal wells.

VOLUMES OF RESERVOIRS

The total surface area and total thickness of the upper and lower geopressured sands were found by grid intergrating the corresponding data in the perimeter outlined in Plates 17 and 18. A one square inch square grid was used in the integrations. Map scales are 1" = 2,000'. Volumes were calculated by multiplying surface area times average thickness for each grid and adding all grid units in the prospect.

Volumes found are considered the maximum volumes one could conceivably expect to find. The perimeters chosen correspond to major faults and structural ridges across which the flow of fluids is undoubtedly restricted. The minor faults were ignored in these calculations to arrive at a maximum reservoir volume.

The volume of the upper geopressured sands is .921 miles³ (1.482 kilometers³), while the volume of the lower geopressured sands is 1.023 miles³ (1.646 kilometers³). Multiplying the

volumes by the average porosities yields an estimate of the total available fluids in the upper sands of .235 miles³ (.378 kilometers³) and in the lower sands of .241 miles³ (.388 kilometers³).

METHANE CONTENT

There has been debate among scientists throughout the world as to how much methane can actually be in solution. It is acknowledged that the solubility of methane increases with increasing pressure and temperature and decreases with increasing salinity.

U. S. studies indicate that 40 - 50 cu. ft./bbl of methane may be dissolved at 10,000 psi and 300°F (148.9°C) in distilled water. According to Bernard (1978) the above concentration would be halved if a sodium chloride content of 150,000 ppm (170 gm/L) is present. Russian studies, however, indicate the possible methane in solution is much higher, near 1000 cu. ft./bbl at 18,000 psi and 350°F (176.7°C) in distilled water. It is easy to see that much research is yet to be done in the estimations of methane solubility.

Randolph (1977) argues that there is a considerable amount of free natural gas trapped in the pores of geopressured aquifers. He states that "this gas becomes mobile as aquifer pressure is reduced by water production."

Jones (1979) feels that enough methane is in solution to actually "milk" a geopressured reservoir for its natural gas. Letting a well flow under controlled blowout conditions would release the pressure in the reservoir and in turn release the methane in solution. If Mr. Jones is correct in his "Champagne" theory, it is conceivable that many of the natural gas caps sought in petroleum exploration may have formed when faulting released pressure within deep geopressured reservoirs allowing natural gas to migrate to suitable traps along fault planes.

Figure 13 (Bonham, 1978) was used to estimate the concentration of methane in solution for the upper and lower geopressured sands. The solubility of methane in assumed pure water for the upper sands is approximately 4,200 parts per million by weight. The estimated concentration for the lower sands is 4,800 parts per million by weight.

Applying Bernard's findings on the effect of salinities upon methane in solution the estimates for the upper geopressured sands is now 2763.74 parts per million by weight. The estimated concentration for the lower geopressured sands is 3296.83 parts per million by weight.

This corresponds in more commonly used units, to a volumetric solubility of methane in solution of approximately 22.9 cu. ft./bbl of formation water for the upper geopressured sands and 27.3 cu. ft./bbl of formation water in the lower geopressured sands.

FIGURE 13
SOLUBILITY OF METHANE IN WATER
(BONHAM, 1978)

CONCLUSIONS

A combination of reservoir, structural and seismic analysis has led to the following conclusions:

1. The lower geopressured sands (Heterostegina sands) are limey in nature and erratic throughout the study area. The upper geopressured sands (Abbeville sands) were found to be "cleaner" but still tending to be somewhat erratic. If production of the sands were to be established numerous perforations in each well would be necessary to assure drainage of the net thicknesses of the sands.
2. Optimistic volumes of both the upper and lower geopressured sands are more likely not sufficient to supply necessary water volumes for the establishment of an electricity generating facility.
3. It has been found that numerous deep faults have broken up the maximum volumetric area of both sands into a number of fault blocks that would greatly reduce the drainage accomplished by any single well.
4. It is doubtful that the temperature of either reservoir meets the requirements of geothermal production. In addition to the relatively low temperatures, the high salinity of the study area would reduce the amount of methane available from solution.

5. Should a well be drilled for testing purposes, the optimum location would be almost directly in the center of section 25-12S-3E. The location would assure maximum thickness of combined geopressured sands in what appears to be a fault free section.

6. From analysis of the study area it was observed that better sand development in the Abbeville-Planulina trend can be found southward of the Erath structure. This thicker section may offer more favorable conditions for geopressured-geothermal considerations.

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APPENDIX A

COMPUTER PROGRAM

```
dimension compn(16), welln(16), Locat(5)
Tsum=0.
Psum=0.
Ssum=0.
Fisum=0.
XKsum=0.
xNA=999.
write(11,3000)
3000 format(/5x,'well name',7x,'location',3x,'Rmf'x6x,'Tmf',
2x,'SP', & 2x,'Tfm',2x,'mudwt',1x,'depth',3x,'Rwt',3x,'
salinity',5x,'psi', & 9x,'Rt',6x,'F',5x,'PHI%',6x,'perm')
4000 format (21x,5a2)
read(10,2000)num,Sw,a,xm,A,B
2000 format(v)
1000 format(16a2)
1050 format(5a2)
ynum=num
do 10 i=1,num
read(10,1000) (compn(i2),i2=1,16)
read(10,1000) (welln(j),j=1,16)
read(10,1050) (Locat(k),k=1,5)
read(10,2000) Rmf,Tmf,SP,Tfm,wtmud,depth,Rt
Rmf75=Rmf*(Tmf+7.)/82.
```



```
if(Rmf75.ge.0.1) go to 50
Rmfe = (146.*Rmf-5.)/(337.*Rmf+77.)
go to 51
50 Rmfe = .85*Rmf
51 xk=.133*Tfm+60.
Rwe75=10.**(SP/xk)*Rmfe
if(Rwe75.ge.0.12) go to 52
Rw75 = (77.*Rwe75+5.)/(146.-337.*Rwe75)
go to 53
52 Rw75 = 10.**(.69*Rwe75-0.24)-0.58
53 Rwt=Rw75*82./(Tfm+7.)
y=(.300e+06)/(Rwt*(Tfm+7.)-1.)
ppm=y**1.05
psi=wtmud/19.27*depth
RO=Rt*Sw**2
F=Ro/Rwt
ym1=1/xm
PHI=(a/F)**ym1*100.
B1=1/B
XK=(A/F)**B1
Tsum=Tfm+Tsum
Psum=psi+Psum
Ssum=ppm+Ssum
if(Rt.eq.xNA) go to 85
Fisum = PHI + Fisum
```

```
XKsum = XK + XKsum  
go to 86  
85 ynum = ynum -1  
86 write(11,1000) (compn(i3),i3=1,16)  
write (11,1000) (welln(j),j=1,16)  
write (11,4000) (Locat(k),k=1,5)  
write (11,5000)Rmf,Tmf,SP,Tfm,wtmud,depth,Rwt,ppm,psi,Rt,F,PHI,XK  
5000 format(29x,f7.2,3x,f5.0,1x,f4.0,1x,f4.0,1x,f5.2,1x, & f6.0,  
1x,f6.3,1x,e9.4,2x,f7.0,2x,f9.3,2x,f5.2,2x,f5.1,2x,f9.0)  
10 continue  
xnum=num  
Tavg=Tsum/xnum  
Pavg=Psum/xnum  
Savg=Ssum/xnum  
fiavg=Fisum/ynum  
XKavg=XKsum/ynum  
write(11,600) num,Tavg,Savg,Pavg,Fiavg,XKavg  
6000 format*//5x,'number of wells = ',i3/5x,'average temperature  
=', & f4.0/5x,'average salinity = ',e10.5/5x,'average pressure  
=',f6.0/ & 5x,'average porosity = ',f4.1/5x,'average permeability  
=',f7.0)  
stop  
end
```

35
 1
 .62
 2.15
 20.29
 .148
 Texaco
 Lula Mae Edwards 1
 11-135-4E
 .49 78 -70 220 17.1 13000
 .45
 Phillips Petroleum & Shelly Oil
 Perrin Unit 1
 15-135-4E
 .25 75 -60 208 17.3 12400
 .30
 Phillips Petroleum
 Caldwell "C" 1
 40-135-4E
 .17 185 -60 200 17.3 12650
 .31
 Tidewater Assoc. Oil Co.
 R.V. Rose 1
 40-135-4E
 .18 75 -35 210 15.8 13500
 .40
 Phillips Petroleum Co.
 Juanita 1
 41-135-4E
 .30 220 -70 238 17.2 12350
 .27
 Phillips Petroleum Co.
 Belaire 1
 41-135-4E
 .17 75 -40 194 17.5 12070
 .30
 Texaco Inc. & Gordon St. Inc.
 Bernard LeBlanc 1
 49-135-4E
 .26 92 -68 194 17.5 12465
 .42
 Cities Service Oil Co.
 Baudin A-1
 13-125-4E
 .39 68 -75 206 15.3 13100
 .48
 Vertex
 Edler Moore
 15-125-4E
 .58 72 -68 220 16.2 13980
 .37
 Trunkline Gas & Cyprus Oil
 Joe Stansbury (Type Lea)
 16-125-4E
 .12 204 -50 204 16.0 13485
 .45
 Texaco Inc.
 Joe Boudreaux Unit 6-1
 16-125-4E
 .42 200 -48 204 16.2 13500

.48
 Texaco
 C.S. Steen Syrup
 17-125-4E
 .27 218 -45 220 15.9 13600
 .30
 Texaco
 Alison Mitchell Unit 3-1
 20-125-4E
 .30 80 -45 225 16.2 13700
 .37
 Texaco
 Adolfe Lyons et al Unit 4-1
 21-125-4E
 .24 209 -48 205 15.6 13600
 .29
 Texaco
 Armet Landry Unit 5-1
 21-125-4E
 .19 204 -53 201 15.8 13590
 .24
 Texaco
 Vallot 1
 21-125-4E
 .73 72 -45 217 17.0 13770
 .55
 H.L. Hunt
 E. Vincent 1
 21-125-4E
 .57 68 -48 230 15.7 13820
 .45
 Phillips Petroleum
 Erath Sugar
 28-125-4E
 .47 100 -57 210 15.8 13410
 .45
 Hauthorne Oil & Gas Corp.
 Erath Sugar Co.
 36-125-4E
 .58 66 -73 216 16.1 14600
 .33
 Chevron Oil Co.
 E.J. LeBlanc 1
 41-125-4E
 .26 70 -80 222 17.6 13300
 .32
 Consolidated Gas Supply Corp.
 Ralph Thibodeaux 1
 42-125-4E
 .50 84 -80 206 16.5 13428
 .25
 Texaco Inc.
 C.C. Derouen Unit 7-1
 43-125-4E
 .63 70 -60 244 15.8 13582
 .30
 H.L. Hunt
 C.F. Broussard 1
 47-125-4E
 .70 70 -58 220 14.8 13372

.45
 Richardson & Bass
 Amerada - C.H. Brookshire Unit 1
 5-125-3E
 .40 90 -45 210 16.5 11400
 .48
 Richardson & Bass
 A. M. Broussard 1
 8-125-3E
 .91 68 -60 200 17.0 11600
 .55
 Superior Oil Co.
 L. S. Goldberg no.1
 30-125-3E
 .54 76 -82.5 218 17.5 11735
 .25
 Sun Oil Co.
 Mailhes 1
 44-125-3E
 .19 212 -45 190 15.2 12545
 .32
 George R. Brown
 L.M. Wise
 48-125-3E
 .42 75 -80 208 16.2 12370
 .43
 Continental Oil
 M.L. Boudin 1
 52-125-3E
 .56 61 -90 193 17.6 11782
 .26
 George R. Brown
 Carrie Mandel 1
 56-125-3E
 .27 208 -80 205 16.9 12315
 .26
 George R. Brown
 Louise LeBoeuf
 60-125-3E
 .43 222 -77 208 17.3 12300
 .30
 Sinclair Oil & Gas Co.
 L. Mestepey 1
 15-135-3E
 .19 236 -40 230 18.3 13700
 .22
 Tennessee Gas
 Luke Detraz A-1
 17-135-3E
 .12 240 -30 226 18.0 13680
 .30
 W.T. Burton
 Veasey 1
 45-135-3E
 .45 80 -40 235 18.4 14670
 .60
 W.T. Burton
 George Eldridge 1
 66-135-3E
 .20 70 -70 205 17.9 13800

.36

APPENDIX B

A 94

well name	location	Rmf	Inf	SP	Tfm	mudwt	depth	Rut	salinity	psi	Rt	F	PHIX	Perm
Texaco Lula Mae Edwards 1	11-13S-4E													
		0.49	78.	-70.	220.	17.10	13000.	0.030	.8818e+05	11536.	0.450	14.91	22.8	8.
Phillips Petroleum & Skelly Oil Perrin Unit 1	15-13S-4E													
		0.25	75.	-60.	208.	17.30	12400.	0.024	.1237e+06	11132.	0.300	12.31	26.9	29.
Phillips Petroleum Caldwell "G" 1	40-13S-4E													
		0.17	185.	-60.	200.	17.30	12450.	0.021	.1573e+06	11357.	0.310	14.68	23.0	9.
Tidewater Assoc. Oil Co. R.V. Rose 1	40-13S-4E													
		0.18	75.	-35.	210.	15.80	13500.	0.029	.9685e+05	11069.	0.460	15.72	22.2	6.
Phillips Petroleum Co. Juanita 1	41-13S-4E													
		0.30	220.	-70.	238.	17.20	12350.	0.021	.1237e+06	11023.	0.270	12.63	24.6	25.
Phillips Petroleum Co. Belair 1	41-13S-4E													
		0.17	75.	-40.	194.	17.50	12070.	0.028	.1140e+06	10961.	0.300	10.81	26.5	71.
Texaco Inc. & Gordon St. Inc. Bernard LeBlanc 1	49-13S-4E													
		0.26	92.	-68.	194.	17.50	12465.	0.024	.1411e+06	11320.	0.420	17.81	21.0	2.
Cities Service Oil Co. Baudin A-1	13-12S-4E													
		0.39	68.	-75.	206.	15.30	13100.	0.025	.1200e+06	10401.	0.480	19.06	20.3	2.
Vertex Edier Moore	15-12S-4E													
		0.58	72.	-68.	220.	16.20	13980.	0.036	.7206e+05	11755.	0.370	10.38	27.0	93.
Trunkline Gas & Cyprus Oil Joe Stansbury (TYPE LOG)	16-12S-4E													
		0.12	204.	-50.	204.	16.00	13485.	0.020	.1634e+06	11197.	0.450	22.35	18.9	1.
Texaco Inc. Joe Boudreaux Unit 6-1	16-12S-4E													
		0.42	200.	-48.	204.	16.20	13500.	0.044	.6103e+05	11349.	0.480	10.88	26.4	67.
Texaco C.S. Steen Syrup	17-12S-4E													
		0.27	218.	-45.	220.	15.90	13600.	0.031	.8449e+05	11222.	0.300	9.60	28.0	157.
Texaco Alson Mitchell Unit 3-1	20-12S-4E													
		0.30	80.	-45.	225.	16.20	13700.	0.033	.7614e+05	11517.	0.370	11.11	24.1	59.
Texaco Adolfe Lyons etal Unit 4-1	21-12S-4E													
		0.24	209.	-48.	205.	15.60	13600.	0.029	.1018e+06	11010.	0.290	10.07	27.3	114.
Texaco Armel Landry Unit 5-1														

Texaco Vallot 1	21-12S-4E	0.19	204.	-53.	201.	15.80	13550.	0.024	.1324e+06	11110.	0.240	10.04	27.4	116.
H.L. Hunt E. Vincent 1	21-12S-4E	0.73	72.	-45.	217.	17.00	13770.	0.074	.3151e+05	12148.	0.550	7.42	31.5	891.
Phillips Petroleum Erath Sugar	21-12S-4E	0.57	68.	-48.	230.	15.70	13820.	0.049	.4695e+05	11260.	0.450	9.14	28.6	218.
Hawthorne Oil & Gas Corp. Erath Sugar Co.	28-12S-4E	0.47	100.	-57.	210.	15.80	13410.	0.039	.6851e+05	10995.	0.450	11.57	25.6	45.
Chevron Oil Co. E.J. LeBlanc 1	36-12S-4E	0.58	66.	-73.	216.	16.10	14600.	0.033	.8219e+05	12198.	0.330	10.14	27.3	108.
Consolidated Gas Supply Corp. Ralp Thibodeaux 1	41-12S-4E	0.26	70.	-80.	222.	17.60	13300.	0.019	.1604e+06	12147.	0.320	17.00	21.4	3.
Texaco Inc. C.C. Berouen Unit 7-1	42-12S-4E	0.50	84.	-80.	206.	16.50	13428.	0.027	.1104e+06	11498.	0.250	9.30	28.4	194.
H.L. Hunt C.F. Broussard 1	43-12S-4E	0.63	70.	-60.	244.	15.80	13582.	0.038	.5920e+05	11136.	0.300	7.88	30.6	593.
Richardson & Bass Amerada - C.M. Brookshire Unit 1	47-12S-4E	0.70	70.	-58.	220.	14.80	13372.	0.047	.5157e+05	10270.	0.450	9.50	28.1	169.
Richardson & Bass A. M. Broussard 1	5-12S-3E	0.40	90.	-45.	210.	16.50	11400.	0.043	.5836e+05	9761.	0.480	10.77	26.5	72.
Superior Oil Co. L. S. Goldberg no.1	8-12S-3E	0.91	68.	-60.	200.	17.00	11600.	0.063	.4154e+05	10234.	0.550	8.77	29.2	290.
Sun Oil Co. Mailhes 1	30-12S-3E	0.54	76.	-83.	218.	17.50	11735.	0.026	.1063e+06	10657.	0.250	9.54	28.0	164.
George R. Brown L.M. Wise	44-12S-3E	0.19	212.	-45.	190.	15.20	12545.	0.028	.1165e+06	9895.	0.320	11.49	25.7	47.
Continental Oil M.L. Boudin 1	48-12S-3E	0.42	75.	-80.	208.	16.20	12370.	0.024	.1242e+06	10399.	0.430	17.70	21.0	3.
George R. Brown Carrie Randel 1	52-12S-3E	0.56	61.	-90.	193.	17.60	11782.	0.026	.1267e+06	10761.	0.260	10.11	27.3	111.

George R. Brown Louise LeBoeuf	56-12S-3E	0.27	208.	-80.	205.	16.90	12315.	0.020	.1616e+06	10800.	0.260	12.86	24.4	22.
Sinclair Oil & Gas Co. L. Mestepey 1	60-12S-3E	0.43	222.	-77.	208.	17.30	12300.	0.026	.1158e+06	11043.	0.300	11.69	25.5	41.
Tennessee Gas Luke Detraz A-1	15-13S-3E	0.19	236.	-60.	230.	18.30	13700.	0.020	.1423e+06	13010.	0.220	11.07	26.2	60.
W.T. Burton Vezey 1	17-13S-3E	0.12	240.	-30.	226.	18.00	13480.	0.023	.1175e+06	12778.	0.300	12.82	24.4	22.
W.T. Burton George Eldridge 1	45-13S-3E	0.45	80.	-40.	235.	18.40	14670.	0.047	.4857e+05	14008.	0.600	12.82	24.4	22.
	66- 13S-3E	0.20	70.	-70.	205.	17.90	13800.	0.020	.1646e+06	12819.	0.360	18.05	20.8	2.

number of wells = 35
 average temperature = 213.
 average salinity = .10259e+06
 average pressure = 11308.
 average porosity = 25.5
 average permeability = 110.

27
 1
 .62
 2.15
 25.79
 .1585
 Texaco
 Lula Mae Edwards 1
 11-135-4E
 .38 85 -75 235 17.0 13800
 .30
 Phillips Petroleum & Shelly Oil
 Perrin Unit 1
 15-135-4E
 .25 75 -68 215 17.3 13000
 .29
 Phillips Petroleum
 Caldwell "6" 1
 40-135-4E
 .09 218 -65 220 17.3 13400
 .33
 Phillips Petroleum Co.
 Juanita 1
 41-135-4E
 .30 220 -70 250 17.3 12900
 .33
 Phillips Petroleum Co.
 Belaire 1
 41-135-4E
 .18 75 -40 199 17.5 12700
 .45
 Texaco Inc. & Gordon St. Inc.
 Bernard LeBlanc 1
 49-135-4E
 .18 88 -60 216 17.5 13100
 .40
 Cities Service Oil Co.
 Baudin A-1
 13-125-4E
 .51 67 -60 208 17.0 13800
 .43
 Verton
 Edler Moore
 15-125-4E
 .48 73 -60 225 16.2 14350
 .42
 Trunkline Gas & Cyros Oil
 Joe Stansbury (TYPE LOW)
 16-125-4E
 .13 215 -45 215 17.1 14420
 .32
 Texaco Inc.
 Joe Boudreaux Unit 6-1
 16-125-4E
 .22 228 -45 228 17.5 14400
 .36
 Texaco
 C.S. Steen Syrup
 17-125-4E
 .17 240 -50 240 17.5 14600

.40
 Texaco
 Alson Mitchell Unit 3-1
 20-125-4E
 .34 76 -40 235 17.7 14400
 .43
 Texaco
 Adolfe Lyons et al Unit 4-1
 21-125-4E
 .20 225 -40 225 17.4 14650
 .63
 Texaco
 Arnel Landry Unit 5-1
 21-125-4E
 .33 222 -40 222 17.3 14350
 .55
 Texaco
 Vallot 1
 21-125-4E
 .73 66 -80 234 17.5 14515
 .49
 H.L. Hunt
 E. Vincent 1
 21-125-4E
 .56 61 -70 232 17.0 14529
 .58
 Phillips Petroleum
 Erath Sugar 1
 28-125-4E
 .31 74 -25 245 16.8 14570
 .42
 Chevron Oil Co.
 E.J. LeBlanc 1
 41-125-4E
 .26 70 -35 245 17.6 15112
 .36
 Richardson & Bass
 Amerada - C.M. Brookshire Unit 1
 5-125-3E
 .23 248 -32 248 17.4 14100
 .38
 Richardson & Bass
 A. M. Broussard 1
 8-125-3E
 .78 82 -30 250 17.8 14000
 1.4
 Sun Oil Co.
 Mailhes 1
 44-125-3E
 .16 280 -63 225 16.0 15000
 .35
 George R. Brown
 L.M. Wise
 48-125-3E
 .54 75 -58 240 17.3 13620
 .63
 Continental
 M.L. Boudin
 52-125-3E
 .56 61 -38 210 17.6 12800

.30
 George R. Brown
 Carrie Randel 1
 56-125-3E
 .36 75 -34 230 17.1 13595
 .50
 George R. Brown
 Louise Le Boeuf
 60-125-3E
 .07 42 -25 222 18.2 13170
 .33
 Tennessee Gas
 Luke Detraz A-1
 17-135-3E
 .13 246 -28 246 18.8 14700
 .41
 W.T. Burton
 Veezey 1
 45-135-3E
 .44 88 -30 248 18.5 15551
 1.7

well name	location	Ref	Inf	SP	Tfm	mudwt	depth	Rut	salinity	psi	Rt	F	PHIX	perm
Texaco Lula Mae Edwards 1	11-13S-4E													
		0.38	85.	-75.	235.	17.00	13800.	0.023	.1152e+06	12174.	0.300	13.12	24.2	71.
Phillips Petroleum & Skelly Oil Perrin Unit 1	15-13S-4E													
		0.25	75.	-68.	215.	17.30	13000.	0.022	.1396e+06	11671.	0.290	13.47	23.9	60.
Phillips Petroleum Caldwell "G" 1	40-13S-4E													
		0.09	218.	-65.	220.	17.30	13400.	0.016	.2115e+06	12030.	0.330	21.14	19.4	4.
Phillips Petroleum Co. Juanita 1	41-13S-4E													
		0.30	220.	-70.	250.	17.30	12900.	0.021	.1212e+06	11581.	0.330	15.93	22.1	21.
Phillips Petroleum Co. Relaire 1	41-13S-4E													
		0.18	75.	-40.	199.	17.50	12700.	0.028	.1087e+06	11533.	0.450	16.00	22.0	20.
Texaco Inc. & Gordon St. Inc. Bernard LeBlanc 1	49-13S-4E													
		0.18	88.	-60.	216.	17.50	13100.	0.020	.1494e+06	11897.	0.400	19.64	20.0	6.
Cities Service Oil Co. Baudin A-1	13-12S-4E													
		0.31	47.	-60.	208.	17.00	13800.	0.039	.6862e+05	12174.	0.430	10.97	26.3	220.
Verten Edler Moore	15-12S-4E													
		0.48	75.	-60.	225.	16.20	14350.	0.036	.7007e+05	12064.	0.420	11.76	25.4	142.
Trunkline Gas & Cyrous Oil Joe Stansbury (TYPE LOG)	16-12S-4E													
		0.13	215.	-45.	215.	17.10	14420.	0.021	.1443e+06	12796.	0.320	15.24	22.6	28.
Texaco Inc. Joe Boudreaux Unit 6-1	16-12S-4E													
		0.22	228.	-45.	228.	17.50	14400.	0.027	.9921e+05	13077.	0.360	13.58	23.8	37.
Texaco C.S. Steen Syrup	17-12S-4E													
		0.17	240.	-50.	240.	17.50	14600.	0.021	.1288e+06	13259.	0.400	19.46	20.1	6.
Texaco Alson Mitchell Unit 3-1	20-12S-4E													
		0.34	76.	-40.	235.	17.70	14400.	0.040	.5794e+05	13227.	0.430	10.70	26.6	258.
Texaco Adolfe Lyons et al Unit 4-1	21-12S-4E													
		0.20	225.	-40.	225.	17.40	14650.	0.027	.9703e+05	13228.	0.630	23.03	18.6	2.
Texaco Arnel Landry Unit 5-1	21-12S-4E													
		0.33	222.	-40.	222.	17.30	14350.	0.041	.6112e+05	12883.	0.550	13.55	23.8	58.
Texaco Vallot 1														

H.L. Hunt E. Vincent 1	21-12S-4E	0.73	66.	-80.	234.	17.50	14515.	0.033	.7471e+05	13182.	0.490	15.04	22.7	30.
	21-12S-4E	0.56	61.	-70.	232.	17.00	14529.	0.032	.7597e+05	12817.	0.580	17.90	20.9	10.
Phillips Petroleum Erath Sugar 1	28-12S-4E	0.31	74.	-25.	245.	16.80	14570.	0.046	.4762e+05	12702.	0.420	9.19	28.5	674.
	41-12S-4E	0.26	70.	-35.	245.	17.60	15112.	0.034	.6645e+05	13802.	0.360	10.48	26.9	294.
Richardson & Bass Amerada - C.M. Brookshire Unit 1	5-12S-3E	0.23	248.	-32.	248.	17.40	14100.	0.033	.6950e+05	12732.	0.380	11.62	25.6	153.
	8-12S-3E	0.78	82.	-30.	250.	17.80	14000.	0.118	.1618e+05	12932.	1.400	11.83	25.4	136.
Sun Oil Co. Matthes 1	44-12S-3E	0.16	280.	-63.	225.	16.00	15000.	0.018	.1637e+06	12455.	0.350	19.13	20.3	7.
	48-12S-3E	0.54	75.	-58.	240.	17.30	13620.	0.040	.5673e+05	12228.	0.630	15.71	22.2	23.
Continental M.L. Boudin	52-12S-3E	0.56	61.	-38.	210.	17.60	12800.	0.068	.3569e+05	11691.	0.300	4.38	40.3	71613. [*] invalid
	56-12S-3E	0.36	75.	-34.	230.	17.10	13595.	0.044	.5388e+05	12064.	0.500	11.44	25.8	168.
George R. Brown Louise Le Boeuf	60-12S-3E	0.07	42.	-25.	222.	18.20	13170.	0.019	.1632e+06	12439.	0.330	17.76	21.0	11.
	17-13S-3E	0.13	246.	-28.	246.	18.80	14700.	0.024	.1051e+06	14341.	0.410	17.44	21.2	12.
Tennessee Gas Luke Detraz A-1	45-13S-3E	0.44	88.	-30.	248.	18.50	15551.	0.059	.3517e+05	14930.	1.700	28.82	16.8	0.

number of wells = 27
 average temperature = 230.
 average salinity = .93948e+05
 average pressure = 12663.
 average porosity = 23.6
 average permeability = 2746.95

APPENDIX C

REDUCED SCALE PLATES

These plates are reductions of the large plates included in the master's thesis at The University of Southwestern Louisiana by Michael P. Duhon and James R. Dungan entitled Subsurface and Seismic Investigation of the Geopressured-Geothermal Potential of the Abbeville Area of South Louisiana, September 1979. They are here for quick reference and comparison as the large folded plates are cumbersome. In the reduction process some information has been lost and it is recommended that the large plates be used for any detailed analysis of this work or for any further work.

ABBEVILLE AREA
VERMILION PARISH, LOUISIANA

TYPE LOG
TEXACO NO. 1 STANSBURY

STRUCTURE MAP
TOP OF Amphistegina 8

GEOL. MICHAEL DUNN
SURV. W. H. FRANK, S. L. WILKINS
AUGUST 1, 1939

- LEGEND
- NO VALUE
 - OIL WELL
 - GAS WELL
 - ⊙ GAS CONDENSATE WELL
 - ◇ DRY & ABANDONED WELL
 - ⊖ ABANDONED OIL WELL
 - ⊖ ABANDONED GAS WELL
 - ⊖ ABANDONED GAS COND. WELL
 - ⊖ TOP OF SAND AT WELL
 - PROPOSED FAULT CUT AT WELL

- LEGEND
- NO VALUE
 - GAS WELL
 - GAS CONDENSATE WELL
 - DRY & ABANDONED WELL
 - ABANDONED OIL WELL
 - ABANDONED GAS WELL
 - ABANDONED GAS COND. WELL
 - TOP OF SAND AT WELL
 - 100' FAULT LUT AT WELL

- LEGEND
- NO VALUE
 - OIL WELL
 - GAS WELL
 - GAS CONDENSATE WELL
 - DRY & ABANDONED WELL
 - ABANDONED OIL WELL
 - ABANDONED GAS WELL
 - ABANDONED GAS-COND. WELL
 - TOP OF SAMPLER WELL
 - SHUT-IN FAULT CUT OFF WELL

NORTH (A)

SOUTH (A')

CHEVRON
LABANC NO 1
SEC 41 T-15S R-4E

TEXACO
DEMOER NO 1
SEC 41 T-15S R-4E

TEXACO
STANBURY NO 1
SEC 41 T-15S R-4E

TEXACO, ET AL
LYONS, ET AL NO 1
SEC 41 T-15S R-4E

PHILLIPS
ERATH SUB NO 1
SEC 41 T-15S R-4E

GOLDING
HARRINGTON NO 1
SEC 41 T-15S R-4E

PHILLIPS
CALDWELL NO 6-1
SEC 41 T-15S R-4E

PHILLIPS
JUANITA UNIT NO 1
SEC 41 T-15S R-4E

PHILLIPS
BELVINE NO 1
SEC 41 T-15S R-4E

ABBEVILLE AREA
A-A' STRUCTURAL
CROSS SECTION

A-100

NORTH (S)

SOUTH (S)

WELL LOGS (from left to right):
1. NATURAL GAS, 100% CH₄, 0% C₂H₆, 0% C₃H₈, 0% C₄H₁₀, 0% C₅H₁₂, 0% C₆H₁₄, 0% C₇H₁₆, 0% C₈H₁₈, 0% C₉H₂₀, 0% C₁₀H₂₂, 0% C₁₁H₂₄, 0% C₁₂H₂₆, 0% C₁₃H₂₈, 0% C₁₄H₃₀, 0% C₁₅H₃₂, 0% C₁₆H₃₄, 0% C₁₇H₃₆, 0% C₁₈H₃₈, 0% C₁₉H₄₀, 0% C₂₀H₄₂, 0% C₂₁H₄₄, 0% C₂₂H₄₆, 0% C₂₃H₄₈, 0% C₂₄H₅₀, 0% C₂₅H₅₂, 0% C₂₆H₅₄, 0% C₂₇H₅₆, 0% C₂₈H₅₈, 0% C₂₉H₆₀, 0% C₃₀H₆₂, 0% C₃₁H₆₄, 0% C₃₂H₆₆, 0% C₃₃H₆₈, 0% C₃₄H₇₀, 0% C₃₅H₇₂, 0% C₃₆H₇₄, 0% C₃₇H₇₆, 0% C₃₈H₇₈, 0% C₃₉H₈₀, 0% C₄₀H₈₂, 0% C₄₁H₈₄, 0% C₄₂H₈₆, 0% C₄₃H₈₈, 0% C₄₄H₉₀, 0% C₄₅H₉₂, 0% C₄₆H₉₄, 0% C₄₇H₉₆, 0% C₄₈H₉₈, 0% C₄₉H₁₀₀, 0% C₅₀H₁₀₂, 0% C₅₁H₁₀₄, 0% C₅₂H₁₀₆, 0% C₅₃H₁₀₈, 0% C₅₄H₁₁₀, 0% C₅₅H₁₁₂, 0% C₅₆H₁₁₄, 0% C₅₇H₁₁₆, 0% C₅₈H₁₁₈, 0% C₅₉H₁₂₀, 0% C₆₀H₁₂₂, 0% C₆₁H₁₂₄, 0% C₆₂H₁₂₆, 0% C₆₃H₁₂₈, 0% C₆₄H₁₃₀, 0% C₆₅H₁₃₂, 0% C₆₆H₁₃₄, 0% C₆₇H₁₃₆, 0% C₆₈H₁₃₈, 0% C₆₉H₁₄₀, 0% C₇₀H₁₄₂, 0% C₇₁H₁₄₄, 0% C₇₂H₁₄₆, 0% C₇₃H₁₄₈, 0% C₇₄H₁₅₀, 0% C₇₅H₁₅₂, 0% C₇₆H₁₅₄, 0% C₇₇H₁₅₆, 0% C₇₈H₁₅₈, 0% C₇₉H₁₆₀, 0% C₈₀H₁₆₂, 0% C₈₁H₁₆₄, 0% C₈₂H₁₆₆, 0% C₈₃H₁₆₈, 0% C₈₄H₁₇₀, 0% C₈₅H₁₇₂, 0% C₈₆H₁₇₄, 0% C₈₇H₁₇₆, 0% C₈₈H₁₇₈, 0% C₈₉H₁₈₀, 0% C₉₀H₁₈₂, 0% C₉₁H₁₈₄, 0% C₉₂H₁₈₆, 0% C₉₃H₁₈₈, 0% C₉₄H₁₉₀, 0% C₉₅H₁₉₂, 0% C₉₆H₁₉₄, 0% C₉₇H₁₉₆, 0% C₉₈H₁₉₈, 0% C₉₉H₂₀₀, 0% C₁₀₀H₂₀₂, 0% C₁₀₁H₂₀₄, 0% C₁₀₂H₂₀₆, 0% C₁₀₃H₂₀₈, 0% C₁₀₄H₂₁₀, 0% C₁₀₅H₂₁₂, 0% C₁₀₆H₂₁₄, 0% C₁₀₇H₂₁₆, 0% C₁₀₈H₂₁₈, 0% C₁₀₉H₂₂₀, 0% C₁₁₀H₂₂₂, 0% C₁₁₁H₂₂₄, 0% C₁₁₂H₂₂₆, 0% C₁₁₃H₂₂₈, 0% C₁₁₄H₂₃₀, 0% C₁₁₅H₂₃₂, 0% C₁₁₆H₂₃₄, 0% C₁₁₇H₂₃₆, 0% C₁₁₈H₂₃₈, 0% C₁₁₉H₂₄₀, 0% C₁₂₀H₂₄₂, 0% C₁₂₁H₂₄₄, 0% C₁₂₂H₂₄₆, 0% C₁₂₃H₂₄₈, 0% C₁₂₄H₂₅₀, 0% C₁₂₅H₂₅₂, 0% C₁₂₆H₂₅₄, 0% C₁₂₇H₂₅₆, 0% C₁₂₈H₂₅₈, 0% C₁₂₉H₂₆₀, 0% C₁₃₀H₂₆₂, 0% C₁₃₁H₂₆₄, 0% C₁₃₂H₂₆₆, 0% C₁₃₃H₂₆₈, 0% C₁₃₄H₂₇₀, 0% C₁₃₅H₂₇₂, 0% C₁₃₆H₂₇₄, 0% C₁₃₇H₂₇₆, 0% C₁₃₈H₂₇₈, 0% C₁₃₉H₂₈₀, 0% C₁₄₀H₂₈₂, 0% C₁₄₁H₂₈₄, 0% C₁₄₂H₂₈₆, 0% C₁₄₃H₂₈₈, 0% C₁₄₄H₂₉₀, 0% C₁₄₅H₂₉₂, 0% C₁₄₆H₂₉₄, 0% C₁₄₇H₂₉₆, 0% C₁₄₈H₂₉₈, 0% C₁₄₉H₃₀₀, 0% C₁₅₀H₃₀₂, 0% C₁₅₁H₃₀₄, 0% C₁₅₂H₃₀₆, 0% C₁₅₃H₃₀₈, 0% C₁₅₄H₃₁₀, 0% C₁₅₅H₃₁₂, 0% C₁₅₆H₃₁₄, 0% C₁₅₇H₃₁₆, 0% C₁₅₈H₃₁₈, 0% C₁₅₉H₃₂₀, 0% C₁₆₀H₃₂₂, 0% C₁₆₁H₃₂₄, 0% C₁₆₂H₃₂₆, 0% C₁₆₃H₃₂₈, 0% C₁₆₄H₃₃₀, 0% C₁₆₅H₃₃₂, 0% C₁₆₆H₃₃₄, 0% C₁₆₇H₃₃₆, 0% C₁₆₈H₃₃₈, 0% C₁₆₉H₃₄₀, 0% C₁₇₀H₃₄₂, 0% C₁₇₁H₃₄₄, 0% C₁₇₂H₃₄₆, 0% C₁₇₃H₃₄₈, 0% C₁₇₄H₃₅₀, 0% C₁₇₅H₃₅₂, 0% C₁₇₆H₃₅₄, 0% C₁₇₇H₃₅₆, 0% C₁₇₈H₃₅₈, 0% C₁₇₉H₃₆₀, 0% C₁₈₀H₃₆₂, 0% C₁₈₁H₃₆₄, 0% C₁₈₂H₃₆₆, 0% C₁₈₃H₃₆₈, 0% C₁₈₄H₃₇₀, 0% C₁₈₅H₃₇₂, 0% C₁₈₆H₃₇₄, 0% C₁₈₇H₃₇₆, 0% C₁₈₈H₃₇₈, 0% C₁₈₉H₃₈₀, 0% C₁₉₀H₃₈₂, 0% C₁₉₁H₃₈₄, 0% C₁₉₂H₃₈₆, 0% C₁₉₃H₃₈₈, 0% C₁₉₄H₃₉₀, 0% C₁₉₅H₃₉₂, 0% C₁₉₆H₃₉₄, 0% C₁₉₇H₃₉₆, 0% C₁₉₈H₃₉₈, 0% C₁₉₉H₄₀₀, 0% C₂₀₀H₄₀₂, 0% C₂₀₁H₄₀₄, 0% C₂₀₂H₄₀₆, 0% C₂₀₃H₄₀₈, 0% C₂₀₄H₄₁₀, 0% C₂₀₅H₄₁₂, 0% C₂₀₆H₄₁₄, 0% C₂₀₇H₄₁₆, 0% C₂₀₈H₄₁₈, 0% C₂₀₉H₄₂₀, 0% C₂₁₀H₄₂₂, 0% C₂₁₁H₄₂₄, 0% C₂₁₂H₄₂₆, 0% C₂₁₃H₄₂₈, 0% C₂₁₄H₄₃₀, 0% C₂₁₅H₄₃₂, 0% C₂₁₆H₄₃₄, 0% C₂₁₇H₄₃₆, 0% C₂₁₈H₄₃₈, 0% C₂₁₉H₄₄₀, 0% C₂₂₀H₄₄₂, 0% C₂₂₁H₄₄₄, 0% C₂₂₂H₄₄₆, 0% C₂₂₃H₄₄₈, 0% C₂₂₄H₄₅₀, 0% C₂₂₅H₄₅₂, 0% C₂₂₆H₄₅₄, 0% C₂₂₇H₄₅₆, 0% C₂₂₈H₄₅₈, 0% C₂₂₉H₄₆₀, 0% C₂₃₀H₄₆₂, 0% C₂₃₁H₄₆₄, 0% C₂₃₂H₄₆₆, 0% C₂₃₃H₄₆₈, 0% C₂₃₄H₄₇₀, 0% C₂₃₅H₄₇₂, 0% C₂₃₆H₄₇₄, 0% C₂₃₇H₄₇₆, 0% C₂₃₈H₄₇₈, 0% C₂₃₉H₄₈₀, 0% C₂₄₀H₄₈₂, 0% C₂₄₁H₄₈₄, 0% C₂₄₂H₄₈₆, 0% C₂₄₃H₄₈₈, 0% C₂₄₄H₄₉₀, 0% C₂₄₅H₄₉₂, 0% C₂₄₆H₄₉₄, 0% C₂₄₇H₄₉₆, 0% C₂₄₈H₄₉₈, 0% C₂₄₉H₅₀₀, 0% C₂₅₀H₅₀₂, 0% C₂₅₁H₅₀₄, 0% C₂₅₂H₅₀₆, 0% C₂₅₃H₅₀₈, 0% C₂₅₄H₅₁₀, 0% C₂₅₅H₅₁₂, 0% C₂₅₆H₅₁₄, 0% C₂₅₇H₅₁₆, 0% C₂₅₈H₅₁₈, 0% C₂₅₉H₅₂₀, 0% C₂₆₀H₅₂₂, 0% C₂₆₁H₅₂₄, 0% C₂₆₂H₅₂₆, 0% C₂₆₃H₅₂₈, 0% C₂₆₄H₅₃₀, 0% C₂₆₅H₅₃₂, 0% C₂₆₆H₅₃₄, 0% C₂₆₇H₅₃₆, 0% C₂₆₈H₅₃₈, 0% C₂₆₉H₅₄₀, 0% C₂₇₀H₅₄₂, 0% C₂₇₁H₅₄₄, 0% C₂₇₂H₅₄₆, 0% C₂₇₃H₅₄₈, 0% C₂₇₄H₅₅₀, 0% C₂₇₅H₅₅₂, 0% C₂₇₆H₅₅₄, 0% C₂₇₇H₅₅₆, 0% C₂₇₈H₅₅₈, 0% C₂₇₉H₅₆₀, 0% C₂₈₀H₅₆₂, 0% C₂₈₁H₅₆₄, 0% C₂₈₂H₅₆₆, 0% C₂₈₃H₅₆₈, 0% C₂₈₄H₅₇₀, 0% C₂₈₅H₅₇₂, 0% C₂₈₆H₅₇₄, 0% C₂₈₇H₅₇₆, 0% C₂₈₈H₅₇₈, 0% C₂₈₉H₅₈₀, 0% C₂₉₀H₅₈₂, 0% C₂₉₁H₅₈₄, 0% C₂₉₂H₅₈₆, 0% C₂₉₃H₅₈₈, 0% C₂₉₄H₅₉₀, 0% C₂₉₅H₅₉₂, 0% C₂₉₆H₅₉₄, 0% C₂₉₇H₅₉₆, 0% C₂₉₈H₅₉₈, 0% C₂₉₉H₆₀₀, 0% C₃₀₀H₆₀₂, 0% C₃₀₁H₆₀₄, 0% C₃₀₂H₆₀₆, 0% C₃₀₃H₆₀₈, 0% C₃₀₄H₆₁₀, 0% C₃₀₅H₆₁₂, 0% C₃₀₆H₆₁₄, 0% C₃₀₇H₆₁₆, 0% C₃₀₈H₆₁₈, 0% C₃₀₉H₆₂₀, 0% C₃₁₀H₆₂₂, 0% C₃₁₁H₆₂₄, 0% C₃₁₂H₆₂₆, 0% C₃₁₃H₆₂₈, 0% C₃₁₄H₆₃₀, 0% C₃₁₅H₆₃₂, 0% C₃₁₆H₆₃₄, 0% C₃₁₇H₆₃₆, 0% C₃₁₈H₆₃₈, 0% C₃₁₉H₆₄₀, 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Sept., 1979

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ABBEVILLE AREA
VERMILION PARISH, LOUISIANA

TEMPERATURE MAP
TOP LOWER GEOPRESSURE SANDS

2000
CENT. BY MICHAEL DUNHAM
SURF. BY W. B. PAINTE - C. L. HALL AND
AUGUST 1979

- LEGEND
- NO VALVE
 - OIL WELL
 - GAS WELL
 - GAS CONDENSATE WELL
 - DRY & ABANDONED WELL
 - ABANDONED OIL WELL
 - ABANDONED GAS WELL
 - ABANDONED GAS COND. WELL
 - TEMPERATURE AT WELL
 - INCOMPATIBILITY

ABBEVILLE AREA
 VERMILION PARISH, LOUISIANA
SALINITY MAP
 TOP LOWER GEOPRESSURED SANDS
 2000 C 1 30,000 PPM
 GEO. D. W. HARRIS, DOWNEY
 SUPV. W. B. FARMER, L. L. KIRKLAND
 AUGUST, 1979

LEGEND
 ● OIL WELL
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 ⊙ GAS CONDENSATE WELL
 ⊖ DRY & ABANDONED WELL
 ⊕ ABANDONED OIL WELL
 ⊗ ABANDONED GAS WELL
 ⊘ ABANDONED GAS COND. WELL
 ■ SALINITY/Well IN PARTS/MILLION
 ■ UNCONFORMITY
 ■ NO VALUE