INTRODUCTION

A study of the hydrogeology of deep sedimentary basins using the Neogene deposits of the northern Gulf of Mexico basin as a model was initiated by the U.S. Geological Survey in the 1960's (Jones, 1969). This study led to investigations of geopressured-geothermal resources in this basin (Papadopulos and others, 1975; Wallace and others, 1979) and of the waste storage capabilities of the Wilcox Group in Texas (Jones and others, 1976). Techniques for delineating pressure, temperature, and salinity variations within the geologic framework were developed in conjunction with these and related studies. The purpose of this hydrologic atlas is to delineate the hydrogeology of the onshore Cenozoic aquifers of south Texas, using these techniques.

The location of the study area in Texas is shown in figure 1. Hydrogeologic cross section *A–A'* is shown in figure 2. The surface geology of the area and the line of section *A–A'* are shown in figure 3. Geophysical logs of oil tests provided the framework for this section. Interpretations presented are based upon data from these logs; information from published ground water and geological reports; and structural and geologic interpretations from maps prepared by Peppard, Scouten and Associates for the U.S. Geological Survey under Purchase Order Numbers 67482 and 67483.

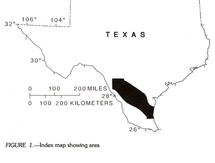

FIGURE 1.—Index map showing area

Some of the correlation lines on cross section *A–A'* (fig. 2) where chosen by mapping the top of a distinctive marker-bed appearing on the well log near the faunal horizon referenced (table 1). These lines, while not being formal stratigraphic boundaries, are the best available representation of the structural and stratigraphic relationships. These lines (fig. 2) are shown for some beds of Cretaceous age which are not otherwise described in this study.

Continuous aquifers and confining systems, composed of multiple stratigraphic units, are identified as major hydrogeologic units. Minor aquifers occur in the confining systems. These minor aquifers, generally contained in one stratigraphic unit, are identified by suffixing "aquifer" to the geographic part of the name of the containing rock-stratigraphic unit (table 1).

This atlas complements Baker's (1979, p. 1–43) delineation of Cenozoic stratigraphy and major Miocene hydrogeologic units in the Coastal Plain of Texas. His determinations are projected and added to, thus extending correlation into older Cenozoic units and geopressured sediments. Baker described, as major hydrogeologic units, the Catahoula confining system (restricted), the Jasper aquifer, the Burkeville confining system, and the Evangeline and Chicot aquifers (table 1). In this atlas, the Midway confining system (restricted), the Carrizo-Wilcox aquifer, and the Oligocene-Eocene confining system are identified as additional major hydrogeologic units. The newly recognized Oligocene-Eocene confining system underlies the Catahoula confining system. This definition removes the need for Baker's restriction. The Midway confining system (restricted) is the basal hydrogeologic unit described. Minor aquifers consisting of sandstones in the Midway Group, Reklaw Formation, Queen City Sand, Sparta Sand, Yegua Formation, Jackson Group, equivalent of the Vicksburg Group, Catahoula Tuff, "Anahuac" Formation, and Fleming Formation occur within confining systems of hydrogeologic units. Deep in the subsurface, a major hydrogeologic unit, the Jasper aquifer, is correlated with the "Miocene" and "Frio" aquifers and the "Anahuac" confining system. Geopressured sandstones form geopressured aquifers within the Wilcox Group, Carrizo Sand, Queen City Sand, Yegua Formation, Jackson Group, equivalent of the Vicksburg Group, and "Frio" Formation and are identified as separate aquifers (table 1).

Stratigraphic nomenclature used in this atlas is a combination of that of the U.S. Geological Survey and of nomenclature commonly used in the subsurface by the petroleum industry. Therefore, it does not necessarily conform to the usage of the Geological Survey.

GEOLOGY

Geologic relations shown in figure 2 and described in this atlas are representative of those found in the onshore Cenozoic deposits of the northern Gulf of Mexico basin. Two centers of maximum accumulation of these deposits in the Gulf Coast geosyncline are shown in figure 4. These materials, which are mostly sand, silt, and clay, were deposited under conditions similar to those presently occurring along the northern Gulf Coast, that is, by river systems crossing the low lying coastal plain and building deltas into the Gulf. Inland deposits compacted and rose above sea level while seaward sediments, has contributed to the structural complexity. Subsequent movement deformed and caused salt to penetrate the Cenozoic sediments at several locations. The Piedras Pintas salt dome (fig. 2, wells 33–34) is a result of such movement. Limestones of Cretaceous and older age, deposited along the inner margin of the Gulf of Mexico before the younger clastic sediments, resisted subsequent deformation and subsidence. Overlying sediments of the Paleocene and Eocene Wilcox Group greatly thicken and are offset by massive growth faults at the Wilcox flexure (fig. 5), immediately gulfward of this Cretaceous limestone shelf (fig. 2, wells 21–30).

Bruce (1973, p. 878–886) related regional faults to geopressured shale. Figures 5, 6, and 7 are from his discussion of this relation. Figure 5 is a diagrammatic cross section illustrating the fault systems (flexures) that are present in the Tertiary sediments of south Texas. Figure 6 is a seismic illustration that shows a large growth fault system related to a residual shale mass. The numbers on either side of the fault system indicate the depositional sequence of sand and shale units. Figure 7 is a seismic illustration that shows faulting related to fault angles. Section *A–A'* of this atlas (fig. 2) is located about 100 miles (160 km) southwest and parallel to section *A–A'* of figure 5. The high ridge of low density, geopressured shale at the coast in figure 5 is not present in figure 2. If the section of figure 2 was extended offshore, it would show a similar high ridge of geopressured shale about midway across the continental shelf. While, as this comparison shows, the specific relations are not the same, the general features shown in figure 5 are similar to those that would be found by any dip section of the coastal and offshore Tertiary sediments of Texas.

The vertical scales in figures 6 and 7 are depth interpreted from time. This results in scale variance with depth. Consequently, vertical exaggeration is about 1/4 at the top of these illustrations and 2.5 at the bottom. Even with this varied vertical exaggeration, these illustrations give a much better visual representation of the subsurface than shown in figure 2, which is greatly exaggerated vertically (52 to 1). Vertical distortion especially affects perception of bed dips and fault inclinations. Many faults that appear nearly vertical in figure 1 were constructed using points from different horizons. Note how the occurrence of the top of geopressured sediments. The true inclination of most of these faults at this position is approximately 45°. With the vertical exaggeration of 52 to 1, beds with actual dip of about 1.5° appear to dip at 45°. The faults, rooted in geopressured sediment shown in figure 2 (wells 21–45), have similar relations to pressure as those illustrated in figure 7; that is, the fault's vertical inclination becomes less in higher pressured sediments. Study of figures 5, 6, and 7 contributes a better understanding of the fault systems that appear in figure 2. Excerpts from Bruce's presentation that are pertinent to the understanding of figures 2, 5, 6, and 7 follow:

"Regional contemporaneous faults of the Texas coastal area are formed on the seaward flanks of deeply buried linear shale masses characterized by low bulk density and high fluid pressure. From seismic data, these masses, commonly tens of miles in length, have been observed to range in sks up to 25 mi (40 km) in width and 10,000 ft (3,000 meters) vertically. These features, aligned subparallel with the coast represent residual masses of undercompacted sediment between sandstone-shale deposoms in which greater compaction has occurred. Most regional contemporaneous fault systems in the Texas coastal area consist of comparatively simple down-to-basin faults.*** In cross-sectional view, faults in these systems flatten and converge at depth to planes related to fluid pressures and form the geometric basis of underlying shale masses.***

The principal process involved in the development of residual shale masses similar to those found in southern Texas is considered to be differential compaction resulting from differential loading and shale diagenesis, both of which control subsur-face fluid movement. In the initial stages of residual shale-mass development, water is free to escape from both the shale and the adjacent sandstone-shale sections. At first the water loss is greater from the shales, because of the relatively higher water content. However, as subsidence continues, water loss from the shale decreases progressively, as a result of decreasing permeability, until a critical depth is reached where orderly expulsion of water from the shale section is restricted and abnormally high pore pressure is developed within the shale mass. If subsidence continues to depths where fluid pressure within the shale approaches total overburden pressure, compaction ceases.***

During the process of abnormal pressure development within the shale mass, the flanking sections of interbedded sandstones and shales continue to compact normally with water loss through the permeable sandstone layers. Water expulsion through the sandstone layers continues as long as the interlayered permeable strata are in communication with the surface.

Additional compaction occurs within the flanking sediments when the critical temperature-pressure level is reached at which montmorillonite is altered to illite. During this process, large volumes of interlayer water are transferred from the montmorillonite into the pore-water system of the host sedimentary section, as suggested by Powers (1967) and Burst (1969). This released interlayer water also can escape through permeable sandstone layers present within the sedimentary section. The amount of water in motion during this stage of clay-mineral diagenesis is considered by Burst (1969) to be 10–15 percent of the compacted bulk volume of the shale involved. This second-stage water loss does not affect the pressured shale section because permeable strata are not present within the mass to permit the escape of fluids. The extended period of water loss from the interbedded sandstone-shale section reduces the thickness of the flanking sediments, leaving them draped on the landward side of the pressured shale mass, and further accentuates the faulting that has developed on the seaward side.***

Flattening at depth is normal for contemporaneous faults in the Texas coastal area. Subsurface data indicate fault flattening to be coincident with progressive increases in fluid pressure with depth."

The first growth fault system (the Wilcox flexure of fig. 5), shown in section *A–A'* (fig. 2, wells 21–30) underlies Webb and Duval Counties. The principal faults in this system are rooted in geopressured Cretaceous or lower Tertiary shales. Most of these faults terminate upward in nongeopressured Claiborne or Jackson sediments and do not reach the surface. Most movement on these faults coincided with deposition of the Wilcox Group and Carrizo Sand.

Other large growth-fault systems, associated with the Vicksburg equivalent and "Frio" and younger flexures (fig. 5), occur downdip, (fig. 2, wells 36 to 45), beneath Jim Wells, Kleberg, and Kenedy Counties. The principal faults of these systems originate in geopressured Eocene, Oligocene, or Miocene shales and most terminate in Oligocene or Miocene normally pressured sediments. The principal movement on these faults coincided with Oligocene or Miocene deposition, and most of the faults do not extend to the surface.

Other faults are also present in figure 2. Those that extend through the Wilcox Group beneath La Salle County (wells 15–20) appear to be isostatic adjustments originating in the Cretaceous sedimentary rocks. Relations between these faults and occurrence of geopressure are absent or ambiguous.

Faults underlying eastern Duval County (fig. 2, wells 32–35) are associated with deep-seated salt movement. These faults are rooted in geopressured Claiborne shales and terminate upward in nongeopressured sediments. The attitude of the beds in this area indicates structural adjustment resulting from withdrawal of salt beneath some areas and emplacement of salt in other areas, such as the Piedras Pintas salt dome (fig. 2, between wells 33–34). This dome penetrates the Miocene sediments and terminates in the Pliocene Goliad Sand. Below the top of the Jackson Group, it is encased in geopressured shale. The salt of the uppper part of the dome is surrounded by normally pressured shales of the Jackson Group, Frio Clay, and Catahoula Tuff. Cap rock at the top of the dome is surrounded by the Oakville Sandstone, the Fleming Formation, and the Goliad Sand.

PRESSURE

Two lines of equal fluid-pressure gradient are shown in figure 2, the 0.5 pound per square inch per foot (lb/in²ft) (11.3 kilopascal per meter (kPa/m)) and the 0.7 lb/in²ft (15.8 kPa/m). Control points to map these gradients were picked using the method described by Wesselman and Heath (1977, p. 1–34). The 0.5 lb/in²ft (11.3 kPa/m) fluid-pressure gradient was chosen to approximate the top of geopressure in figure 2. The 0.7 lb/in²ft (15.8 kPa/m) fluid-pressure gradient was chosen to approximate the top of highly geopressured sediments. This gradient is most easily determined because designers of wells that penetrate highly geopressured sediments commonly collect data and set protection casing close to it.

Sediments above the 0.5 lb/in²ft (11.3 kPa/m) isogradient are considered to be hydropressured (normally pressured). Water from these sediments, tapped by a well, will normally rise above the bed in which it occurs to a position near the land surface. Sediments below this gradient are geopressured and water from wells penetrating these geopressured aquifers will initially flow, having a shut-in pressure equal to the gradient difference between normally pressured aquifers and the screened aquifer times the depth.

The position of the lines depicting fluid-pressure gradients varies in respect to the land surface on section *A–A'* (fig. 2). These gradients are first indicated below well 19. Well 21 is the first well on the section that penetrated geopressured sediments. From well 21 to a high–point occurring in shale of the Jackson Group between wells 34 and 35, the gradients come closer to each other and the land surface while rising through younger sediments. From the Vicksburg flexure (fig. 2, wells 36–38 and fig. 5) to well 45, the gradients separate and are depressed in respect to the land surface while they continue to occur in progressively younger beds.

The highest and most closely spaced gradients occur at the top of geopressured shales that contain very little sandstone. The depressed and more widely spaced gradients occur where the gradients cross zones consisting of interbedded geopressured shales and sandstones.

TEMPERATURE

Depths to six temperature horizons are shown in the cross section (fig. 2). Controls for mapping these geotherms were interpolated from bottom-hole temperature measurements recorded in conjunction with geophysical surveys made in the wells. These measurements were corrected before interpolation to approximate equilibrium conditions. An empirical equation developed by a committee of the American Association of Petroleum Geologists (Kehle, 1971) was used for this purpose. An average temperature of near-surface ground water, determined for a county, was used as an upper reference temperature for interpolation.

Relations between corrected and uncorrected temperatures are shown in figure 8. This vertical temperature profile is typical of many south Texas wells. The break in slope occurring below the second measurement, marks the increase in temperature gradient commonly associated with the top of the geopressured zone.

Sediments in the geopressured zone are mostly shales, and they have the lowest thermal conductivities of the sediment types present in the study area. Lower thermal conductivity and higher heat-storage capacity produce the higher temperature gradient. Evidence of the temperature gradient break illustrated in figure 8 also can be seen in wells 25, 29 and 30 in the section (fig. 2).

The position of the geotherms demonstrates that heat flow is from the interior of the earth. The lateral (horizontal) variations show that this flow is not uniform. The undulations of the geotherms are the result of the interaction of two factors. The first factor is the differences in thermal conductivities of the different materials present. Shale is about one-half as thermally conductive as sandstone, one-third as conductive as dense limestone, one-sixth as conductive as salt, and up to twice as conductive as water. The second factor is mass transfer of heat by fluid movement. Different mechanisms causing water movement are operative in the study area. Expulsion of waters of compaction creates a flow of warm water out of the sediments, while high mounds of water in the outcrops, replenished by recharge, supply relatively cool meteoric water that circulates down into the sediments displacing waters of deposition and compaction. These opposing flows of water of different origins, which usually possess distinctly different chemical compositions and temperatures, mix where they meet. This mixed water, along with surplus recharge waters, is discharged at the land surface as effluent flow. Probably, very little of the waters of compaction reach the surface without mixing. As water is a relatively poor conductor of heat and has a high heat storage capacity, mass movement produces significant transfer of stored heat. Consequently, where water movement has occurred, the position of the geotherms normally has changed.

The local high in the 212°F (110°C) and 248°F (120°C) geotherms in wells 26 and 27 probably indicates heat transfer from geopressured sediments below to the top of the Carrizo-Wilcox aquifer by hot water that has moved up along the faults that are present near the bottom of well 27. Wallace, Taylor, and Wesselman (1977, p. GI–25–42) documented and discussed similar occurrences in south Texas.

Temperatures above 401°F (205°C) occur beneath Duval County (fig. 2) in wells 29 and 30. In these wells, the 401°F (205°C) geotherm occurs at about 14,000 ft (4,300 m). These temperatures are the highest observed at this depth on the section. The maximum temperatures in wells 2,000 ft (610 m) deeper updip (well 21) and 5,000 ft (1,525 m) deeper downdip (well 45) were 365°F (185°C) and 347°F (175°C), respectively. The high temperatures are on the updip side of a thermal high that marks a large area underlain by geopressured shales. These geopressured shales, which contain little or no sandstone, are evident on the geophysical logs from depths above 10,000 ft (3,050 m) to depths of about 20,000 ft (6,100 m) (fig. 2, wells 31–37).

The depression of the geotherms on the updip side of the thermal high is probably due to the presence of calcareous Cretaceous rocks beneath non-geopressured Upper Cretaceous shale (fig. 2, wells 1–17). These generally dense limestones are the best conductors of heat, with the exception of salt, in the study area. The depression on the downdip side of the high results from the presence of large deposits of sandstone.

Temperature control in well 45 (fig. 2) is insufficient to detail the variations in temperature at the Piedras Pintas salt dome (fig. 2, wells 33–34). Control, if present, would probably show a local thermal high at and above the top of the salt. With a thermal null somewhere between, the deeper parts of the salt in the geopressured shale would appear as a thermal low. These effects are expected because of the relatively high thermal conductivity of the salt.

CHEMICAL QUALITY

Chemical quality of the water in the aquifers is differentiated into six ranges in figure 2. Two methods were used to determine approximate chemical quality. One method combined geophysical well-log resistivities with dissolved-solids determinations of water from nearby wells. This method was used to distinguish the water that contained dissolved solids less than 1000 milligrams per liter (< 1000 mg/L). The second method used a computer program to calculate approximate water salinities as sodium chloride (NaC) from spontaneous potential (SP) measurements taken from the geophysical logs of the control wells. This method was used to estimate water quality on the remainder of the section. These estimates, where possible, were also correlated with chemical analyses. However, only a few analyses were available from the deeper aquifers; consequently, most of the water-quality values shown with dissolved-solids concentration of more than 1000 mg/L are calculated values. These values, while useful in describing gross horizontal and vertical variations, are not as accurate as values based upon chemical analyses.

Water salinity in Gulf Coast aquifers generally increases with depth in the hydropressured zone. Maximum salinity at most locations occurs near the bottom of this zone or the top of the geopressured zone. At greater depths, less saline water, released by clay-compaction and diagenesis, reverses the trend (Schmidt, 1973, p. 237; Wallace, Taylor, and Wesselman, 1977, p. GI–51). The younger aquifers of the Gulf Coast are commonly the most saline while older aquifers commonly contain less saline water (Timm and Maricelli, 1953, p. 603–607). Examination of figure 2 produces general agreement with these statements.

Water that has a salinity greater than 110,000 mg/L, commonly occurs in aquifers of Oligocene and Miocene age, mostly in the hydropressured zone, overlying aquifers with waters of less salinity (fig.2,wells 40-45).The source of this water is unknown. Hypotheses that explain occurrences of highly saline water as "membrane-filtered" and as the result of a "salt-filtering" process have been advanced (White, 1965, p. 342–366; DeSitter, 1947, p. 2040). Salt, extruded into the aquifers then dissolved by circulating ground water, is another explanation. Comparison data, these

The water that has a salinity greater than 110,000 mg/L in the Yegua and Jackson aquifers (fig. 2, wells 29–33) was probably derived from dissolution of salt associated with the Piedras Pintas (fig. 2, wells 33–34) and the Palangana salt domes. The Palangana dome, with salt occurring within 500 ft (150 m) of the surface (Hawkins and Jirik, 1966, p. 70), is located 1 mi (1.6 km) west of well 33. The high salinity of the water and the local thermal high shown by the 158°F (70°C) geotherm, where it crosses this aquifer (fig. 2, well 31), both support the conclusion that this water probably traveled from below or downdip, past the salt of these domes, and possibly others that were dissolved, to its present position. This is the only water on the cross section (fig. 2) with salinity greater than 110,000 mg/L in an aquifer older than Oligocene.

The following observations support the hypothesis that perhaps the more saline water resulted from the dissolution of intruded salt by circulating waters:

1. Water with salinity greater than 110,000 mg/L (fig. 2, wells 40–45) occurs randomly in the "Frio" aquifer, "Anahuac" confining system, and "Miocene" aquifer. This water does not appear to be related to pressure differential or shale membrane processes. Dissolution of intruded salt, present in these normally pressured and often massive sands is a more apparent hypothetical source of the increased salinity.
2. Isolation of this water in faulted segments of the aquifers indicates fault movement followed or was coincident with dissolution.
3. Geotherms crossing these aquifers do not indicate recent differential movement of the water.

HYDROGEOLOGIC UNITS

Definition of the Cenozoic hydrogeologic units as they appear on section *A–A'* (fig. 2) follows.

"A hydrogeologic unit is a single stratum or a combination of strata that function in bulk as either a water-bearing or a water-retarding rock complex relative to adjacent strata." (Toth, 1978, p. 807)

In this atlas, major water-bearing units are identified as aquifers and major water-retarding units are identified as confining units. Minor aquifers are recognized as occurring within the confining units, and minor confining layers are recognized as influencing interconnection between sandstones and sands within the aquifers. Studies of the occurrence of geopressure and of differences in temperature and salinity were used in conjunction with study of structural and stratigraphic relationships to make these definitions. Table 1 shows the correlation of stratigraphic units and hydrogeologic units.

Midway Confining System (Restricted)

The Midway confining system (restricted) is the oldest Cenozoic hydrogeologic unit. It is formed by shales of the Midway and Wilcox Groups of Paleocene age. The base of the system is not differentiated in this atlas, as the exact placement of the Cenozoic-Cretaceous boundary is not known. The confining system has a different upper boundary than that of the Midway Group because sandstones of the Midway Group, if in contact with the overlying Carrizo-Wilcox aquifer, are included in that aquifer and because shales of the Wilcox Group in contact with shales of the Midway Group are included in the confining system. The top of the confining system forms the lower boundary of the Carrizo-Wilcox aquifer from the outcrop to the intersection of the aquifer with the 0.5 lb/in²ft (11.3 kPa/m) pressure gradient (wells 1–21).

Aquifers in the Midway Confining System (Restricted)

The sandstones that occur within the 300 ft interval below the base of the Carrizo-Wilcox aquifer in wells 1 and 3 are the only Midway aquifers present. The sandstones shown below these Midway aquifers are considered to be of Cretaceous age. Mason (1960, p. 14–15) reports that the Midway Group is 320 to 500 ft thick in the subsurface of Dimmit County (wells 9–14). He further reports that no known aquifers in this group underlie Dimmit County.

Carrizo-Wilcox Aquifer

The Carrizo-Wilcox aquifer is a hydrogeologic unit formed by sandstones of the Carrizo Sand and the Wilcox Group which are hydraulically connected in many places. Together, these units are considered a primary aquifer in Texas (Baker and others, 1963, p. 1). The aquifer is underlain by shales or silts of the Midway confining system (restricted). The upper boundary of the aquifer generally is marked by silts or shales of the Reklaw Formation, which occur at the base of the Oligocene-Eocene confining system. However, from Dewitt County, south and west to the Rio Grande, sandstone commonly replaces silt and clay in the Reklaw, forming an interconnection between the Carrizo-Wilcox and Queen City aquifers (wells 4 and 9). The Carrizo-Wilcox aquifer system (wells 1–29) in many localities can be subdivided. In wells 11–21, the middle Wilcox shale divides the aquifer system. Faults transect this aquifer system in many places (wells 8–9, 13–15, 22–29). The Carrizo Sand and Wilcox Group thicken at faults downdip (wells 22–31), and aquifer continuity is affected at many horizons.

A large body of fresh water (less than 1,000 mg/L) extends along the top of this aquifer from the outcrop to depths of about 5,000 ft (1,500 m). A discussion of this occurrence follows the description of hydrogeologic units.

Geopressured Aquifers in the Carrizo Sand and Wilcox Group

Geopressured sediments, offset by faults, terminate the Carrizo-Wilcox aquifer downdip (wells 21–29). In the geopressured sediments, sandstones in the Carrizo Sand and Wilcox Group are compartmentalized into separate geopressured aquifers (wells 25–31) by numerous faults. Because of the strike orientation of the major faults, these aquifers generally have a greater continuity in the strike direction.

Oligocene-Eocene Confining System

The Oligocene-Eocene confining system is a hydrogeologic unit formed by shales in the upper part of the Claiborne Group of Eocene age, the Jackson Group of Eocene age, and the equivalent of the Vicksburg Group of Oligocene age. This unit overlies the Carrizo-Wilcox aquifer (wells 1–29) and underlies the Catahoula confining system (wells 25–35). The Oligocene-Eocene confining system is terminated downdip by progressive (wells 25–35).

Aquifers in the Oligocene-Eocene Confining System

This system contains many separate aquifers that are named by modifying the name of the stratigraphic unit in which they occur. Most of these sandstones terminate in nongeopressured shales at or updip from the faults of the Vicksburg flexure (fig. 5 and wells 36–38, fig. 2). Aquifers that are shown include sandstones in the Reklaw Formation (wells 4 and 9), the Queen City Sand (wells 1–31), the Sparta Sand (wells 13–22), the Yegua Formation (wells 16–34), the Jackson Group (wells 19–34), the Frio Clay (wells 25–33) and the equivalent of the Vicksburg Group (wells 34–38). The more numerous and thicker Vicksburg aquifers are extensions of sandstone aquifers found updip in the Frio Clay. The faults associated with the Piedras Pintas salt dome (wells 32–35) displace these sandstones in many places. In this vicinity, the interconnection of aquifers within the Frio Clay and the Vicksburg equivalent is restricted or absent. Other faults associated with the Wilcox flexure (fig. 5 and wells 15–32, fig. 2) extend into the aquifers of this system. The displacement of these faults can affect aquifer continuity.

Geopressured Aquifers in the Queen City Sand, Yegua Formation, Jackson Group, and Equivalent of the Vicksburg Group

Most aquifers of the Oligocene-Eocene confining system terminate updip from geopressured sediments. However, sandstones in the Queen City Sand, Yegua Formation, Jackson Group, and Vicksburg equivalent, offset from the aquifers of the confining system by faults, occur in the geopressured zone (wells 29–39). These geopressured aquifers are compartmentalized by faulting and generally have greater continuity in the strike direction.

Catahoula Confining System

The Catahoula confining system is a hydrogeologic unit formed by shales of the Catahoula Tuff of Miocene and Oligocene age. This unit overlies the Oligocene-Eocene confining system and underlies the Jasper aquifer (wells 25–36). This system terminates in the vicinity of the Vicksburg flexure (fig. 5 and wells 36–38, fig. 2) by merging into an expanded Jasper aquifer (wells 36–40).

Aquifers in the Catahoula Confining System

Sandstones within the Catahoula Tuff are interbedded with shales of the Catahoula confining system. These sandstones comprise individual aquifers within the confining system. Many of these aquifers merge downdip with the Jasper aquifer. Faulting, which occurs in the area of transition, may restrict hydraulic interconnection.

Jasper Aquifer

The Jasper aquifer is a hydrogeologic unit formed by sandstones of the Oakville Sandstone of Miocene age and Catahoula Tuff of Miocene and Oligocene age. This unit overlies the Catahoula confining system and the geopressured "Frio" Formation (wells 29–41). It is overlain by the Burkeville confining system (wells 31–41). Downdip, this unit is broken into three hydrogeologic units; the "Frio" aquifer, the "Anahuac" confining system, and the "Miocene" aquifer. At and near the outcrop (wells 29–36), the Jasper aquifer is composed solely of the Oakville Sandstone. Downdip, at growth faults associated with the Vicksburg flexure (fig. 5 and wells 37–41, fig. 2), the Oakville Sandstone and sandstone of the Catahoula Tuff merge to form a greatly thickened aquifer. The faults along which this thickening and increased sand-content occur also may affect aquifer continuity. Interconnection of the sandstones across the Vicksburg flexure is therefore restricted. Merging of the sandstones of the Oakville Sandstone and the Catahoula Tuff into the Jasper aquifer also occurs in the outcrop in nearby areas (Baker, 1979, fig. 11, p. 25). This merging is due to stratigraphic change along strike and is not affected by faults.

"Frio" Aquifer

The "Frio" aquifer is the lowermost of three subsurface hydrogeologic units that are equivalent to the updip Jasper aquifer (wells 42–45). Composed of sandstones of the "Frio" Formation of Oligocene age and identified only in the deep subsurface, this unit is overlain by the "Anahuac" confining system and underlain by geopressured sediments in the lower part of the "Frio" Formation. Downdip it terminates in shale or geopressured sediment. The "Frio" Formation has a distinctive faunal assemblage, found only in the subsurface, that is used extensively for geologic correlation. Nongeopressured sandstones of the "Anahuac" Formation, where interconnected, are included in the "Frio" aquifer. Faulting in this aquifer restricts aquifer continuity. The "Frio" Formation is equivalent to the lower part of the Catahoula Tuff (Baker, 1979, p. 4).

Geopressured Aquifers in the "Frio" Formation

Sandstones in the "Frio" Formation occur in the geopressured zone, underlying the Jasper aquifer and "Frio" aquifer (wells 39–45). These "Frio" geopressured aquifers occur within shales of the "Frio" Formation and they are compartmentalized by faults. These are the youngest geopressured sediments shown in figure 2. This occurrence is unusual in that, on strike along most of the Texas coast, geopressured sediments are generally first encountered in the "Anahuac" Formation.

Aquifers in the "Anahuac" Confining System

Sandstones that occur within the shale of the "Anahuac" Formation comprise the "Anahuac" aquifers within the "Anahuac" confining system (wells 42–45). These "Anahuac" aquifers are extensions of sandstones of the updip Jasper aquifer. However, due to faulting, the interconnection with the Jasper aquifer is restricted and in some places, may not occur.

"Miocene" Aquifer

The "Miocene" aquifer is the uppermost of three subsurface units that are equivalent to the updip Jasper aquifer. The "Miocene" aquifer is composed of sandstones of the "Anahuac" Formation of Oligocene age that occur above the "Anahuac" confining system, plus interconnected sandstones of the upper part of the Catahoula Tuff, Oakville Sandstone, and Fleming Formation of Miocene age that occur below the Burkeville confining system (wells 41–45). The "Miocene" aquifer is zoned by distinctive faunal assemblages and is faulted. The faulting may restrict aquifer continuity. This is the youngest aquifer that can be seen to be affected by faulting in figure 2. Commonly, the lower beds of the aquifer are faulted while the upper beds of the aquifer are undisturbed.

"Anahuac" Confining System

The "Anahuac" confining system is the middle of three subsurface hydrogeologic units that are equivalent to the updip Jasper aquifer. The "Anahuac" confining system is composed of shales and their contained sandstones of the "Anahuac" Formation of Oligocene age. These sediments separate the "Frio" aquifer below from the "Miocene" aquifer above (wells 41–45). Sandstones of the "Anahuac" Formation in contact with the "Frio" or "Miocene" aquifers are included in those aquifers. Updip, where "Anahuac" shales do not separate the "Miocene" and "Frio" aquifers, all three units merge into the Jasper aquifer.

Burkeville Confining System

The Burkeville confining system, composed mostly of shale of the Oakville Sandstone and the Fleming Formation of Miocene age, separates the underlying Jasper and "Miocene" aquifers from the overlying Evangeline aquifer. This system effectively separates these aquifers in Texas from the outcrop to the coastline. The system is hydrologically breached only where pierced by salt domes. This unit contains a distinctive faunal assemblage that can be traced to the outcrop in some areas.

Aquifers in the Burkeville Confining System

Sandstones of the Fleming Formation of Miocene age comprise the Fleming aquifers within the Burkeville confining system (wells 39–43). In figure 2, no faults extend into the Burkeville confining system and the aquifers of the confining system terminate, by facies changes, updip and downdip.

Evangeline Aquifer

The Evangeline aquifer, composed of interconnected sandstones of the upper part of the Fleming Formation of Miocene age and the Goliad Sand of Pliocene age, is underlain by the Burkeville confining system and overlain by the Chicot aquifer (wells 31–45). The Evangeline and Chicot aquifers are principal sources of water for much of the Texas Gulf Coast. Both aquifers consist mostly of nonmarine deposits. Therefore, faunal identification and zoning are impractical in most areas. These aquifers are separated by, and hydraulically continuous with, different hydrologic and geological properties. The Evangeline aquifer is composed mostly of sand aquifers that have one-half to one-eighth the permeability of the Chicot aquifer. Also, beds of the Evangeline aquifer usually have a regional dip that is at least twice that of the base beds of the Chicot aquifer.

Chicot Aquifer

The Chicot is the uppermost aquifer of the Texas Gulf Coast. Composed of Quaternary sand and gravel, it is confined by surface and interbedded clays of the same age throughout much of the area (wells 35–45), in many areas, interbedded clay beds divide the aquifer into separate units. A basal unit of sand or gravel is commonly present. Therefore, where separation of this unit and the underlying Evangeline aquifer occurs, it is usually by clay in the Goliad Sand.

FIGURE 3.—Index map showing line of section and geology

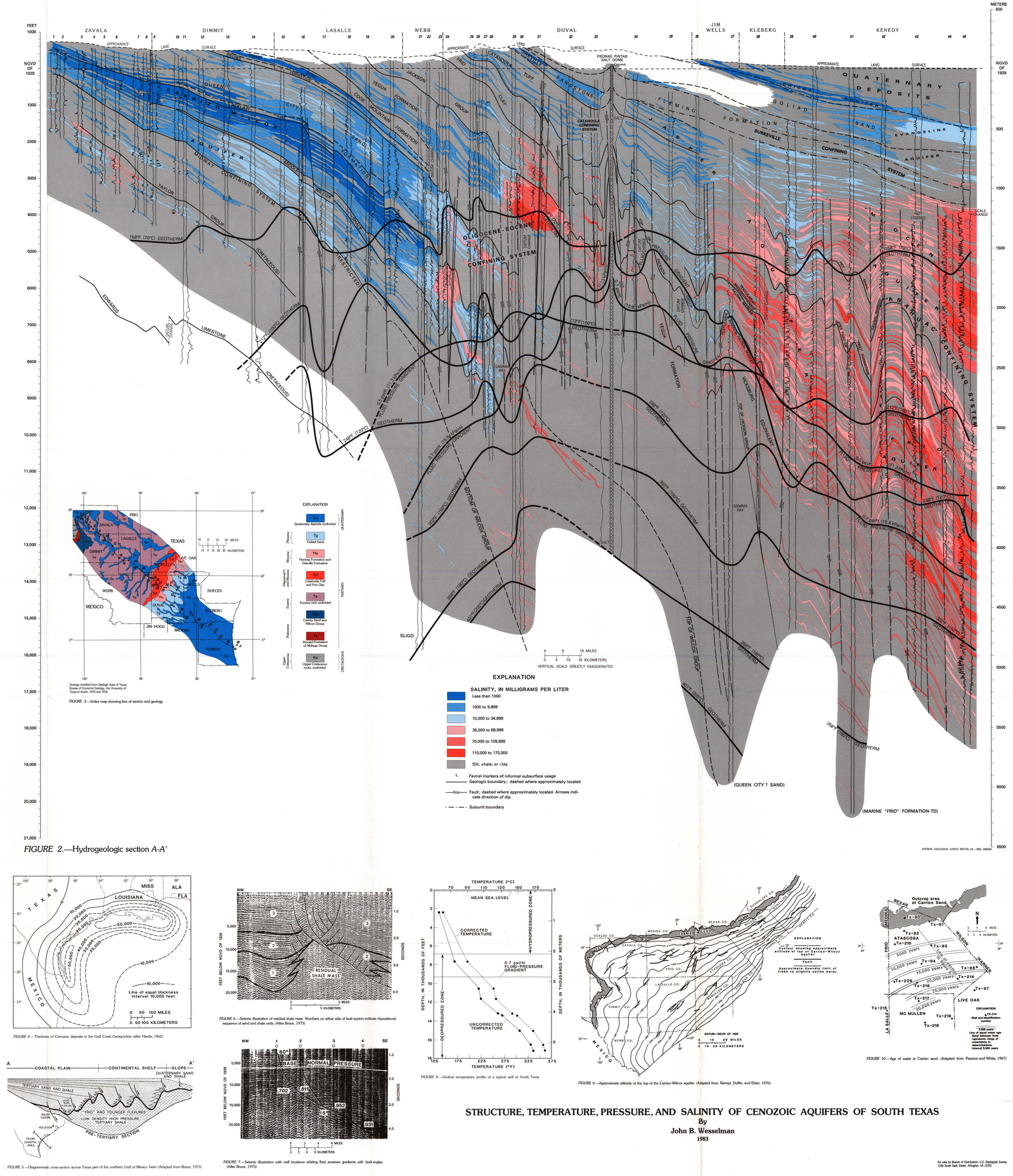

FIGURE 2.—Hydrogeologic section *A-A'*

FIGURE 4.—Thickness of Cenozoic deposits in the Gulf Coast Geosyncline (after Hardin, 1962)

FIGURE 5.—Diagrammatic cross-section across Texas part of the northern Gulf of Mexico basin (Adapted from Bruce, 1973)

FIGURE 6.—Seismic illustration of residual shale mass. Numbers on either side of fault system indicate depositional sequence of sand and shale units. (After Bruce, 1973)

FIGURE 7.—Seismic illustration with well locations relating fluid pressure gradients with fault angles. (After Bruce, 1973)

FIGURE 8.—Vertical temper