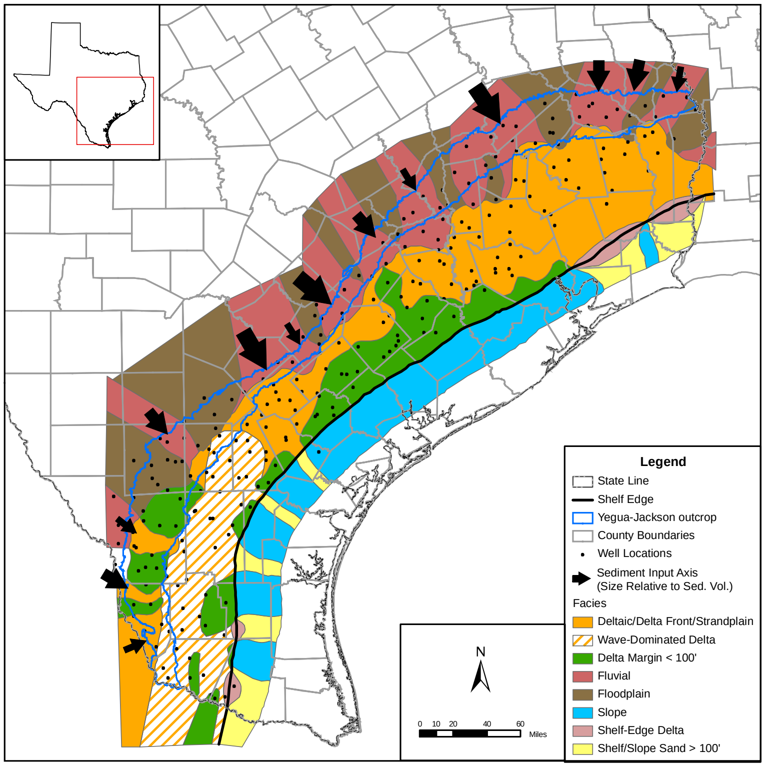
Structure of the Yegua-Jackson Aquifer of the Texas Gulf Coastal Plain



Report

by
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September 2007

Texas Water Development Board

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1. GEOSCIENTIST SEAL

This report documents the work of the following Licensed Texas Geoscientists:

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Mr. Kelley was the Project Manager for this work and was responsible for oversight on the project.

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Executive Summary

This report documents the development of the structure, lithology, and depositional framework for the Yegua-Jackson Aquifer in Texas. The Texas Water Development Board (TWDB) designated the Eocene-age Yegua-Jackson interval as a minor aquifer in the 2002 State Water Plan. This elevation in status from "other aquifer" resulted from the recognition of the large number of wells in the TWDB database completed in the Yegua-Jackson and the relatively large use of water from this interval. The Yegua-Jackson structure presented in this report has been developed specifically to support the TWDB Groundwater Availability Section in their future development of a Yegua-Jackson Aquifer Groundwater Availability Model.

Since 1999, the Texas Legislature has funded the Groundwater Availability Modeling program aimed at providing standardized tools for the assessment of the State's groundwater resources. Due to the early success of the Groundwater Availability Modeling program, Senate Bill 2 (77th Legislature in 2001) mandated that the TWDB shall obtain or develop Groundwater Availability Models for all major and minor aquifers in Texas in coordination with groundwater conservation districts and regional water planning groups (Texas Water Code Section 16.012). The results of this research provide direct support for the future development of the Yegua-Jackson aquifer Groundwater Availability Model and the advancement of the understanding of the hydrogeology, and controls on availability and sustainability, of the aquifer.

The Yegua-Jackson Aquifer exists predominantly in the outcrop or near-outcrop areas of the Yegua Formation and Jackson group. In Texas, this outcrop area stretches in a relatively thin band approximately parallel to the coastline, from Starr County in the Rio Grande Valley to Sabine County in East Texas, and is thus bracketed by the Rio Grande River to the south, and the Toledo Bend Reservoir (along the Sabine River) to the east. The width of this outcrop varies from less than 10 miles in Gonzales County to near 40 miles in La Salle County, with an area of approximately 11,000 square miles.

The Yegua Formation overlies the Cook Mountain Formation and is uppermost in the Middle Eocene Upper Claiborne group. This group is overlain by the Upper Eocene to Oligocene Jackson Group. In Texas, the Jackson Group consists of the Whitsett, Manning, Wellborn, and Caddell formations (or their analogues). The Yegua-Jackson interval continues across the Sabine River into Louisiana, where the Yegua Formation is called the Cockfield Formation, and

the Jackson Group is undifferentiated. Thickness of the total interval ranges from less than 1,800 feet over the San Marcos Arch to more than 3,000 feet in the Houston and Rio Grande depositional basins. Structural dips vary from about 20 to 360 feet per mile, with the greater dips occurring in the downdip regions and across the San Marcos Arch, a persistent structural feature that was mildly active during the time of Yegua and Jackson deposition. The Yegua-Jackson interval is comprised of interbedded sands, silts, and clays deposited in settings ranging from fluvial to marginal marine (deltaic and barrier/strandplain) to shallow marine shelf. Deltas in the Rio Grande Embayment of South Texas are considered by many workers to have greater wave influence and, consequently, a greater tendency toward shore-parallel alignment and internal fabric. In contrast, deltas from the middle of the Texas coast northeastward have greater fluvial influence and, thus, large sand bodies are more often aligned perpendicular to the coast.

Our analysis was initiated with a complete review of previous published information regarding the stratigraphy and hydrogeology of the aquifer. An abundant body of previous work exists for the Yegua-Jackson interval because of its extensive resources of oil, gas, coal, and uranium. Geologic investigations extend from initial and broad stratigraphic investigations in the 19th century to modern-day detailed subsurface structural, chronostratigraphic, micropaleontologic, and depositional analyses. The hydrogeologic literature is more limited in quantity and scope than the stratigraphic literature and includes county water resource studies by both the United States Geologic Survey and the TWDB.

The structure analysis was comprised of the following activities: collection of available geologic and geophysical data; chronostratigraphic analysis of the sequence stratigraphic units within the Yegua-Jackson; lithologic analysis of resulting aquifer layers; and mapping of aquifer layer structure, net sand distributions, and depositional systems. Data used to support structure development is comprised of three types: (1) stakeholder data; (2) borehole geophysical logs; (3) literature data on Yegua-Jackson structure and on Yegua-Jackson lithology and depositional systems. Contact was attempted with all thirteen Groundwater Conservation Districts in the Yegua-Jackson Aquifer boundaries in an attempt to collect relevant source data. Our solicitation for additional data from stakeholders resulted in no electric log data which could directly be used in the project.

A grid of well logs and cross sections established by Dodge and Posey (1981) were used as a basis to develop a collection of geophysical logs. Where original logs were missing or inadequate for the study (did not cover the stratigraphic interval) and where wells were needed to create a more uniform grid, additional well logs were obtained from Bureau of Economic Geology files. Additionally, geophysical logs from two Yegua-Jackson wells in the TWDB library were gathered, and about 30 logs were obtained from the files of the Texas Commission on Environmental Quality Surface Casing Division. A total of 250 geophysical logs were selected, gathered, and scanned at 300 to 400 dots per inch resolution. Well locations were confirmed from Tobin basemaps, and latitudes and longitudes were transferred to a geographic information system database with a resulting accuracy of approximately 1 mile. The spontaneous potential and resistivity curves from 150 logs were digitized for consistent, repeatable percent-sand calculations.

For this study, maximum flooding surfaces within fine-grained highstand deposits were correlated in geophysical well logs arranged in dip-oriented cross sections, connecting low-resistivity markers in downdip shale sections with shales or abrupt-based sands in updip sandy and silty intervals. Initial correlations of very low frequency maximum flooding surfaces defined the chronostratigraphic base of the Yegua and an interval suspected of containing the top of the Jackson. Early attempts to correlate high-frequency maximum flooding surface-bounded units within the Yegua and Jackson intervals produced inconsistent results. A strike-oriented section was created to assist in the recognition of major depositional packages that contain multiple maximum flooding surface-bounded units. The resulting four major layers were then correlated in dip sections and loop-tied along parallel strike sections.

The Yegua interval includes at least eight stratigraphically distinct higher frequency genetic units that have been grouped into two main aquifer layers in this study. The Jackson interval consists of at least seven genetic intervals that have also been grouped into two aquifer layers for this study. The project has successfully developed a chronostratigraphic framework for the Yegua-Jackson Aquifer that spans its entire extent in Texas. The four major layers (third-order genetic units) include, from the bottom upward, the Lower Yegua, Upper Yegua, Lower Jackson, and Upper Jackson layers, which each span one to two million years of deposition (third-order genetic units) and are of appropriate scale for regional groundwater availability modeling (generally 400 to 800 feet thick, thickening in the downdip direction). As previously mentioned, these four aquifer layers are comprised of 15 or more finer units which are of fourth-order scale, each spanning a period of 100,000 to 400,000 years.

The chronostratigraphic Lower Yegua Unit is underlain, by definition, by a maximum flooding surface. This surface outcrops outside of the current Yegua-Jackson Aquifer boundary, and was thus not suitable as an aquifer layer boundary. To resolve this, we added a lithostratigraphic surface to serve as the bottom of the lowermost aquifer layer. This surface is referred to as the Base Yegua-Jackson Aquifer. The Base Yegua-Jackson Aquifer was picked to coincide with the first significant Yegua sands above the shales of the Cook Mountain Formation. Because the Base Yegua-Jackson Aquifer surface is lithostratigraphic in nature, it correlates well with the updip limit of the Yegua-Jackson Aquifer as determined through lithostratigraphic surface mapping.

A semi-automated approach was used for estimating aquifer lithology, defined as either being sand or shale. The automated approach was based on a simple set of rules that an analyst might use in interpreting a well log manually. The set of rules were applied in a consistent manner to the digitized electric log data for each well and yielded picks of sand or shale every 0.5 feet (the vertical resolution of the log data). Values were summed over each layer to yield total sand thickness by layer. In the Lower Yegua Layer, sand deposition occurs nearly equally in the Houston and Rio Grande embayments, decreasing over the San Marcos Arch. However, in the Upper Yegua and Lower and Upper Jackson Layers, the Rio Grande embayment appears to receive more sandy sediment than the Houston embayment.

For the four Yegua-Jackson Aquifer layers, sand thickness trends from this study and other published studies were incorporated with interpretations of depositional setting based upon log curve shape and previous work. Within each aquifer layer, the dominant regional depositional facies distributions were interpreted, then those boundaries were hand-drawn, then digitized, for incorporation as a geographic information system layer. In many cases, sand thickness values were used as proxies for determining position within a larger depositional system. The resulting facies-based regions of a layer will be of help in the conceptualization and implantation of hydraulic properties into future groundwater availability models of the aquifer.

The work documented in this report will provide basic data required to develop a Groundwater Availability Model capable of supporting the management of groundwater resources in the

Yegua-Jackson Aquifer. The chronostratigraphic approach used in this study is more reliable than previous lithostratigraphic approaches at identifying and correctly connecting aquifer layers and intervening aquitards. The result is a more reliable three-dimensional description of the aquifer that, if implemented in a numerical groundwater model, should provide a more accurate description of aquifer dynamics. This is important because several regions have developed water management strategies in the 2007 State Water plan that include the drilling of new wells and water desalinization in the Yegua-Jackson Aquifer. With the implementation of those proposed water management strategies, production from the aquifer is expected to exceed 15,000 acre-feet per year by 2040.

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1. Introduction

The Texas Water Development Board (TWDB) designated the Eocene-age Yegua-Jackson interval as a minor aquifer in the 2002 (TWDB, 2002) water plan. This increase in status from “other aquifer” was a consequence of the recognition of the large number of wells in the TWDB database completed in the Yegua-Jackson and the relatively large use of water from this interval (Preston, 2006). In the 2007 State Water Plan (TWDB, 2007), it is reported that the existing groundwater and supplies in the aquifer is 7,285 acre-feet per year (assuming existing wells and infrastructure) with a total availability estimated at 25,000 acre-feet per year. Several regions have developed water management strategies in the 2007 State Water plan which include the drilling of new wells and desalinization. With the implementation of the proposed water management strategies, production from the aquifer is expected to exceed 15,000 acre-feet per year by 2040.

Because the Yegua-Jackson has been designated a minor aquifer and because it has significant water use and projected use, the TWDB will seek to develop a groundwater availability model of the aquifer. From a hydrogeologic perspective, there has been very little work done in the Yegua-Jackson Aquifer, especially at a scale larger than an individual county (Preston, 2006). As a result, the TWDB sponsored this study to develop the Yegua-Jackson Aquifer structure for the complete Texas section. The Yegua-Jackson Aquifer exists predominantly in the outcrop or near-outcrop areas of the Yegua Formation and Jackson Group. In Texas, this outcrop area stretches in a relatively thin band approximately parallel to the coastline, from Starr County in the Rio Grande Valley to Sabine County in East Texas, and is thus bracketed by the Rio Grande River to the south, and the Toledo Bend Reservoir (along the Sabine River) to the east. The width of this outcrop varies from less than 10 miles in Gonzales County to near 40 miles in La Salle County, with an area of approximately 11,000 square miles (Preston, 2006).

The study began with a review of the abundant body of previous work existing for the Yegua-Jackson interval. The literature review was followed by a gathering of geophysical well logs, chronostratigraphic analysis, digital lithologic analysis, and mapping of structure, sand distribution, and depositional systems. The analysis incorporates stratigraphic interpretations from 250 well logs within the outcrop and along the downdip boundaries of the aquifer. This log data has been used to subdivide the Yegua and Jackson intervals into four major genetic units on the basis of maximum flooding surfaces, which are presumed to be time-synchronous. These four genetic units correspond to four layers into which the Yegua-Jackson Aquifer was subdivided, with one exception. The maximum flooding surface at the base of the lower Yegua genetic unit occurs within the underlying shale-dominated Cook Mountain Formation and outcrops outside of the Yegua-Jackson Aquifer boundary. In this case, a lithostratigraphic surface, referred to as the Base Yegua-Jackson Aquifer, was created and used to bound the lowest aquifer layer.

The spontaneous potential and resistivity curves from 150 logs were digitized for consistent, repeatable percent-sand calculations. The accumulated new structural and lithologic data were then incorporated with trends from previous studies to produce updated maps spanning the aquifer trend from Mexico to Louisiana.

The Yegua interval includes at least eight stratigraphically distinct units that have been grouped into two main layers in this study. The Jackson interval consists of at least seven genetic intervals that have also been grouped into two layers for this study. The four layers of the combined Yegua-Jackson interval are each third-order units whose deposition spans one to two million years. The 15 or more finer units which comprise these four layers are of fourth-order scale, each spanning a period of 100,000 to 400,000 years. In the Lower Yegua Layer, sand deposition occurs nearly equally in the Houston and Rio Grande embayments, decreasing over the San Marcos Arch. However, in the Upper Yegua and Lower and Upper Jackson Layers, the Rio Grande embayment appears to receive more sandy sediment than the Houston embayment.

The Yegua-Jackson section was described through the development of 30 dip sections and 3 strike sections. Initial correlations defined the base of the Yegua and an interval suspected of containing the top of the Jackson. Early attempts to correlate finer-scale maximum flooding surface-bounded units within the Yegua and Jackson intervals produced inconsistent results. A strike-oriented section was created to assist in the recognition of major depositional packages that contain multiple maximum flooding surface-bounded units. Major layers were then correlated in dip sections and loop-tied along parallel strike sections.

Cumulative sand thickness in aquifer studies has been determined in the past using many different approaches, yielding results that are sometimes difficult for subsequent workers to reproduce. To overcome this issue, 150 well logs were selected, and spontaneous potential and resistivity curves digitized. Baseline values for shale and/or sand were established and a cutoff value was used that produced results similar to geologist estimates. Because the study interval included freshwater, transitional, and saline water-saturated sediments, different algorithms and cutoffs were used for each interval. In freshwater zones, the resistivity curve was used to delineate lithology. In saline zones, spontaneous potential was used. In transitional zones, either curve or a combination of curves was used, depending on mud resistivity and resulting spontaneous potential behavior.

The project has successfully developed a chronostratigraphic framework for the Yegua-Jackson Aquifer that spans its entire extent in Texas. The four major layers (third-order genetic units) include, from the bottom upward, the Lower Yegua, Upper Yegua, Lower Jackson, and Upper Jackson. These layers are of appropriate scale for regional groundwater availability modeling (generally 400 to 800 feet thick, thickening in the downdip direction). Sand content in these layers is typically greatest in the Houston and Rio Grande embayments of southeast Texas and South Texas, respectively.

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2. Study Area and Geologic Setting

This section of the report will describe the general study area in terms of location, physiography and climate and will also describe the geologic setting for the Yegua-Jackson Aquifer of Texas.

2.1 Description of the Study Area

The Yegua-Jackson Aquifer of Texas includes the outcrop of the Yegua Formation and the Jackson Group as well as a small area downdip of the outcrop. It lies just north of the extensive Gulf Coast Aquifer and just south of the Sparta Aquifer. The Yegua-Jackson Aquifer roughly parallels the Gulf Coast shoreline and lies from 70 to 120 miles inland of the coast (Figure 2-1). It is a narrow band ranging from 15 to 40 miles wide (Preston, 2006) extending almost 500 miles within Texas from the Mexican border to the Louisiana border and including parts of 35 counties (Preston, 2006). The aquifer extends north from the Mexican border in Starr County, paralleling the Rio Grande into Webb County, where it turns to the northeast. It becomes narrower (and dips more steeply) in the central extent from Wilson to Fayette counties, arching farther away from the coast to the north. The aquifer trends northeast from Bee County to Houston County, where it bends more eastward to meet the Louisiana border in Sabine County.

Rainfall varies across the study area, from an average of only about 20 inches per year in South Texas to over 50 inches per year in East Texas (Larkin and Bomar, 1983). This climate trend not only impacts aquifer recharge and downdip extent of fresh water, but also affects soil development and vegetation types. These latter issues can potentially complicate surface geology mapping, especially in East Texas where soils are thick and vegetation is extensive.

Land surface within the study area generally slopes gradually east and southeast across the upper coastal plain of Texas. Relief is generally subdued across the rolling lowlands, although outcrops of certain indurated sands can produce local topographic variations exceeding several tens of feet (Preston, 2006).

This study incorporated both available surface mapping and subsurface data to collect adequate information for numerical aquifer modeling. Thus, the study area extends as much as 60 miles downdip (coastward) of the southern aquifer boundary. Within this 36,000 square-mile area, geophysical well logs from oil and gas wells and a few water wells were selected and linked into a system of dip- and strike-oriented cross sections to evaluate the three-dimensional structure, stratigraphy, and lithology of the aquifer (Fig. 2-2, Plate 1).

2.2 Geologic Setting

The alternating sand- and clay-rich Yegua-Jackson interval includes the Middle Eocene Upper Claiborne Group (Yegua and Cook Mountain formations) and the overlying Upper Eocene to Oligocene Jackson Group (Caddell, Wellborn, Manning, and Whitsett formations), as shown in Figure 2-3. These units dip toward the modern coastline and are part of the progressive filling of the Gulf of Mexico basin by sand, silt, and clay carried from the mountains of northern Mexico and the Rocky Mountains, as well as from other areas of Texas and the western part of the North American continental interior. These sediments, deposited in rivers and deltas, and even farther offshore, create a gradual down-warping (subsidence) of the Earth’s crust along the edges of the basin. Thus, sediments of the Yegua-Jackson interval dip more steeply toward the gulf than the current land surface. Additionally, because sediment deposition has outpaced the slow subsidence, the current shoreline has built farther toward the center of the Gulf of Mexico than the shoreline that existed during Yegua-Jackson deposition.

Yegua-Jackson deposition was focused in the Houston and Rio Grande Embayments (Figure 2-1), where downwarping of the crust by tectonic forces was greatest. The northwest-southeast trending San Marcos Arch (Figure 2-1) represents a long-standing tectonically uplifted area in Central Texas and acts to separate the Houston and Rio Grande Embayments. To the west and south of the Yegua-Jackson outcrop lay the Del Rio and Picachos foldbelts (Figure 2.1), which are associated with tectonic compression in northeastern Mexico, possibly before, during, and after Yegua-Jackson deposition. During the early phases of the development of the Gulf of Mexico Basin, salt was deposited in layers because the basin was small and did not have good circulation with the open ocean. As a result, evaporation exceeded water influx over many millions of years. Salt was generally deposited south and east of the Balcones escarpment trend, and areas of especially thick salt accumulation occurred in the Rio Grande and Houston Embayments (Figure 2-1). Basinward sliding of this salt layer may have had localized affects on Yegua-Jackson deposition and post-deposition structure. A less obvious tectonic feature which might slightly impact Yegua-Jackson structure is a series of northwest-trending transfer faults that are known from offshore Texas that were initiated during the opening of the Gulf of Mexico

(Figure 2-1). These transfer faults appear to have influenced salt tectonics in the Gulf of Mexico (Huh and others, 1996) and may have had minor lateral movement throughout the Tertiary. Transfer faults may also bound areas of differential salt movement under the study area.

The Yegua-Jackson interval is overlain in outcrop by an interval variously mapped as Catahoula Formation and Frio Formation (Plate 2; Barnes 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, and 1992). This interval varies laterally from clay-rich to locally sand-rich and, in South Texas, contains tuff and volcaniclastic conglomerates. Over much of the aquifer area and in the subsurface, this interval overlying the Yegua-Jackson interval includes the Oligocene-age Vicksburg and overlying Frio Formations, which reflect later pulses of sandy sediment influx into the Gulf of Mexico basin. In East Texas, Anders (1967) states that it is not possible to separate the overlying Vicksburg sediments from Jackson sediments. Thus, in eastern counties the Vicksburg has probably been mapped by Barnes (1968a, 1968b, 1992) as part of the Jackson Group.

Below the Yegua-Jackson interval in outcrop is a generally shaly interval mapped as the Cook Mountain Formation of the upper Claiborne Group or, in South Texas, as the Laredo Formation (Plate 2; Barnes, 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). In the subsurface, the study interval is underlain by shale-rich Cook Mountain Formation and, beneath that, the sand-rich Sparta Formation of the Lower Claiborne Group. The Cook Mountain Formation thins in the updip direction, almost pinching out before reaching outcrop in some locations. The Cook Mountain Formation separates the Sparta Aquifer below from the Yegua-Jackson Aquifer above.

Thickness of the total Yegua-Jackson interval ranges from less than 1,800 feet over the San Marcos Arch in Central Texas to more than 3,000 feet in the Houston and Rio Grande depositional basins of East and South Texas, respectively. Structural dips vary from about 20 to 360 feet/mile (Preston, 2006), with the greater dips occurring in the downdip regions and across the San Marcos Arch. The interval is comprised of interbedded sands, silts, and clays deposited in settings ranging from fluvial to marginal marine (deltaic and barrier/strandplain) to shallow marine shelf (Galloway and others, 1979). Deltas in the Rio Grande Embayment of South Texas are considered by many workers to have greater wave influence and, consequently, a greater tendency toward shore-parallel alignment and internal fabric. In contrast, deltas from the middle of the Texas coast northeastward have greater fluvial influence and, thus, large sand bodies are more often aligned perpendicular to the coast.

The generalized chronostratigraphy and lithostratigraphy for the Yegua-Jackson interval are shown in Figure 2-4 in relation to underlying and overlying units. Figure 2-4 also shows the tectonic, oceanographic/climatic, and eustatic changes occurring during interval deposition. The Yegua Formation was deposited during a strong influx of sediment, primarily in the Houston Embayment. The Jackson Group was deposited in a much smaller sediment influx, and was deposited primarily on the shelf built by Yegua deposits. The Vicksburg Formation, above the Jackson Group, was deposited during a phase of sediment influx predominantly in the Rio Grande Basin. Throughout this time, rhyolitic volcanism was active in the Big Bend area of Texas and Mexico, contributing ash, bentonite, and tuff to the Yegua and Jackson interval.

Ages and paleontologic markers for the Yegua-Jackson interval are shown in Figure 2-5. Age dating by Harland and others (1990) indicates that major Yegua sand deposition began approximately 40 million years ago and is marked in the sedimentary record by the extinction of the benthic foraminifera *Ceratobulimina eximia* (Fang, 2000). A shaly interval below this, which marks the maximum high sea level between the Yegua depositional cycle and underlying Sparta depositional cycle, is indicated updip by the extinction of *Clavulinoides guaybalensis*, and downdip by the extinction of the planktonic foraminifera *Globorotalia spinulosa* and *Truncorotaloides topilensis* (Fang, 2000). The extinction of *Operculinoides sabinensis* occurs within the Cook Mountain Formation but may lie above the maximum flooding event. Benthic foraminifera *Anomalina umbonata* and *Nodosaria mexicana* occur in the lower part of the Yegua, and the extinction of *Eponides yeguaensis* occurs near the middle of the Yegua at an age of 38.6 million years (age from Harland and others, 1990). *Discorbis yeguaensis* occurs in the upper part of the Yegua and *Nonionella cockfieldensis* roughly corresponds to the top of the Yegua at an age of 38 million years (age from Harland and others, 1990).

The benthic foraminifera *Camerina moodysbranchensis* extinction occurs near the base of the Jackson Group. According to Galloway and others (1991), *Textularia dibollensis* is the diagnostic species of the Caddell Formation, while *Textularia hockleyensis* occurs in the upper part of the Jackson Group. The Whitsett Formation contains the extinction of *Massalina pratti* and, in deeper-water settings, the extinction of *Marginulina cocoaensis*. These are generally considered to mark the top of the Jackson Group, and correspond with an age of approximately 36 million years (Galloway and others, 1991). The extinction point of *Textularia warreni* occurs within, and near the top of, the Vicksburg Formation. The age of the top of the Vicksburg Formation is approximately 33 million years (Galloway and others, 1991). Other markers for the Vicksburg include *Loxostoma delicata* and the planktonic foraminifera *Globigerina ampliapertura*.

2.2.1 Lithology of Geologic Units

Although the lithology of geologic units comprising the Yegua-Jackson Aquifer can be generalized as interbedded sand, silt, and clay, a slightly more detailed description is provided to clarify outcrop-to-subsurface relationships as well as to highlight minor mineralogic constituents that might impact hydrologic properties. Outcrop descriptions of geologic units are inherently different from subsurface descriptions. Weathering of geologic units at outcrop creates differential erosion, leaving sands and more cemented lithologies standing in relief as low hills above the more easily eroded clays that commonly form lowlands and river valleys. This concept is especially applicable in areas of low rainfall, but can be negated in wetter areas such as East Texas, where sands and muds are equally eroded and dissected (Jackson and Garner, 1982). Weathering also oxidizes the sediments, creating distinctive colors, textures, and features. Conversely, subsurface observation is limited to well borings, lithologic logs, and geophysical logs of resistivity and natural gamma-ray values. This information may be less indicative of trace mineralogic content but is more sensitive to slight changes in lithology that reflect changes in depositional setting. Some of these changes are indicative of regional or subregional time-stratigraphic, or chronostratigraphic, relationships and can be widely correlated in the subsurface using well log data. In other words, subsurface data may more accurately relate laterally equivalent sediments deposited during a specific time interval, regardless of their gross lithology. In this way, sands that are hydrologically linked can be grouped together to constitute a ‘flow layer’ within the aquifer. The following lithologic descriptions of geologic units of interest were synthesized from the Geologic Atlas of Texas, published by the Bureau of Economic Geology (BEG) (Barnes, 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, and 1976c) and from county resource reports by the USGS and TWDB (in order from eastern counties to southern counties: Anders, 1967; Guyton and Associates, 1970; Tarver, 1966; Baker and Others, 1974; Follett, 1974; Thompson, 1966; Rogers, 1967; Anders, 1957; Anders and Baker, 1961; and Harris, 1965).

2.2.1.1 Upper Claiborne Group

Sediments of the Upper Claiborne Group (Figure 2-3) include the Cook Mountain and Yegua Formations. The Cook Mountain Formation is a shale-dominated interval between the often sand-dominated Sparta and Yegua Formations. Outcrop descriptions of the Cook Mountain Formation indicate a black, chocolate brown, gray-green or gray fossiliferous shale that weathers to a brownish gray, yellowish brown, and rarely, yellow and bright orange-red. The Cook Mountain also contains minor marl, lignite, and sandstone beds. Calcareous cement, glauconite, carbonaceous debris including large wood fragments, gypsum/selenite, bentonite, and ferruginous and calcareous concretions are widely reported. In parts of East Texas the Cook Mountain contains the Spiller Sand (see Tarver, 1966; Follet, 1974; and Thompson, 1966), which is a fine- to medium-grain-sized lignitic crossbedded argillaceous sandstone up to 100 feet thick containing interbeds of chocolate-brown clay. In South Texas, time-equivalent sediments are mapped as the Laredo Formation (Barnes, 1976b and 1976c). Sandstone is abundant in the Laredo, with thick, glauconitic, micaceous, ferruginous, crossbedded very-fine- to fine-grained sandstone beds predominating. Interbedded brown shales contain marine megafossils and limestone concretions. The Laredo weathers brown to orange-yellow to red. Thickness at outcrop varies widely from less than 300 feet 600 feet (Barnes, 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, and 1976c).

The Yegua Formation, as described in BEG and TWDB references cited above, is a gray to brown sandstone and dark brown to gray shale with minor interbedded lignites. The sandstones are fine- to medium-grained and variously contain bentonite, carbonaceous debris, fossil wood, glauconite, gypsum/selenite, and calcareous cement. Sandstone beds may form low hills which, in some areas, are discontinuous (Anders, 1967; Follet, 1974; and Thompson, 1966), and in some areas can be traced for many miles (Anders, 1967). Although sandstones weather yellowish brown in East Texas (Barnes, 1968a, 1968b), descriptions in South Texas indicate weathering colors of reddish brown, yellow-orange, and light red to tan (Anders, 1957; Barnes, 1976b and 1976c). Shales are often bentonitic, glauconitic, or gypsiferous and variably calcareous. In outcrop, the base of the Yegua Formation is identified as the first significant sand above the Cook Mountain Formation (Tarver, 1966) or as the stratigraphically lowest location where sandstone predominates over shale (Thompson, 1966). The Yegua varies from 400 feet to over 1,000 feet in thickness at the outcrop, being thinnest in East Texas (Barnes, 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, and 1976c).

2.2.1.2 Jackson Group

Sediments of the Jackson Group include, from oldest to youngest, the Caddell, Wellborn, Manning, and Whitsett Formations (Figure 2-3). These units are mapped separately in East and Central Texas but grouped as one unit in South Texas (Barnes, 1968a. 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, and 1992). Additionally, formation names vary locally and some units are further divided. In East Texas, the Caddell Formation laterally transitions eastward to the Moody's Branch Formation, the eastward equivalent of a combined Wellborn and Manning Formations is the Yazoo Formation, and the Whitsett transitions to the Nash Creek Formation to the east (Barnes, 1968b). In southern Central Texas, from southern Wilson County to central Duval County (Barnes 1974c, 1975, and 1976a), the Whitsett Formation is divided into an upper unit, containing the Dubose Member above and the Deweesville Sandstone Member below, and a lower unit containing the Conquista Clay Member above and the Dilworth Sandstone Member below.

In general terms, the Jackson Group is described as a variously sand- or clay-dominated succession, with sand content being greatest in South Texas. It contains some lignites, marine fossils, glauconite, and marl beds. It is often bentonitic, with ash and tuff content appearing to increase from East Texas to South Texas. The Jackson Group is light colored when unweathered, but weathers to a dark gray, with tuffaceous sandstones forming low rugged hills. In Grimes County, Baker and others (1974) describe the weathered Jackson sands as tan to red, with white limy streaks. Interbedded shales are chocolate brown, and ridges of sandstone extend laterally for several miles. Anders and Baker (1961) state that the top of the Jackson is the top of the first persistent sand above the *Textularia hockleyensis* foraminifera extinction. Total Jackson thickness varies from a low of 310 feet in East Texas to a maximum of 875 feet in south Central Texas, thinning again to 360 feet in South Texas (Barnes, 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, and 1976c).

Where individual formations within the Jackson Group are described, the Caddell Formation is a clay or siltstone with sandstone (Barnes, 1968a, 1968b, 1974a, 1974b, and 1974c). The clay is lignitic, bentonitic, glauconitic, locally fossiliferous, and generally brown to olive green, weathering to a dark gray. Sandstones are fine- to medium-grained, lignitic, calcareous, glauconitic, rarely fossiliferous, and generally light gray to yellow-brown. The laterally equivalent Moody's Branch of East Texas is a glauconitic marl, with abundant marine fossils, that is olive gray in color and weathers to a light olive gray. The Caddell Formation is generally less than 50 to more than 150 feet thick.

The Wellborn Formation is a very fine- to coarse-grained sandstone and minor clay, with sand grain size being greatest in South Texas. It is lignitic, containing fossil leaf and wood pieces, can be glauconitic, and contains marine megafossils. It can be massive to crossbedded and variably bentonitic or tuffaceous, locally being silica-cemented and forming resistive ridges. In color it is light gray to light brown, weathering to a dark gray. The Wellborn Formation is generally 150 feet thick, but thins to less than 50 feet in East Texas.

The Manning Formation is generally described as a chocolate brown lignitic clay with lesser sandstone, bentonite, and tuff. However, in East Texas, sandstone predominates (Barnes, 1968a, 1968b). Clays are bentonitic to lignitic, with some thin beds of marine megafossils. Sandstones are laminated to massive to crossbedded, lignitic, and bentonitic to tuffaceous. Sandstones are light yellow-gray, forming resistant ridges. Fossil wood is common throughout the Manning Formation. In East Texas, the Yazoo Formation is laterally equivalent to both the Wellborn and Manning and is a sandy clay with interbeds of silt and glauconitic sand containing marine megafossils. It is light brownish gray. The Manning Formation is 250 to 350 feet thick, but thins to about 200 feet in East Texas.

The Whitsett Formation is generally described as a fine- to medium-grained sandstone that is tuffaceous, lignitic, argillaceous and locally silica-cemented. It can be massive or crossbedded, contains abundant fossil wood, and is light to dark gray, weathering to dark gray. The lateral equivalent of the Whitsett Formation in East Texas, the Nash Creek Formation, is a bentonitic brownish to pale greenish gray clay with interbeds of fine-grained light gray sand. Clays in the Nash Creek Formation weather to a light gray and sands weather to a medium gray (Barnes, 1968a, 1968b). In south Central Texas, the Whitsett Formation is divided into four members (Barnes 1974a, 1974b, 1974c, and 1975). From oldest to youngest, these are the Dilworth Sandstone Member, Conguista Clay Member, Deweesville Sandstone Member, and the Dubose

Clay Member. Sandstone members are generally fine- to medium-grained light gray to yellow-brown sandstone that can be massive to crossbedded, tuffaceous, and heavily bored by *Ophiomorpha*. Interbedded clays and clay members are chocolate brown to yellowish brown, lignitic, bentonitic, and locally contain marine megafossils. The Whitsett Formation and included members are approximately 200 feet thick in south Central Texas but thin eastward, becoming 60 feet or less thick in far East Texas.

In East Texas, the Oligocene-age Vicksburg Formation overlies the Jackson Group and both are mapped as a single unit (Anders, 1967). The Vicksburg Formation includes a lower unit of fine- to medium-grained sandstone and interbedded silt and clay and an upper unit of clay with interbedded silt and sand. This unit as likely mapped in East Texas as part of the Whitsett Formation. Vicksburg thickness is unknown because it cannot be distinguished from the Whitsett Formation.

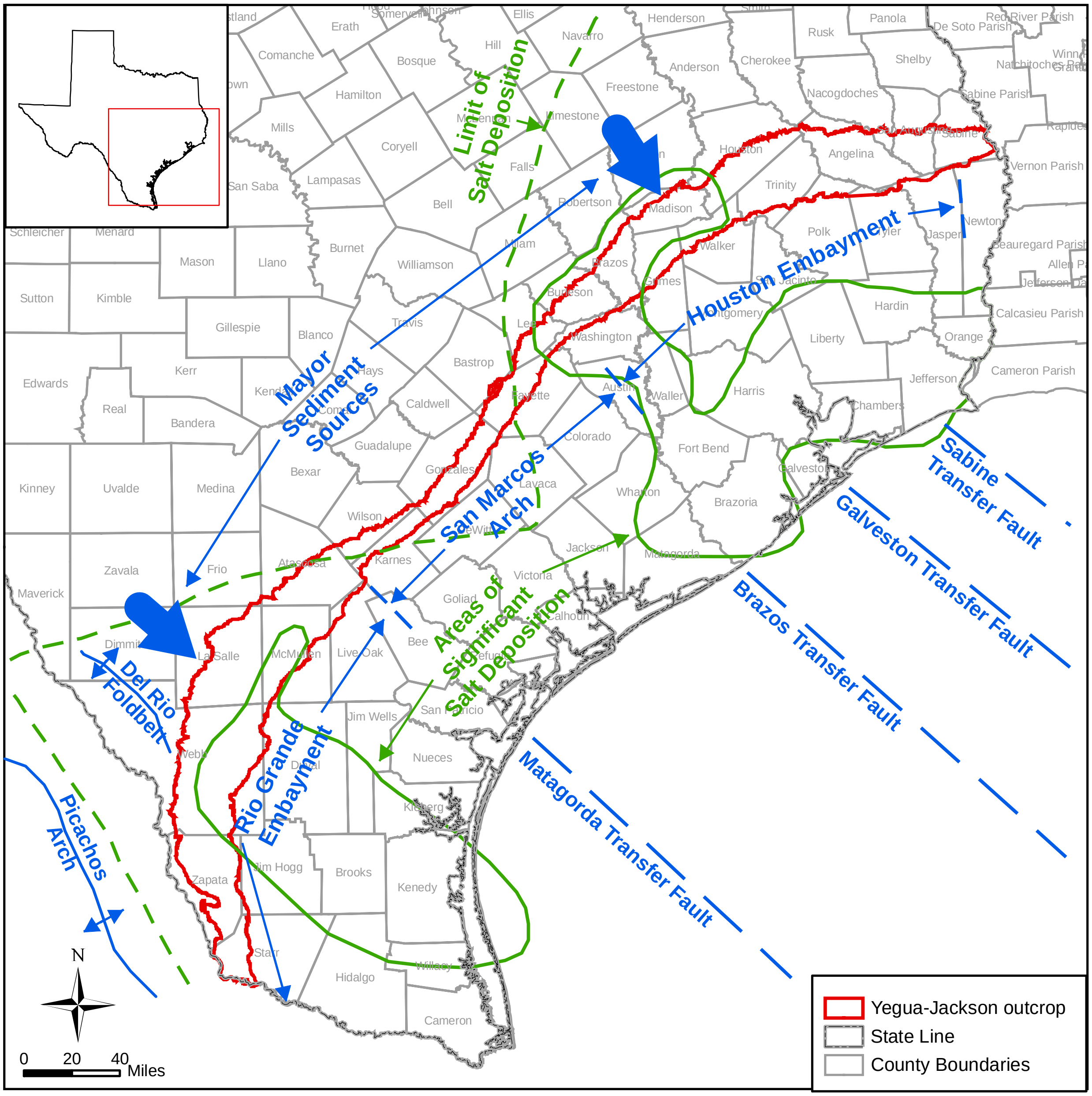

Figure 2-1. **Yegua-Jackson structure development study area, and major structural elements along the Texas Gulf Coast. Areas of significant salt deposition taken from Galloway and others (1983). Transfer Faults from Huh and others (1996). Other features from Ewing (1991).**

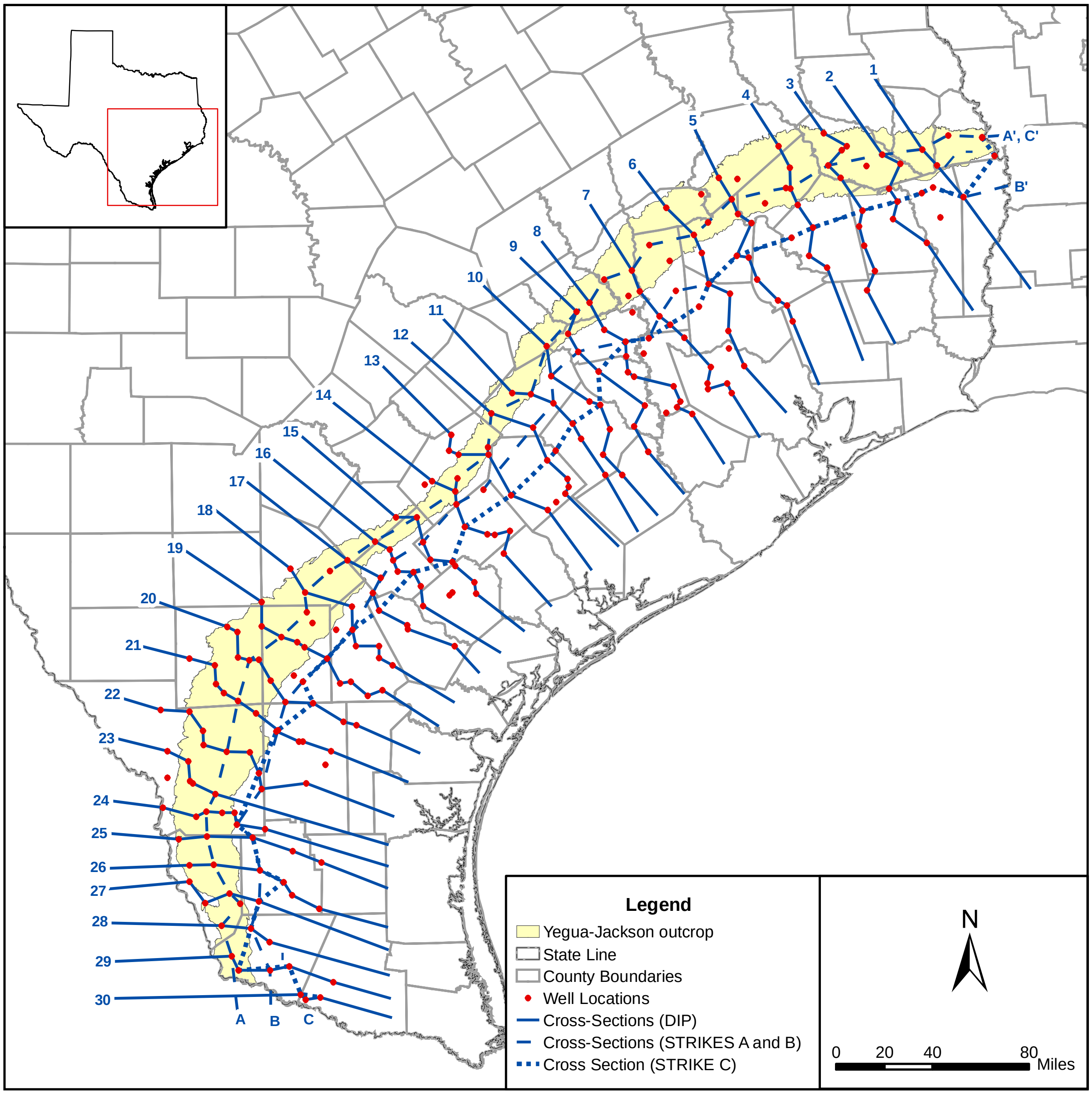

Figure 2-2. **Stratigraphic correlation basemap with cross section lines.**

Series			**Group**	**Formation**
Tertiary	Oligocene			Catahoula
	Eocene-Oligocine		Jackson	Whitsett
	Eocene	Upper		Manning
				Wellborn
				Caddell
		Middle	Upper Claiborne	Yegua
				Cook Mountain

Figure 2-3. Generalized stratigraphic column for the Yegua-Jackson Aquifer (after Preston, 2006).

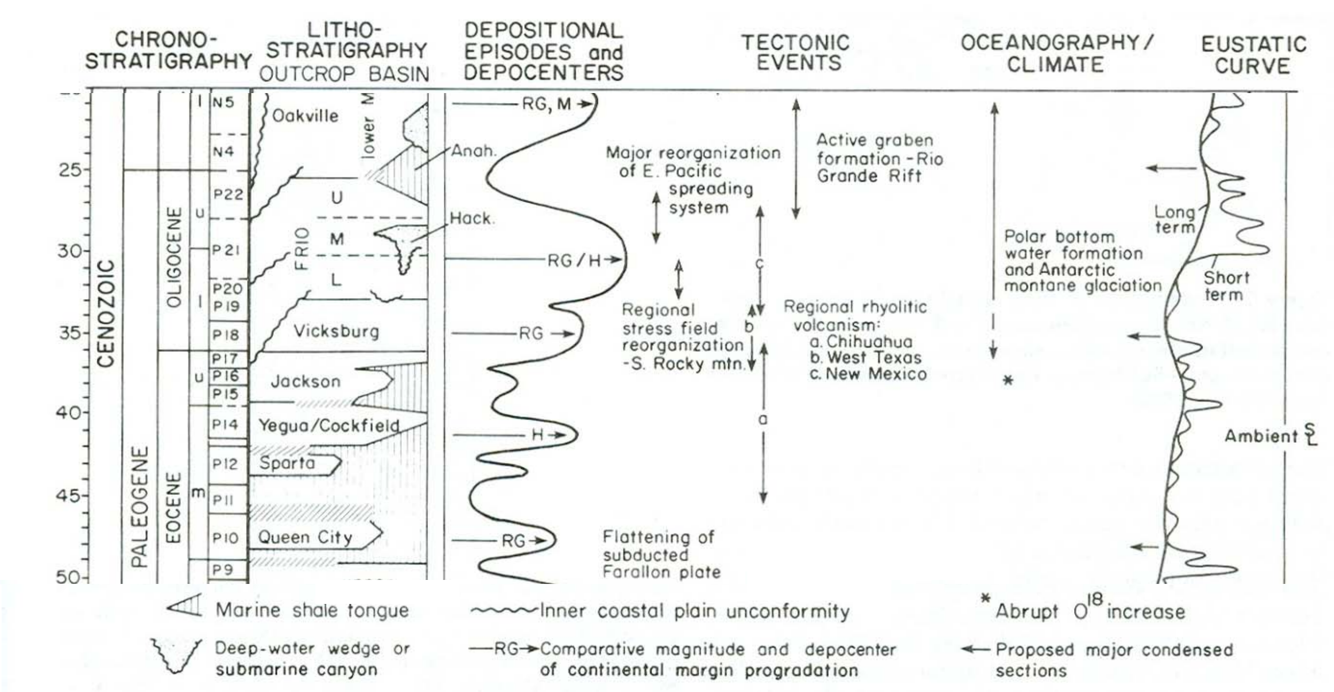

Figure 2-4. Chronostratigraphy, lithostratigraphy, depositional episodes and depocenters, tectonic events, oceanographic and climatic events, and global sea level for the Oligocene and part of the Eocene for the Gulf Coast.

Note: The Eocene-age Yegua and Jackson intervals represent pulses of sediment input after Sparta deposition and before Vicksburg deposition. Modified from Galloway (1989b). Original references for tectonic and oceanographic/climatic events and eustasy include Chapin (1979), McDowell and Clabaugh (1979), Davis (1980), Chapin and Cather (1981), Dickinson (1981), Loutit and Kennett (1981), Gries (1983), Witschko and Dorr (1983), Price and Henry (1984), Eaton (1986), and Haq and others (1987).

Period	**Epoch**	**Stratigraphic Units**		**Age (in 10^6 years)**	**Paleontologic Markers**
				33.0	
Oligocene	Lower	Vicksburg Formation			*Textularia warreni* *Globigerina ampliapertura* *Loxostoma delicata*
				36.0	
Eocene	Upper	Jackson Group	Whitsett Formation		*Marginulina cocoaensis, Massalina pratti*
			Manning Formation		*Textularia hockleyensis*
			Wellborn Formation		
			Caddell Formation		*Textularia dibollensis* *Camerina moodysbranchensis*
	Middle	Yegua Formation		38.0	*Nonionella cockfieldensis*
					Discorbis yeguaensis
				38.6	*Eponides yeguaensis*
					Anomalina umbonata, Nodosaria Mexicana
		Cook Mountain Formation		40.0	*Ceratobulimina eximia* *Operculinoides sabinensis* *Clavulinoides guaybalensis,* *Globorotalia spinulosa, Truncorotaloides topilensis*

Figure 2-5. Paleontologic markers and approximate ages for the Yegua-Jackson interval and adjacent formations. Markers and ages from Fang (2000), Harland and others (1990), and Galloway and others (1991).

3. Previous Work

An abundant body of previous work exists for the Yegua-Jackson interval because of its extensive resources of oil, gas, coal, and uranium. Geologic investigations extend from initial and broad stratigraphic investigations in the 19th century to modern-day detailed subsurface structural, chronostratigraphic, micropaleontologic, and depositional analyses. Hydrogeologic work has been more recent, and includes county water resource studies by both the United States Geologic Survey and the TWDB, as well as compilations of hydrologic parameters.

3.1 Geology

Early outcrop stratigraphy was established by Renick (1926, 1936) and by Sellards and others (1932). The economic importance of oil, gas, coal, and finally uranium resources spurred investigations from the early 1960's through about 1990 (for example, Fisher, 1963; Fisher and others, 1970; Eargle, 1972; Quick and others, 1977; Galloway and others, 1979; Kaiser and others, 1980; Jackson and Garner, 1982; Ewing, 1986; and Galloway and others, 1991). This work established, on the basis of outcrop and subsurface detailed investigations, the general structure, stratigraphy, depositional systems, and lithologic distribution of the Yegua-Jackson interval.

Also during this period, the United States Geological Survey and the TWDB carried out joint studies of the water resources of the Yegua-Jackson in many counties, especially those in Southeast Texas part of the aquifer (for example, Winslow, 1950; Dale, 1952; Anders and Baker, 1961; Thompson, 1966; Rogers, 1967; Wesselman, 1967; Tarver, 1968; Guyton and Associates, 1970; and Baker and others, 1974). These subsurface studies added knowledge regarding localized geology, as well as the distribution of fresh and slightly saline water in the aquifer and aquifer geochemistry.

Yegua-Jackson outcrop distribution was identified and compiled by the Bureau of Economic Geology, The University of Texas, at a 1:250,000 scale during the 1970's, 1980's, and 1990's under the direction of Virgil Barnes (Barnes, 1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a,1976b, 1976c, and 1992). The Yegua and Cook Mountain/Laredo formations were mapped across the state. Over a large area of outcrop belt, the main formations of the Jackson

Group (Caddell, Wellborn, Manning, and Whitsett) were mapped individually, including some local unit names such as the Yazoo shale and the Nash Draw sand.

Studies from the early 1990's to present have been prompted by the discovery of the downdip Yegua oil and gas trend and have employed the technologies of sequence stratigraphy, three dimensional seismic, and organic geochemistry (for example, Sneider, 1992; Goings and Smosna, 1994; Ewing, 1994; Yuliantoro, 1995; Meckel and Galloway, 1996; Swenson, 1997; Ewing and Vincent, 1997; Thomas, 1999; Routh and others, 1999; Galloway and others, 2000; and Fang, 2000). This work has produced a refined chronostratigraphic understanding of the Yegua-Jackson interval that stands in some contrast to the lithostratigraphic-dominated understanding evident in outcrop mapping and in studies from the 1960's, 1970's, and 1980's.

3.2 Hydrogeology

From a hydrogeologic perspective, there has been very little work done in the Yegua-Jackson Aquifer, especially studies at a scale larger than an individual county (Preston, 2006). However, there are over 1,600 wells completed in the aquifer as defined by aquifer code in the TWDB and United States Geological Survey databases (Preston, 2006). Production in 1997 was estimated to have been greater than 11,000 acre-feet per year (TWDB, 2002). As part of the 2002 State Water Plan, the TWDB designated the Yegua-Jackson as a minor aquifer because of the large number of wells completed in the aquifer and because of the relatively large groundwater use.

The Yegua-Jackson Aquifer exists predominantly in the outcrop or near-outcrop areas of the Yegua Formation and Jackson group. In Texas, this outcrop area stretches in a relatively thin band approximately parallel to the coastline, from Starr County in the Rio Grande Valley to Sabine County in East Texas, and is thus bracketed by the Rio Grande to the south, and the Toledo Bend Reservoir (along the Sabine River) to the east. The width of this outcrop varies from less than 10 miles in Gonzales County to near 40 miles in La Salle County, with an area of approximately 11,000 square miles.

The aquifer is comprised of interbedded sands, silts, and clays deposited in settings ranging from fluvial to marginal marine (deltaic and barrier/strandplain) to shallow marine shelf (Galloway and others, 1979). The fluvial and deltaic sands typically provide moderate amounts of fresh to slightly saline water in some areas of the outcrop, or slightly downdip (Preston, 2006). Wells completed in the Yegua-Jackson Aquifer yield anywhere from a few gallons per minute to over

300 gallons per minute with potential for producing up to 600 gallons per minute in the most transmissive portions of the aquifer (Preston, 2006). In a preliminary review of hydrograph data for the Yegua-Jackson, there is evidence of recovering heads from the 1980s until present (Preston, 2006) suggesting reduced pumping, at least locally in the aquifer.

Water quality in the aquifer is highly variable with most groundwater samples in the aquifer-delineated portion of the Yegua-Jackson being fresh to slightly saline with total dissolved solids less than or equal to 3,000 gpm. Freshwater regions of the aquifer are generally found in the thicker, more transmissive, fluivio-deltaic sands in the outcrop and sometimes extending downdip into the confined portions of the Yegua-Jackson Aquifer. Because of lignite within the aquifer, Preston (2006) reports that shallow portions of the aquifer can have very high chloride and sulfate concentrations. Because of uranium in the Jackson Group, some groundwater can also possess high nuclide activities.

In the 2007 State Water Plan (TWDB, 2007) it is reported that the existing groundwater supply in the aquifer is 7,285 acre-feet per year (assuming existing wells and infrastructure) with a total availability estimated at 25,000 acre-feet per year. Several regions have developed water management strategies in the 2007 State Water plan which includes the drilling of new wells and desalinization. With the implementation of the proposed water management strategies, production from the aquifer is expected to exceed 15,000 acre-feet per year by 2040.

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4. Analysis Methodology and Approach

With a literature review of the Yegua-Jackson interval performed, the next steps in the structure development work flow were to:

- gather available geophysical well logs for correlation;
- perform a chronostratigraphic analysis to subdivide geologic units into aquifer layers;
- perform lithologic analysis (net sand); and
- map structure, net sand distribution, and depositional systems.

Details of the approach for each of these steps are provided in following sections.

4.1 Data Selection

Reviews of existing literature and publicly available geophysical well log collections were undertaken at the initiation of this investigation and during the planning for later stages. This section of the report will describe the process used to solicit stakeholder data, the sources for geophysical logs, the sources for information on structural features, and the sources for information on Yegua-Jackson depositional facies.

4.1.1 Stakeholder Data Sources

At the beginning of the project a list of potential stakeholders comprised of the Groundwater Conservation Districts (GCDs) which fall within the boundaries of the Yegua-Jackson Aquifer were compiled. This list was compiled to seek additional data sources for Yegua-Jackson Aquifer structure, sand thickness, or water quality data. At the time, there were 13 Groundwater Conservation Districts located within the boundaries of the aquifer.

Contact was attempted with each of these Groundwater Conservation Districts. The initial contact method was telephone. If that proved unsuccessful, or if follow-up to the telephone call was warranted, emails were also used as a means of communication. For each Groundwater Conservation District contacted, the following talking points were discussed:

- The INTERA Team was introduced along with the mission of the project. It was further stated that we had been contracted by the TWDB to collect, interpret, develop, and document geological and hydrological information that could be used to develop the structure for the Yegua-Jackson Aquifer or could be of benefit to the future development of a groundwater availability model for the Yegua-Jackson Aquifer.

- Any available water-well drillers' reports, geophysical logs, and water quality information within the Yegua-Jackson Aquifer was requested.
- The Groundwater Conservation District representative was made aware that all data gathered will be compiled in a final contract report which would be publicly released.
- Where possible, the phone call was followed-up with an email re-capping the phone conversation and indicating that we needed all data by November 13, 2006.

Table 4-1 lists the Groundwater Conservation Districts in the aquifer area that we solicited information from to support the project. Of the thirteen districts that we attempted to contact, none supplied electric log data which could directly be used in the project. We did receive some drillers logs from Evergreen Groundwater Conservation District, and we received a hydrogeologic study report and associated database from Fayette County Groundwater Conservation District. The Fayette County Groundwater Conservation District did provide some relevant maps which could be used as soft data. All data received by us was delivered to the TWDB Project manager at the Midpoint Technical Progress Meeting held on April 11, 2007.

Table 4-1. Summary of Groundwater Conservation Districts contacted for the study with a summary of data supplied.

Groundwater Conservation District	Contacted	Action	Data Supplied
Bluebonnet	Lloyd Behm	None	None
Brazos Valley	Chip Zahn	emailed request after phone call	None
Evergreen	Mike Mahoney	emailed request after phone call	Drillers Logs
Fayette County	Linda Streicher	emailed request after phone call	Structure/Sand/ Water Quality
Gonzales County	unidentified	emailed request after phone call	None
Live Oak	Lonnie Stewart	None	None
Lost Pines	Joe Cooper	None	None
McMullen	Lonnie Stewart	None	None
Mid-East Texas	Robert Gresham	Left Message - no reply	None
Pineywoods	Assistant	Left Message for David Alford	None
Post Oak Savannah	Gary Westbrook	None	None
Southeast Texas	Larry Sheppard	None	None
Wintergarden	Ed Walker	Could not reach	None

4.1.2 Geophysical Log Sources

A grid of well logs and cross sections established by Dodge and Posey (1981) were mined for both logs and existing stratigraphic interpretations. Many of the original logs for these sections are available at the Bureau of Economic Geology. Where original logs were missing or inadequate for the study (did not cover the stratigraphic interval) and where more wells were needed to create a more uniform grid, additional well logs were obtained from Bureau of Economic Geology files. Also, geophysical logs from two Yegua-Jackson wells in the TWDB library were gathered, and about 30 logs were obtained from the files of the Texas Commission on Environmental Quality Surface Casing Division.

A total of 250 geophysical logs were selected, gathered, and scanned at 300 to 400 dots per inch resolution. A list of wells, their locations, and other information is provided in Appendix A. Well locations were confirmed from Tobin basemaps (see Appendix B for full well names on Tobin Township-Range locations), and latitudes and longitudes were transferred to a geographic information system database with a resulting accuracy of approximately 1 mile. Tobin Maps are the standard for base maps used in the oil exploration industry in Texas and in the Gulf Coast. Tobin started in 1928 developing the first standardized ownership maps in the region. Tobin Maps in Texas utilize the “Tobin Grid” as the reference coordinate system. This system originates from Latitude 30 degrees north, Longitude 100 degrees west and is based on a 7.5 minutes grid.

Where available from log headers, well surface elevations were compared with elevations from the United States Geological Survey digital elevation model. Discrepancies resulted in a review of well locations and this process served as a quality check for both well locations and well datums. In the small percentage of wells where the datum was not known from the log header, digital elevation model elevations were assumed as ground surface and an average of 14 feet was added to approximate a datum consistent with the Kelly Bushing datum of other logs. The Kelly Bushing is an adapter that connects the drilling rig rotary table to the drill string. The Kelly Bushing exists approximately at the level (elevation) of the drill rig floor and is the datum from which depth measurements on geophysical logs are commonly referenced.

A subset of more than 150 logs was digitized by Reservoir Visualization Incorporated and was used to quantify lithology within aquifer units. Spontaneous Potential, resistivity, and rarely gamma-ray or sonic curves were digitized from depth-registered scans of 1in = 100-foot or 1 in = 200-foot logs. Key points defining log shape were digitized. The resulting nonuniform data spacing was normalized to 0.5-foot spacing by Reservoir Visualization Incorporated (see Section 4.4.1.1 for further details).

4.1.3 Structural Geology Sources

Fault locations for the top of the Jackson Group and the top of the Yegua Formation were taken from Quick and others (1977), and fault throws at both the Top Jackson and Top Yegua horizons were estimated at a few points along key faults from structure contour maps in the same publication. Because the Quick and others (1977) study only covered the southern half of the aquifer extent, fault cuts in cross sections from Dodge and Posey (1981) were also incorporated. This was done by digitizing the location on a cross section where a fault displaced either the top Jackson or top Yegua. Fault throws at the base of the Frio Formation (near the top of the Jackson Formation) and the top of the Yegua Formation were estimated. Fault traces from Quick and others (1977) and throws from both sources were posted as line and point information, respectively, on the geographic information system basemap. Because of the large areal extent of the aquifer and the large amount of fault traces within the aquifer, each fault trace map (for the Yegua and the Jackson) was created using three maps representing the southern, central, and northern portions of the aquifer. Figures 4-1 through 4-3 depict the fault traces and throw for the Jackson Group and Figures 4-4 through 4-6 depict the fault traces and throws for the Yegua Formation. Other structural elements, such as salt features and cretaceous shelf edge locations, were taken from Salazar and others (1997), who had converted the Tectonic Map of Texas (Ewing, 1986) into digital GIS layers.

4.1.4 Lithology and Depositional Systems Sources

Contours of total sand thickness for the Upper and Lower Yegua Formation were digitized from maps in Van Dalen (1981) that cover the southern and central parts of the aquifer. Total Yegua Formation sand thickness contours for the complete area of the aquifer were digitized from Fisher (1969). Sand thickness maps covering the full extent of the Yegua Formation from Meckel (1993) were also reviewed. Meckel divided the Yegua into six high-frequency depositional sequences that were grouped into two larger depositional cycles. His intervals 1 through 3 equate to the Upper Yegua Layer of this study and his intervals 4 through 6 equate to our lower Yegua layer. For the Jackson Group, total sand thickness across the full area of the aquifer was digitized from Fisher and others (1970). Information from Van Dalen (1981), Fisher (1969), and Fisher and others (1970) were used as a guide to sand thickness trends and depositional systems in both the Yegua and Jackson units. Because Fisher and others (1970) studied the Jackson Group as a single interval, sand thickness contours were used as general trends in mapping the two (aquifer) layers of the Jackson that this study recognizes.

4.2 Stratigraphic Interpretation Approach

This study sought to improve the understanding and accuracy of the Yegua-Jackson Aquifer framework by incorporating existing data and existing lithostratigraphic interpretations with the concepts of chronostratigraphy. A chronostratigraphic approach provides greater reassurance that the depositional layering that forms the fabric of the aquifer, and thus governs its hydrologic behavior, can be properly identified (see Section 4.2.2 for further explanation).

4.2.1 Incorporation of Existing Data and Knowledge

From the distribution of the 250 wells used, a grid of 30 dip-oriented cross sections and 3 strike-oriented cross sections was created (Figure 2-2, Plate 1). Dip sections extend from the Yegua-Jackson outcrop area downdip (southeast) more than 50 mile and to depths exceeding 6,000 feet subsea to allow a more complete stratigraphic analysis. Strike sections extend from the Mexico to Louisiana borders. Two sections roughly parallel the outcrop and, depending on their location, show either mostly the Jackson interval (A-A’) or mostly the Yegua interval (B-B’). A third strike section, C-C’, was created from selected wells such that coverage of both intervals was optimized.

Previous interpretations of bounding surfaces for the base Yegua, top Yegua, top Jackson, base Vicksburg, and top Jackson/Vicksburg were taken directly from, or correlated into the well grid, from Dodge and Posey (1981), Coleman (1990), and various United States Geological Survey/TWDB county studies. Micropaleontologic markers on Dodge and Posey (1981) sections were correlated into the well grid and also taken directly from annotations on original copies of logs used in the grid. Because of the uncertainty of the source of the latter information, that data was used more as a rough check on correlations.

Outcrop boundaries of the Jackson and Yegua intervals and subunits (e.g., the Wellborn Formation of the Jackson Group or the Cook Mountain Formation of the Upper Claiborne Group) were taken from the geographic information system-based Geologic Atlas of Texas

(Texas Natural Resource Information System, 2006). These boundaries were projected onto cross sections, and surface elevations along section lines were taken from the United States Geological Survey digital elevation model to place outcrop boundaries precisely on cross sections.

4.2.2 Chronostratigraphic Concepts and Interpretation Methodology

4.2.2.1 Concepts

The internal fabric of a sedimentary interval that comprises an aquifer is the result of: (1) processes active during deposition; (2) any mechanical (compaction) or chemical changes that occurred after deposition (diagenesis); and (3) structural modification (folding or faulting). Diagenetic impacts on shallowly buried sedimentary aquifers are usually minor. Structural features must be of significant scale to have dramatic impacts on shallow sandy aquifers, and these can often be assessed from surface mapping. The distribution of sedimentary processes geographically and through geologic time are more difficult to evaluate in the subsurface extent of an aquifer, yet these key features are often the dominant controls on the aquifer framework in terms of fluid flow characteristics. Estimating aquifer framework and heterogeneity on the basis of outcrop and limited subsurface data requires a predictive approach founded on an understanding of the activities that built the aquifer. The concepts of chronostratigraphy and depositional systems provide that predictive capability.

Extensive geologic observations of modern depositional systems, such as deltas, and ancient deposits on scales as large as the fill of an entire sedimentary basin indicate that sedimentary deposition is cyclic, and that this cyclicity is hierarchical. In other words, there are long-lived cycles composed of shorter-term cycles, which, in turn, are composed of even shorter-term cycles. Cycle time spans critical to aquifer framework development can vary from tens of thousands to millions of years.

The observed cyclicity is a result of variations in sediment supply, global sea level (eustasy), and subsidence or uplift. The balance between these factors results in a relative rise or fall of sea level. This may occur by uplift or subsidence, increase or decrease of sediment input, or rise or fall of global sea level. Commonly, a depositional cycle consists of falling relative sea level and basinward shoreline progradation, followed by a stabilization and gradual rise of relative sea level and, consequently of shoreline, in what is referred to as aggradation. Figure 4-7 shows these steps from bottom to top. The cycle is completed by an increased rate of rise of sea level that forces the shoreline landward in ‘retrogradation’ (Figure 4-7). Finer-grained deposits associated with the highest relative sea level position are widespread, thin landward, and include a theoretical surface representing the time of maximum sea level known as a ‘maximum flooding surface.’

The dominant controls on cycle scales of millions of years is not well understood, but is believed to be associated with continental- and global-scale tectonics (Figure 4-8). Controls on cycle scales of tens of thousands to hundreds of thousands of years are widely held to be associated with repetitive changes in: (1) the elliptical path of the Earth around the Sun; (2) the tilt of the Earth’s axis; (3) and in the precession of the Earth’s axis. All of these affect the amount of incoming solar radiation to the Earth, and thus, the climate (Figure 4-8). Climate, in turn, produces changes in global sea level through storage or release of water in glaciers, and climate also impacts sediment supply by affecting the amount of rainfall available to carry sediments to the basin. The end points of cycles (maximum highstand or lowstand of relative sea level) are also times at which tectonic changes inland or at the coast often result in major changes in the courses of rivers, changing the location of major deposition on the coastal plain and shoreline.

An example of why this cyclicity is important to aquifer framework and management can be visualized in offshore Texas. At the peak of the last glacial period, about 20,000 years ago, global sea level was approximately 450 feet lower than today, and large rivers crossed the Texas continental shelf to create deltas more than 60 miles south and east of the current shoreline (Figure 4-9). These sand-rich deposits are representative of parts of aquifers such as the Yegua-Jackson. After deposition, those sandy deposits were then covered by water as the sea rose to its current level and the shoreline retreated to the one we know today. That sand-rich interval is today being covered by a blanket of mud delivered by the rivers of the Gulf Coast, including the Mississippi River, creating a future maximum flooding surface. This mud blanket thins from many feet to tens of feet thick far offshore to just a few inches just beyond the breaking waves of the current shoreline. As sea level falls again in the coming tens to one hundred thousand years, a new layer of sandy material will be deposited above this mud blanket, creating a potentially separate hydrologic unit in the subsurface. The result is two sand-rich aquifer-like layers separated by a wedge-shaped clay-rich layer that would serve, potentially, as an aquitard to limit water flow between the two aquifer layers.

The chronostratigraphic approach used in this study is more reliable than previous lithostratigraphic approaches at identifying and correctly connecting aquifer layers and intervening aquitards. The result is a more reliable three-dimensional description of the aquifer that will yield a more accurate numerical groundwater model.

Unlike lithostratigraphic correlation, which relies on lithologic changes to subdivide sedimentary intervals, chronostratigraphic correlation relies on recognition of depositional surfaces formed at critical times in a depositional cycle. At these relatively brief periods of time, broad areas of the coast are undergoing similar depositional processes. At sea-level highstand times, deposition of fine-grained deposits (potential aquitards) cover a large portion of the sand-rich sediments deposited during the last lowstand (potential aquifers). These highstand times are represented by theoretical maximum flooding surfaces, and their associated fine-grained deposits are especially useful in defining aquifer framework because they often have a characteristic signature on geophysical logs from wellbores. Thus these deposits can be traced across a regional extent in the subsurface. The intervals above and below these fine-grained deposits are sand-rich packages deposited under a common set of conditions, including positions of major sediment input. Predictive methods for evaluating the geographic distribution of sand-rich areas within the package can then be applied. These predictive methods are based on observations of modern depositional processes and systems such as rivers and deltas, which are all being deposited during just one depositional cycle. These methods rely on the commonality of depositional conditions within the time frame of the package, and the location and style of sand-rich deposition will vary from package to package. Differences between packages deposited over short timespans (high-frequency units) are typically less significant than differences in packages deposited over longer timespans (low-frequency units). When assessing aquifer framework, the combining of many high-frequency units or multiple low-frequency units can decrease the reliability of the predicative methods. This is because many different depositional features such as individual deltas are being combined vertically, blurring the crisp picture of each feature by stacking other features together with it.

4.2.3 Methodology

For this study, maximum flooding surfaces within fine-grained highstand deposits were correlated in geophysical well logs arranged in dip-oriented cross sections, connecting low-resistivity markers in downdip shale sections with shales or abrupt-based sands in updip sandy and silty intervals.

Initial correlations of very low frequency maximum flooding surfaces defined the base of the Yegua and an interval suspected of containing the top of the Jackson. Early attempts to correlate high-frequency maximum flooding surface-bounded units within the Yegua and Jackson intervals produced inconsistent results. A strike-oriented section (C-C', see Plate 1 for location of section line) was created to assist in the recognition of major depositional packages that contain multiple high-frequency maximum-flooding-surface-bounded units. The resulting four major depositional packages are bounded by the five most significant maximum-flooding surfaces in the study interval. This is indicated not only by the thickness of associated fine-grained deposits but also by abrupt regional-scale lateral changes in the location and amount of sandy deposition across these five surfaces. Major packages and subunits were then correlated in dip sections and loop-tied along parallel strike sections. These four major packages or units generally correspond to the four operational 'layers' into which the Yegua-Jackson Aquifer was divided (Upper and Lower Jackson Layers and Upper and Lower Yegua Layers). An exception involving one of the layer boundaries is further discussed in Section 4.3.

To document the correlation process, each boundary surface in each well was given a grade of A, B, C, or D, depending on qualitative reliability of the interpreted correlation. Grade A correlations were considered to have an approximate 90 percent likelihood of being within 50 feet of the exact bounding surface. Uncertainty in correlations arises from lateral changes in the appearance of a bounding surface within a shaly interval and the possibility of unrecognized depositional or structural complications that may result in a correlation that is inaccurate by more than 50 feet. A grade of B was assigned when significant anomalies in unit thickness or maximum flooding surface character decreased interpreter confidence, resulting in a 20 percent chance that the correlation is in error by hundreds of feet. Grade C correlations are those where the surface did not occur in a well but where the intercept point was probably within 200 feet of the end (either above or below) of the log data. A grade of D was assigned when a surface was interpreted to intercept a well more than 200 feet above or below log data; this was generally reserved for cases where an approximation of a minimum or maximum value was required to constrain structural mapping.

Additionally, a map depicting the sequence of correlations was prepared (Figure 4-10). This 'genealogical map' shows which wells were key in establishing the stratigraphic framework ('parent' correlations), and the path along which this framework was propagated throughout the study area ('daughter' correlations). As discussed previously, strike cross section C was used to confirm a chronostratigraphic subdivision. Correlations were then carried updip and downdip along dip sections. The order in which correlations were then carried in the strike direction to allow loop tying is shown in Figure 4-10. Such a map is critical in the situation where errors of correlation are later identified. Such 'busts' must be followed back to a well in which correlations are confident, and any correlations dependent on wells that were changed must then also be evaluated for errors. This map was useful during the interpretation process and, although it is hoped otherwise, may be critical to future workers who refine the present interpretation.

4.3 Structure Mapping Approach

The structural elevation, relative to sea level, was mapped across the study area for five key surfaces:

- Top of the Jackson Group (top of Upper Jackson Layer)
- Top of Lower Jackson Layer
- Top of Yegua Formation (top of Upper Yegua Layer)
- Top of Lower Yegua Layer
- Base of Yegua-Jackson Aquifer

The first four of these surfaces are chronostratigraphic, meaning that they correspond to maximum flooding surfaces. The fifth surface, the base of the Yegua-Jackson Aquifer, is a lithostratigraphic surface. It does not follow a maximum flooding surface, but instead generally corresponds to the base of significant sand bodies in the Yegua depositional cycle. A sixth surface, the chronostratigraphic base of the Yegua depositional cycle, was not included in this report. It corresponds to the maximum flooding surface between the Sparta and Yegua depositional cycles.

Elevations of the mapped surfaces in wellbores and at elevations every mile along the outcrop boundary were combined to create structure grids using an interpolation function in ArcGIS 9.2 called "topo to raster". This function's algorithm essentially uses a spline technique that has been modified to allow for abrupt changes in the fitted surface. The grids were given a northern orientation and the grid size was defined at one mile.

Preliminary gridding and contouring was reviewed for anomalies that might indicate correlation errors or data entry errors. Following resolution of any anomalies, adjacent surfaces (for example the Base Yegua-Jackson Aquifer and top of the Lower Yegua Layer) were contoured and the contours overlain to check for negative thicknesses in the intervening interval. A few such situations occurred in areas of rapidly changing dip and poor data spacing. These issues were resolved by adding estimated depths for a surface to increase control for the contouring algorithm. These estimated tops, mentioned previously, are marked with the grade 'D' in the geodatabase and in Appendix C.

A number of faults that offset the Yegua and Jackson are known to exist within the study area (Quick and others, 1977; Dodge and Posey, 1981). These are predominantly downdip of the outcrop area, but throws on some faults reportedly exceed several hundred feet. Additionally, salt-related structures occur as localized features in the Rio Grande Embayment and downdip in the Houston Embayment (Ewing, 1986). Although these features may become important for fine-scale aquifer modeling, data spacing in this study was insufficient to yield well-supported detailed structure contour maps. Instead, fault and fault cut locations and throws and salt feature locations have been posted on structure maps to alert future workers to their presence.

4.3.1 Potential Mismatch of Previously Mapped Outcrop Boundaries and Layer Outcrop Boundaries

Stratigraphic correlations in the outcrop often have the benefit of being physically traceable boundaries along their length, but lack the benefit of subtle lithologic variation provided by geophysical logs from the subsurface. Outcrop correlations are also lithostratigraphic, meaning that they follow lithologic boundaries as opposed to time surfaces. Additionally, soil formation, vegetative cover (especially in East Texas), and broad areas of alluvial cover can decrease the certainty of outcrop correlations. And in some cases there isn't enough lithologic distinction between one unit and the next to be able to separate them in outcrop. This is the case for the Vicksburg Formation of East Texas. It is recognized in the subsurface throughout Texas and Louisiana (Coleman, 1990) and in outcrop in Louisiana, as previously discussed. Because the Vicksburg is not mapped as a separate unit in Texas, it is uncertain when this interval is mapped with the Jackson and when it is mapped with the overlying Catahoula or Frio Formations (see further discussion in Section 5.2.1).

The Jackson Group has been subdivided into members that have been separately mapped in East and Central Texas. This subdivision is, again, lithologically based, and may not be consistent with time-based layers mapped in the subsurface. As a consequence, layer outcrop boundaries used in this study for structural control may not match outcrop boundaries of formations within the Jackson Group.

4.4 Lithologic Interpretation Approach

Cumulative sand thickness in aquifer studies has been determined in the past using many different approaches, yielding results that are sometimes difficult for subsequent workers to reproduce. To overcome this issue, 150 well logs were selected, and spontaneous potential and resistivity curves digitized. Baseline values for shale and/or sand were established and a cutoff value was used that produced results similar to geologist estimates. Because the study interval included freshwater, transitional, and saline water-bearing sediments, different algorithms and cutoffs were used for each interval. In freshwater zones, the resistivity curve was used to delineate lithology. In saline zones, spontaneous potential was used. And in transitional zones, either curve or a combination of curves was used, depending on mud resistivity and resulting spontaneous potential behavior.

4.4.1 Algorithmic Lithologic Analyses

A semi-automated approach was used to estimate the basic lithology, or the relative locations of sands and shales, from appropriate well logs. The automated approach was based on a simple set of rules that an analyst might use in interpreting a well log manually. The set of rules, which we will heretofore refer to as the “algorithm”, was applied consistently to digitized electric log data for approximately 150 wells. The algorithm produced decisions and yielded picks of sand or shale every 0.5 feet (the vertical resolution of the log data). Values were summed over each layer to yield total sand thickness by layer.

4.4.1.1 Electric Logs

A typical electric log will contain a record of the response from one or more tools that were passed down the wellbore after drilling. Each tool will measure a particular characteristic of the formation relative to the tool (or the drilling mud). The three types of responses that were used in the current study are called “spontaneous potential”, “induction log deep”, and “short normal”. The two latter tools are measurements of formation resistivity; in this particular analysis, they were used interchangeably because in most situations the values are very similar, but records from one tool or the other were not available.

The response from any tool that is present during logging was historically recorded on a running strip of paper commonly referred to as a ‘log.’ More recently, the responses are recorded digitally during the actual logging. To apply a machine algorithm to an electric log requires digital log data. If the log is available only on paper, they must be digitized, and there are various companies that specialize in this service. For the current study, the log curves from paper logs were digitized by Reservoir Vizualization Inc. at irregular depth intervals, but spacing was sufficient to capture curve shape. The curve was then reproduced from the points and sampled at half-foot intervals. A digital log may be saved in one of several industry formats. For the current study, the logs were saved in the Log American Standard Code for Information Interchange (ASCII) Standard (version 2) format, which is a straightforward American Standard Code for Information Interchange format.

4.4.1.2 The Code

The algorithm was implemented as a computer program in the Perl language. It can be executed on any computer or operating system that has a Perl interpreter installed. It was tested on Windows 2000 under Cygwin. The code performs some “housekeeping” outside of the actual algorithm implementation, mainly pre- and post-processing data. It contains subroutines for reading the Log American Standard Code for Information Interchange (ASCII) Standard file format and, after processing, writing the Log American Standard Code for Information Interchange (ASCII) Standard format with the additional “tool” or curve of sand/shale lithology. By adding the lithologic picks to the actual digital log, the original electric log curves can be viewed side-by-side or overlain on the resulting picks. This allows for convenient checking of the performance of the algorithm by an analyst.

4.4.1.3 The Algorithm

As indicated previously, the algorithm was based on a simple set of rules that an analyst might use in interpreting a well log manually. The data input to the algorithm for a particular well consisted of the electric log data, the depths of the five layer surfaces (tops of the Upper and

Lower Jackson Layers, the top of the Upper and Lower Yegua Layers, and Base Yegua-Jackson Aquifer), and the depths to the water quality divisions. The three water quality intervals considered in the analysis were “fresh”, “transition”, and “brine”. The reason that these water quality intervals were defined was that the electric log responses were somewhat different, depending on the water quality at a particular location. Each formation interval (and any water quality subinterval) was analyzed independently.

The following provides the fundamentals of the approach. The spontaneous potential response was used predominantly in the brine interval. A negative deflection of the spontaneous potential of some relative magnitude in the brine interval indicates sand. A lack of that deflection indicates shale. In the fresh interval, the spontaneous potential response is often suppressed (i.e., it becomes insensitive), rendering the curve less useful. In the fresh interval, the positive deflection of the resistivity curve of a certain magnitude was indicative of sand, while the lack of this deflection was indicative of shale. In the transition area, the spontaneous potential response may or may not be suppressed, so some check must be made to determine if it is an appropriate metric in that interval. Lacking a sufficient spontaneous potential sensitivity, the resistivity response was used, similar to the fresh interval. Because the resistivity response in the transition interval is less sensitive than in the fresh interval, the magnitude of the deflection indicating sand is less in the transitional interval than in the fresh interval.

Figure 4-11 is a flow chart that provides more detail about the algorithm. The inset box provides the values of the various parameters. Note that several values for each of the fitting parameters, resCutFresh, resCutTrans, resCutBrine, spMinSpanTrans, and spMinSpanBrine were tested during the course of the analysis. The values shown in Figure 4-11 were the final values used for all logs, and provided the best results to date.

The flow process starts by defining the current working interval, which consists of an aquifer layer, subdivided by any water quality divisions. For example, if we started with the Upper Jackson Layer, and the water quality division between fresh and transition occurred inside the layer, we would consider the log values between the top of the Upper Jackson Layer and the fresh/transition division point. In the remainder of this discussion we will call this span the “working interval”. Depending on the water quality type in the working interval, we proceed in one of three different ways.

If the type is fresh, we simply consider the values of the induction log deep resistivity response (if the induction log deep response is not present, we use the short normal response for resistivity). If the response is equal to or exceeds resCutFresh (currently 4 ohms), then the half-foot interval is marked as sand, otherwise it is marked as shale.

If the type is transition, then we check the sensitivity of the spontaneous potential response by taking the difference between spMin and spMax, which we calculated as the 5th and 95th percentiles of the spontaneous potential response in the current interval. We use the 5th and 95th percentiles in order to help eliminate anomalous maximum or minimum values in the working interval dataset. If the sensitivity, or spSpan, is greater than or equal to the defined minimum, spMinSpanTrans (currently 20 mV), then the spontaneous potential response is used. The spontaneous potential response is then compared at each half-foot interval to the spCut, which is halfway between spMin and spMax. If the spontaneous potential response is less than spCut (remembering that the deflection is typically negative for sands) then the half-foot interval is marked as sand, otherwise it was marked as shale. If spSpan is less than spMinSpanTrans, then the resistivity was used to determine lithology. If the response is equal to or exceeds resCutTrans (currently 3 ohms), then the half-foot interval is marked as sand, otherwise it is marked as shale.

If the type is brine, it is handled in the same was as the transition type, except that the values for the parameters spMinSpanBrine and resCutBrine are used. After the sands and shales are marked at each half-foot interval, then the next working interval is considered and the process is repeated. When all of the working intervals have been processed for a particular log, the amended Log American Standard Code for Information Interchange (ASCII) Standard file is written. After all of the logs have been processed, summary sand/shale thickness and percent tables are also written.

4.4.1.4 Quality Control

This automated method of lithology determination speeds the task of net sand thickness determinations and is repeatable because it is applied uniformly to all logs. Log response, however, is not always uniform, nor is the general lithologic character of the various intervals across the study area similar. Therefore, after calculated values were posted on basemaps for each interval, each value was compared to the original log by a geologist to confirm accuracy. In some cases the calculated value was significantly different than a manually calculated value using curve baselines and cutoffs. In those cases, the manual values replaced computed values.

There are least two causes for anomalous values produced by the current algorithm. The first potential cause is drift in the spontaneous potential shale and sand baselines created by gradual changes in electrical properties of the clays or pore waters. Another potential cause of anomalous values occurs in freshwater and transition zones, where vertical variation in salinity affects resistivity-derived sand cutoffs. At least one way to overcome these causes is to actively define baselines for sand and shale for both spontaneous potential and resistivity curves. This process of, essentially, adding additional data curves to a well log can be accomplished easily in many geologic interpretation software packages. As long as future workers are provided with the baseline curves and algorithm used, lithologic interpretations can be accurate and repeatable.

Independent of whether lithology values from logs are determined manually or digitally, there is always the issue of how to treat sand thickness values for incompletely penetrated or logged layers. This study treated known sand thicknesses of incompletely logged intervals as minimum values for the purpose of data contouring. In such cases values are posted as ‘>’ to visually indicate a minimum value and note the associated uncertainty. The alternate approach of not including these minimum values can lead to contouring errors because of a lack of constraint, resulting in mapped areas of no sand where a partial penetration may document tens or hundreds of feet of sand at that point.

4.4.2 Sand Thickness Mapping

Sand thickness values at wellbores, determined algorithmically or manually, were divided by the isopach values at the wellbores to determine the layer sand percent values at the wellbores. From the sand percent values, sand percent grids were created using the “topo to raster” function in ArcGIS 9.2. Preliminary grids and contours were reviewed to correct values below zero percent and above 100 percent. Values below zero were redefined to zero and values above 100 were redefined to 100 to remove spurious data. To create the sand thickness grids, the sand percent grids were multiplied by the layer isopach grids. Layer isopach grids were created by subtracting bounding surface structure grids from one another in the regions downdip of the outcrop, and by subtracting the lower bounding surface grid from the digital elevation maps (DEM) in the outcropping regions (the region where the ground surface forms the upper boundary of the layer). For instance, the upper Jackson layer was created by subtracting the *top of the Lower Jackson Layer* from the *top of the Upper Jackson Layer* in the downdip area and subtracting the *top of the Lower Jackson Layer* from the *digital elevation map* (DEM) in the outcrop area. In the outcrop regions of the layer isopach grids, grid values that were less than 10 feet were redefined to 10 feet. There were no layer isopach grid values less than 10 feet in the down dip areas.

The "topo to raster" function used to create the sand percent grid interpolates values using a spline technique that has been modified to allow for abrupt changes in the fitted surface. In the function, the "enforce" option was turned on to remove sinks. Sinks are areas where lack of data can yield extreme low values through normal interpolation. Sinks are removed by modifying the surface to assume 'drainage' areas surrounding sinks (areas of open contours as opposed to a series of closed contours). The grids were given a northern orientation and the grid size was defined at one mile.

This simple approach was done to evaluate the similarity of layer sand thicknesses to published sand thickness maps of equivalent stratigraphic units created using closer data spacing than possible in this study. In all cases, major features of published maps were captured with just the study wells and unbiased computer contouring. Because this process is simple and easily repeatable as additional data become available, no additional efforts to add biasing were undertaken.

4.5 Depositional Systems Mapping Approach

The distribution of depositional systems within an aquifer layer is important because it provides information on hydrologic parameters above and beyond sand thickness maps. Sand-rich sediments deposited in different settings will have different hydrologic properties because of differing grain size, sorting, sand body size and shape, and degree of interbedding of silts and muds. This affects sediment properties such as horizontal and vertical conductivity and storativity that might be measured at a wellbore. The internal architecture of an aquifer layer, governed by the characteristics of its depositional system setting, creates an overlay of fluid flow behavior on top of typical considerations such as head (fluid pressure) distribution. Large areas of highly conductive sands may impress a lateral (along-strike) flow element to aquifer behavior because of deposition in a wave-dominated, shore-parallel delta. Conversely, dip oriented sand-rich lowstand fluvial channels may provide a localized hydraulic conduit between saline-rich basinal sands and shallower freshwater sands.

For the four Yegua-Jackson layers, sand thickness trends from this study and other published studies were incorporated with interpretations of depositional setting based upon log curve shape and previous work. Regions of a layer dominated by similar depositional facies were outlined by hand, and hand-drawn boundaries were then digitized for incorporation as a geographic information system layer. In many cases, sand thickness values were used as proxies for determining position within a larger depositional system. For example, deltaic settings in a Yegua layer containing less than 100 feet of sand were mapped as delta margins. The resulting facies-based regions of a layer can be used in modeling to constrain hydrologic parameters across a modeling layer.

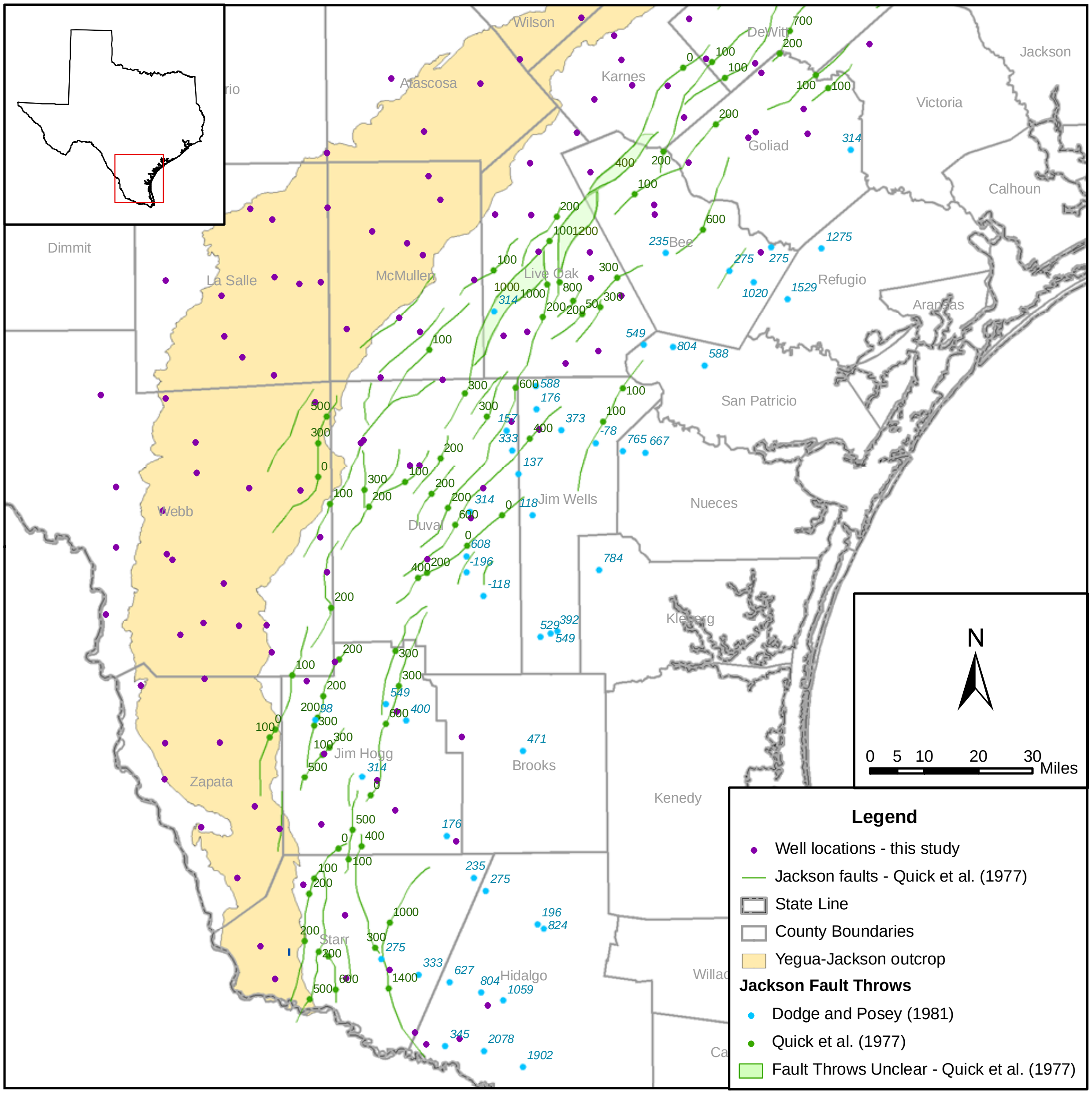


Figure 4-1. Faults for the Jackson Group, Southern Study Area. From Quick and others (1977) and Dodge and Posey (1981).

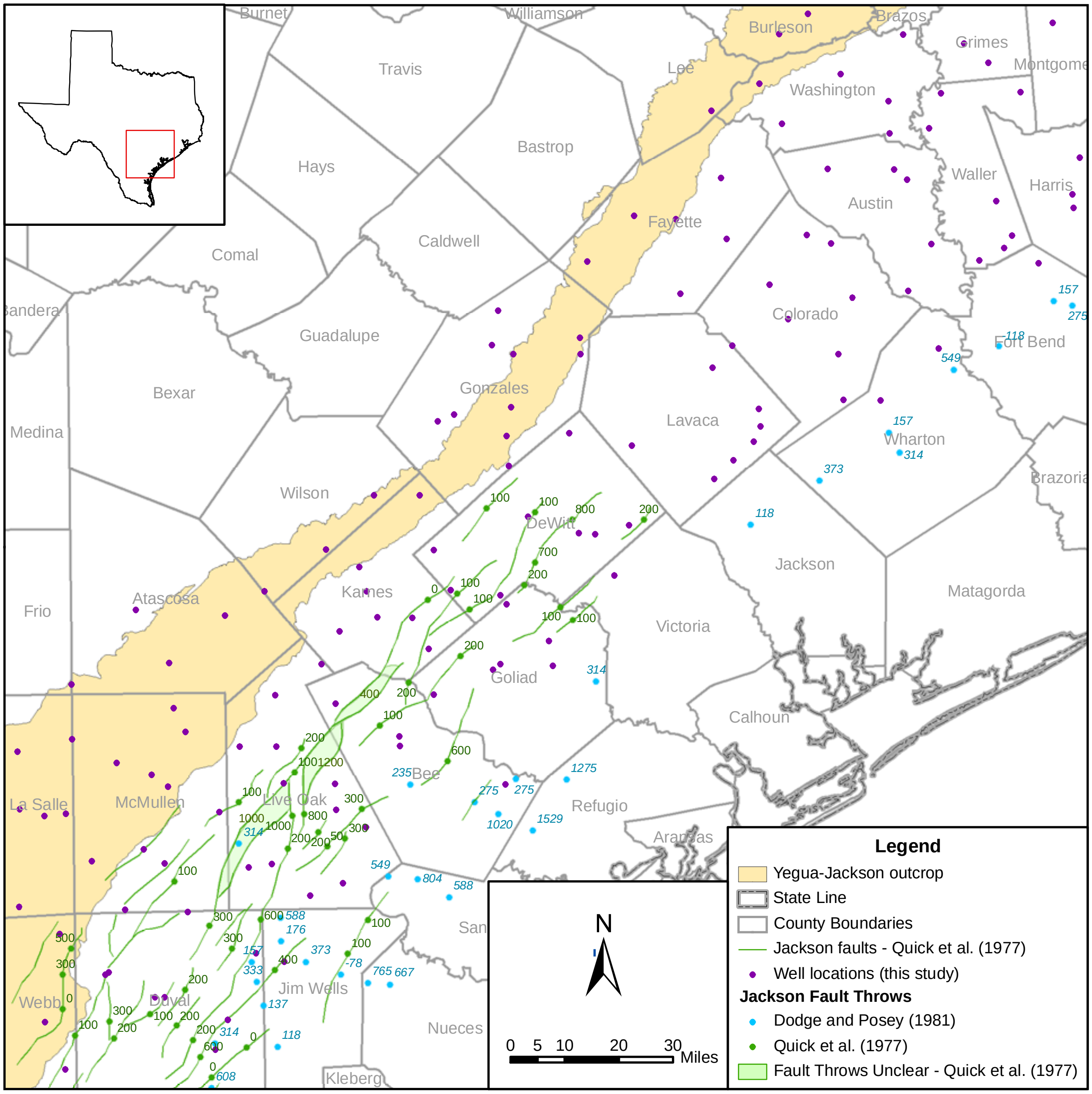


Figure 4-2. **Faults for the Jackson Group, Central Study Area. From Quick and others (1977) and Dodge and Posey (1981).**

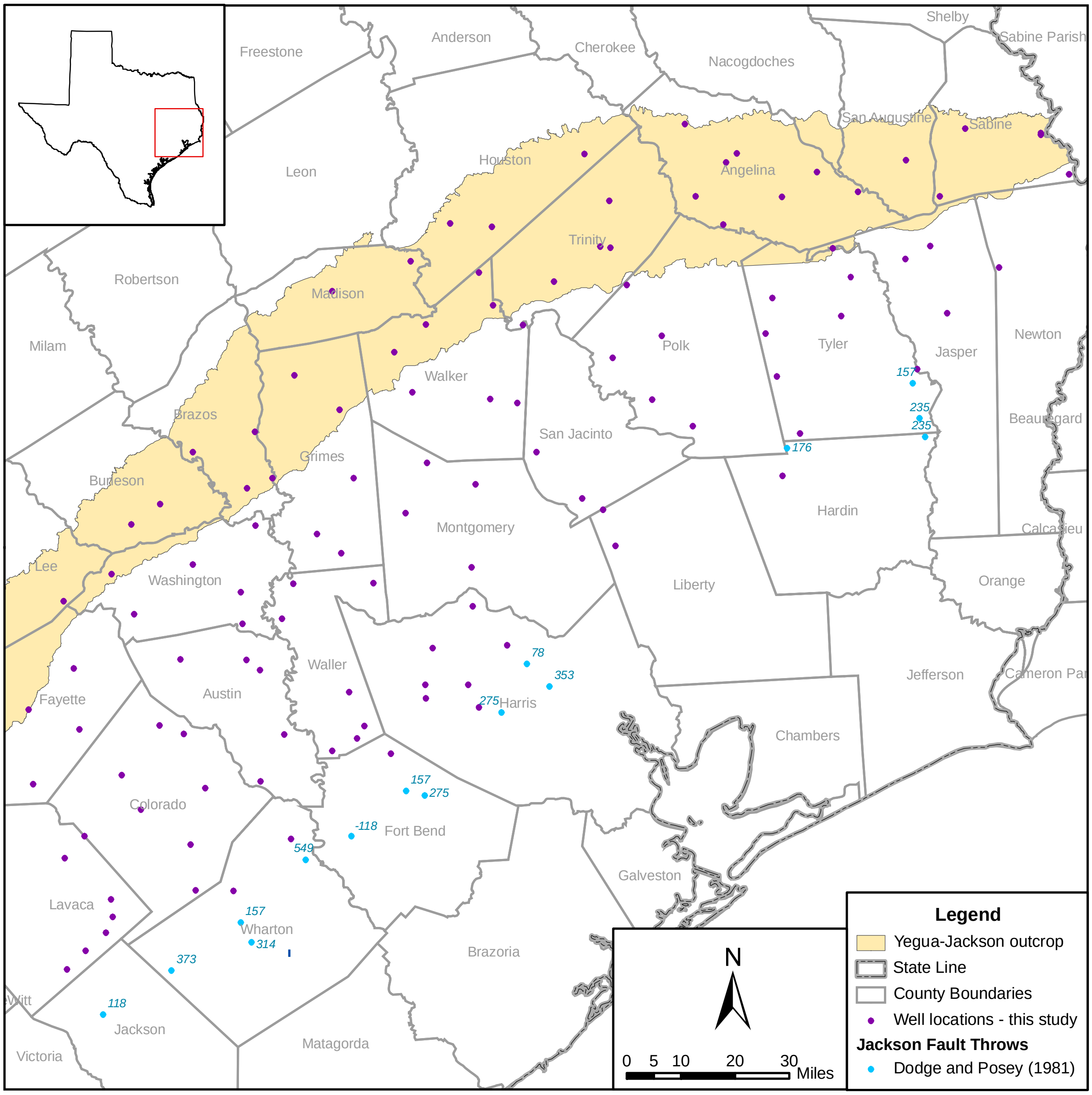


Figure 4-3. **Faults for the Jackson Group, Northern Study Area. From Quick and others (1977) and Dodge and Posey (1981).**

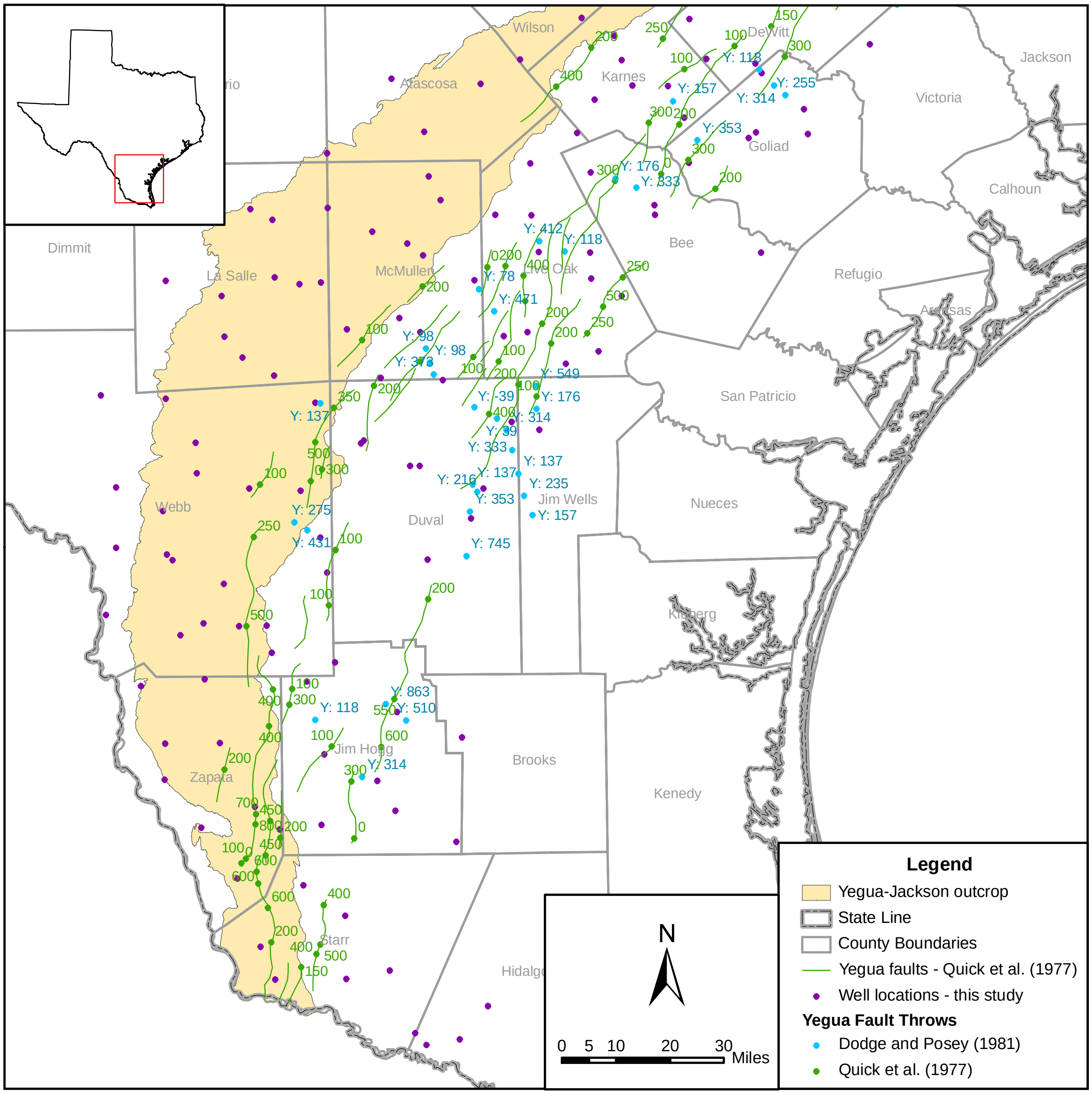


Figure 4-4. **Faults for the Yegua Formation, Southern Study Area. From Quick and others (1977) and Dodge and Posey (1981).**

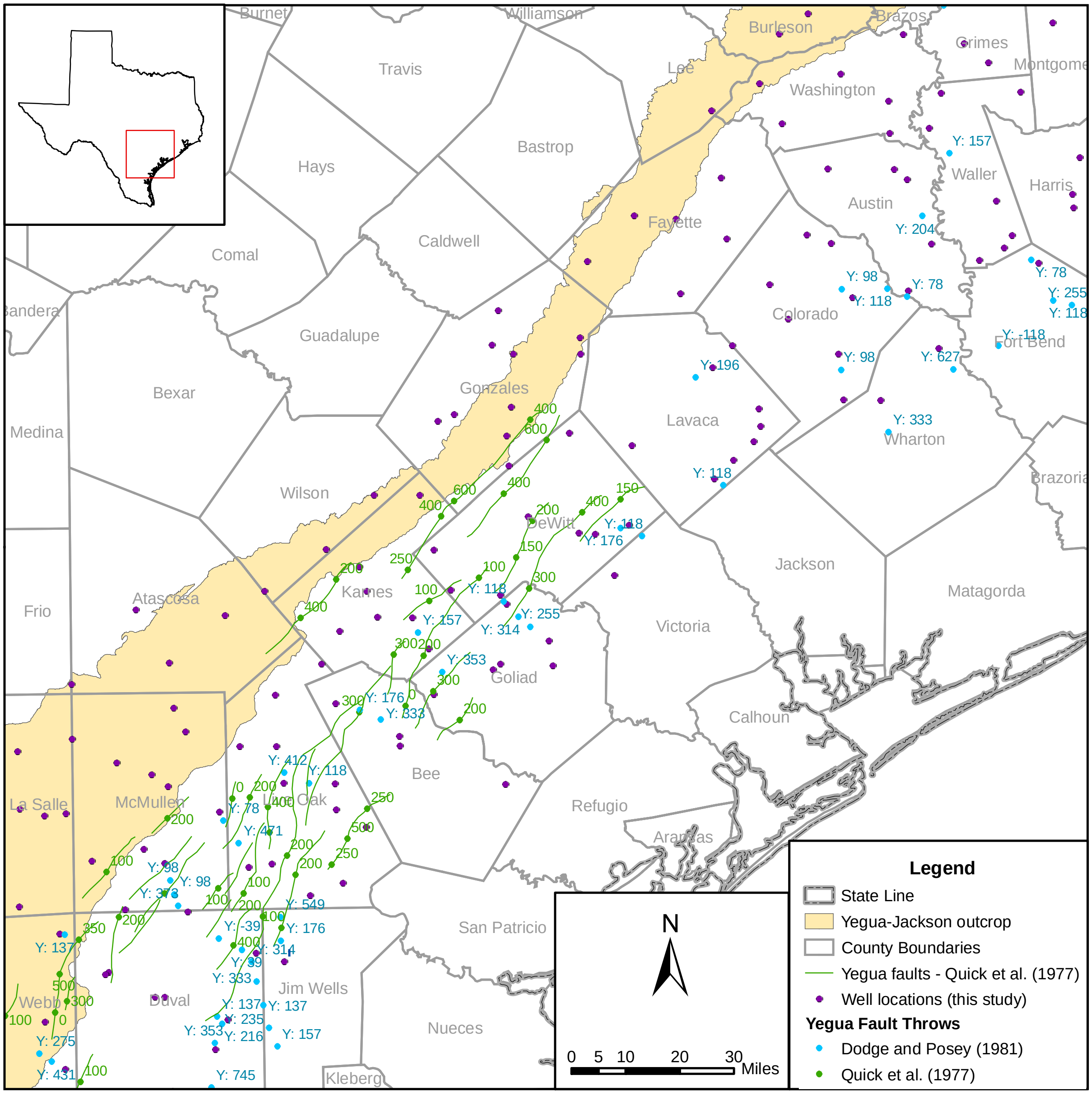


Figure 4-5. **Faults for the Yegua Formation, Central Study Area. From Quick and others (1977) and Dodge and Posey (1981).**

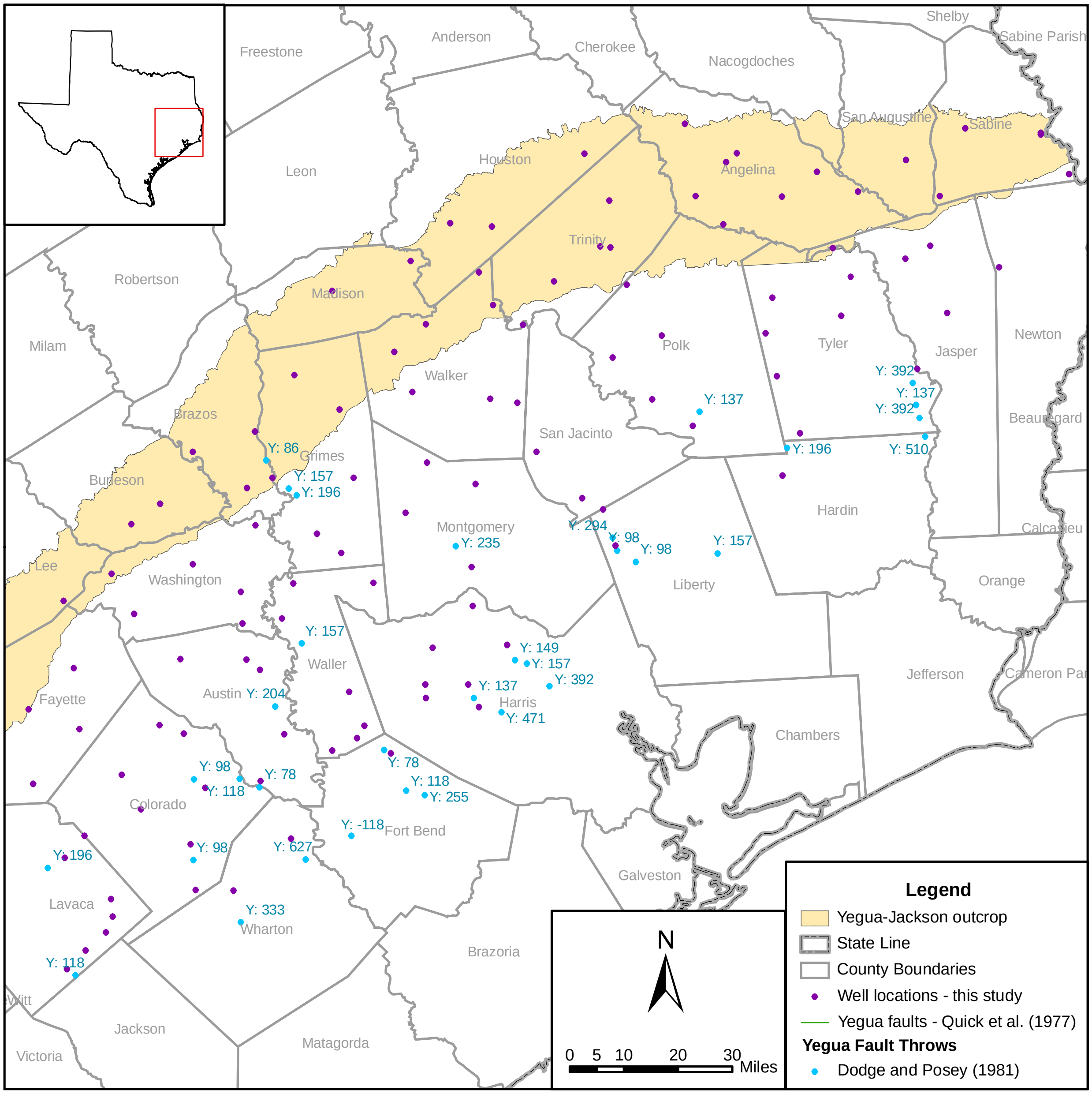


Figure 4-6. **Faults for the Yegua Formation, Northern Study Area. From Quick and others (1977) and Dodge and Posey (1981).**

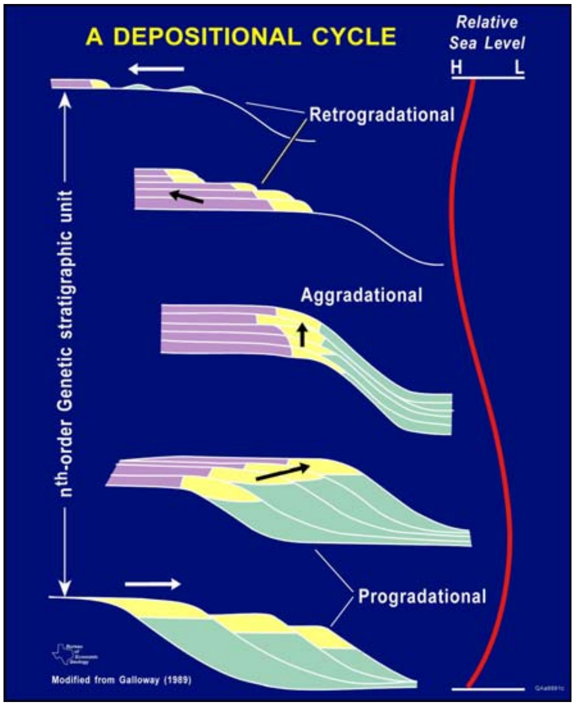


Figure 4-7. Depositional cycles (modified from Galloway, 1989a).

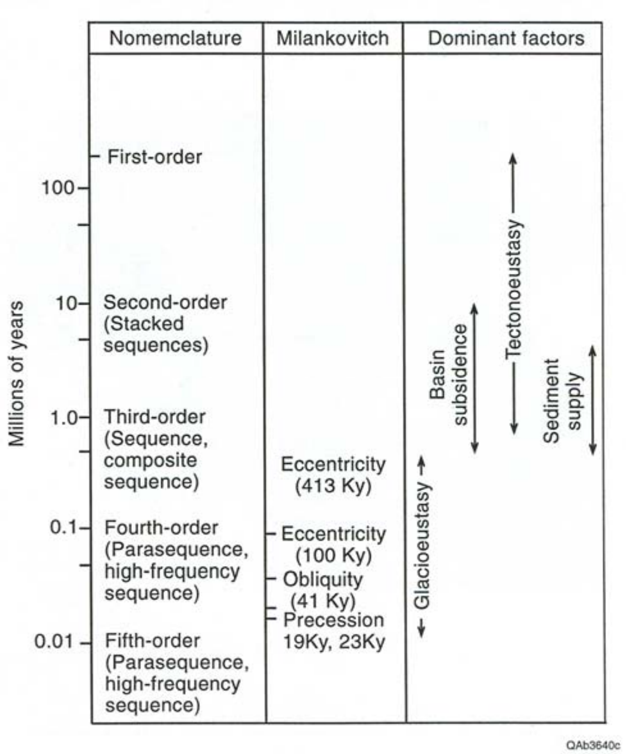
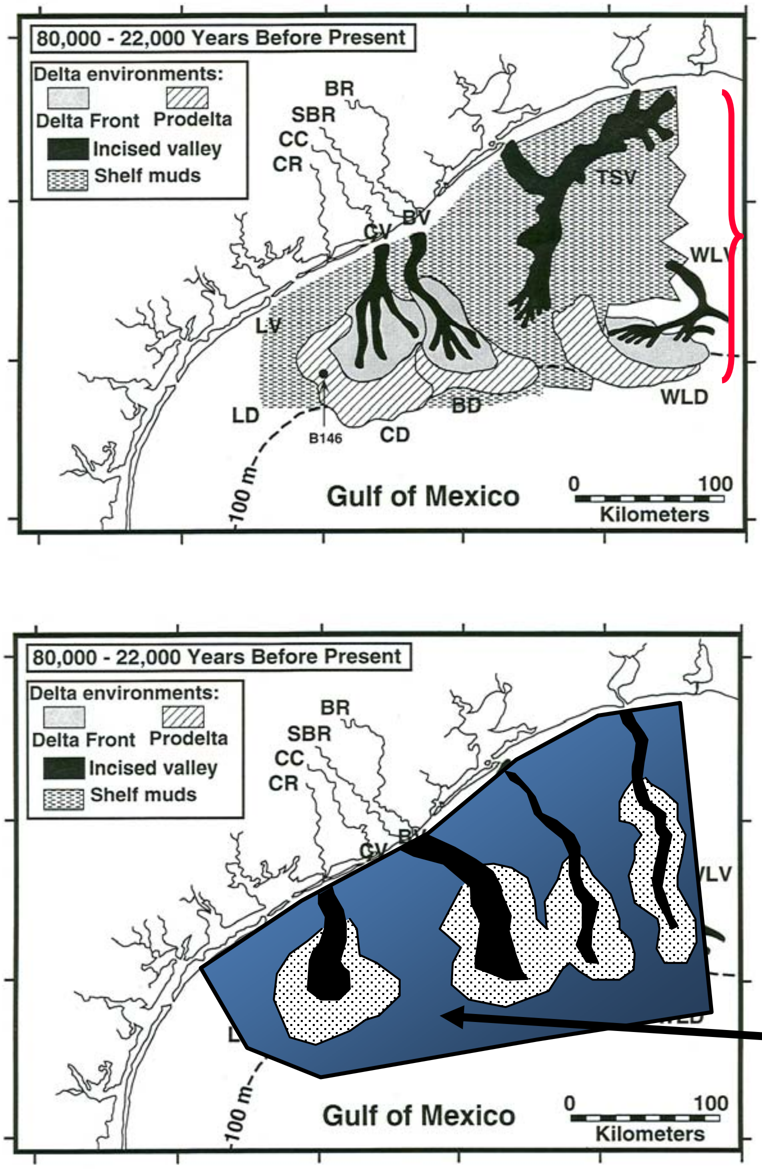


Figure 4-8. Hierarchical cycle nomenclature and dominant factors at each scale. Modified from Fisher (1964), Hays and others (1976), Meckel and Galloway (1996), and Mitchum and Van Wagoner (1991). (Ky = 1,000 years)



Sediments deposited on shelf during last lowstand

Sediments deposited on shelf during next lowstand

Landward-thinning shale blanket

Figure 4-9. **Construction of an aquifer.**

Note: **The upper diagram shows the location of sand-rich deposits at the last maximum glacial period (low sea level position) about 20,000 years ago, as mapped below the Gulf Coast seafloor by seismic data and coring. The shoreline then was more than 60 miles southeast of the current shoreline. The lower diagram shows the widespread mud deposits (blue) that have accumulated since sea level rose back to its current level. It also shows hypothetical sand-rich deposits that might be deposited as sea level gradually falls over the next 120,000 years. The result is two sand-rich layers similar to aquifer layers that are separated by a widespread muddy layer similar to an aquitard, which limits water flow between aquifer layers. LV= Lavaca Valley, CV= Colorado Valley, BV= Brazos Valley, TSV= Trinity/Sabine Valley, WLV= Western Louisiana Valley, LD= Lavaca Delta, CD= Colorado Delta, BD= Brazos Delta, and WLD= Western Louisiana Delta, BR = Brazos River, SBR = San Bernard River, CC = Caney Creek, CR = Colorado River. Modified from Anderson and Rodriguez (1999).**

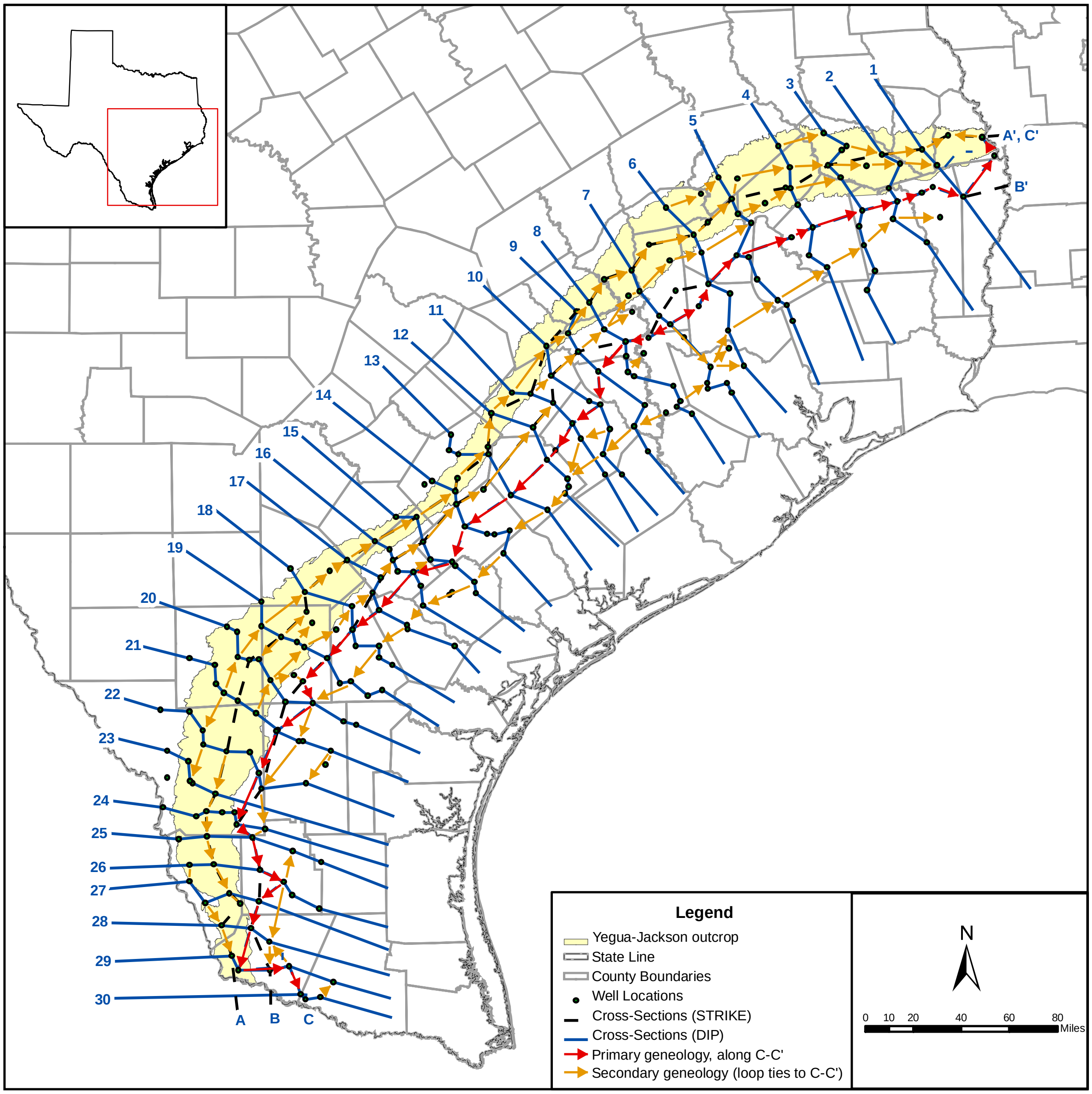


Figure 4-10. Genealogical correlation work flow.

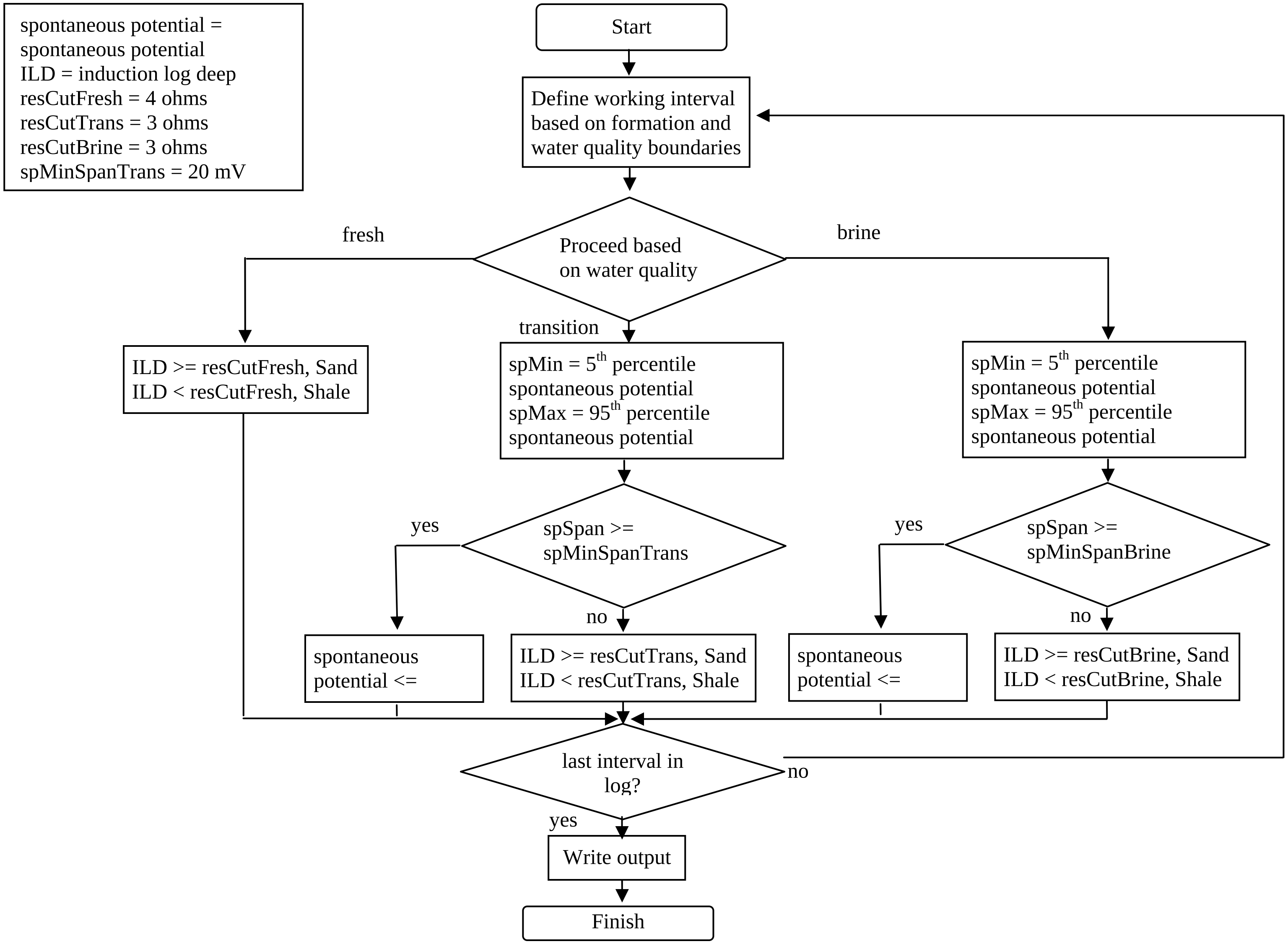


Figure 4-11. **Process chart for automated portion of lithologic log interpretation.**

5. Yegua-Jackson Aquifer Structure, Lithology, and Depositional Systems

Structure, sand thickness, sand percent, and depositional facies were mapped for each of the four layers into which the Yegua-Jackson Aquifer has been divided. The following sections present the interpreted framework for the Yegua-Jackson Aquifer in terms of stratigraphic subdivision, structural mapping of resulting stratigraphic layers, and internal heterogeneity as reflected by sand thickness and depositional facies.

5.1 Stratigraphy

A chronostratigraphic framework was created for the Yegua-Jackson Aquifer on the basis of micropaleontologic information and the three-dimensional distribution of maximum flooding surfaces interpreted from well logs. Comparison with previous works such as United States Geological Survey/TWDB County Resource Reports (in order from eastern counties to southern counties: Anders, 1967; Guyton and Associates, 1970; Tarver, 1966; Baker and Others, 1974; Follett, 1974; Thompson, 1966; Rogers, 1967; Anders, 1957; Anders and Baker, 1961; and Harris, 1965) and published regional studies (Dodge and Posey, 1981; Meckel, 1993; Jackson and Garner, 1982; Ewing, 1986; Fisher and others, 1970; and Coleman, 1990) allowed a comparison of the interpreted layer boundaries with established stratigraphic nomenclature. The interval contains both high-frequency and low-frequency depositional cycles that are resolvable by log correlation.

5.1.1 Major Subdivisions

In the dip direction, interval thickness and sand content change rapidly with respect to log spacing, and can be dramatically influenced by growth faulting. Strike-oriented views display distinct packaging of sand-rich deposits at different stratigraphic intervals and geographic locations. On the basis of this packaging, the Yegua-Jackson Aquifer was divided into four major layers that are bounded by clearly identifiable maximum flooding surfaces, with the exception of the Base Yegua-Jackson Aquifer, which is lithostratigraphic as described in Section 4.3. These four layers are, from the bottom of the aquifer upwards (earliest deposited to latest deposited):

- the Lower Yegua Layer,

- the Upper Yegua Layer,
- the Lower Jackson Layer,
- and the Upper Jackson Layer.

The definitions of these four layers, their boundaries, and their general character are discussed in the following sections. Plates 3 through 11 are selected dip-oriented cross sections (dip sections 3, 4, 6, 9, 14, 17, 20, 24, and 29) that show the thickness and log character of each layer.

Lower Yegua Layer

The basal boundary of the Yegua-Jackson Aquifer is the basal boundary of the deepest aquifer layer, the Lower Yegua Layer. This surface extends from the northern outcrop boundary of the aquifer (base of the Yegua Formation on Barnes, 1992) to the base of the first significant sand (greater than 20 feet thick) above the Cook Mountain Formation in the subsurface (see cross section 3, Plate 3). In some cases it was necessary to place this surface at the base of a group of sands that were not the lowest in the section. This was the case when wells very near the outcrop boundary encountered the basal sand anomalously deep in the interval and a connecting surface would be unrealistically steep or would be in poor correspondence with adjacent wells. This can be seen in cross sections 6 and 20 (Plates 5 and 9, respectively).

During development of the stratigraphic framework, a maximum flooding surface below the base of the Yegua-Jackson Aquifer, above the top of the Sparta Aquifer, and within the Cook Mountain Formation, was correlated and appears on cross sections as the “Bottom Yegua.”

The upper boundary of the Lower Yegua Layer is an maximum flooding surface that marks a regional change in sand distribution. It is commonly reflected in logs as a low-resistivity marker above a trend of upward fining or upward thinning sands (see well DP3-7R, section 4, Plate 4) or as a pronounced low resistivity marker within a shaly interval of tens to a hundred or more feet thick (see well WQ-16, section 6, Plate 5). It can also lie above an abrupt-topped upward-coarsening sand (see well DP2-10, cross section 3, Plate 3) or under a thin symmetrical or upward-coarsening sand (see well DP13-6, section 14, Plate 7).

The Lower Yegua Layer ranges in thickness from less than 500 feet near the updip limit of well control to more than 1,100 feet in middip to downdip parts of the study area (Figure 5-1). Sand deposition prograded gradually from landward (updip) areas to seaward (downdip areas), such that sand is present near the base of the layer in the outcrop area but overlies a progressively thickening blanket of shale in the downdip direction (see section 14, Plate 7). Conversely, the upper part of the layer is most shale-dominated in the updip area, with sand becoming increasingly common toward the top of the layer farther downdip (see section 9, Plate 6). In a strike orientation, sandy deposition was mostly pervasive in the Houston and Rio Grande embayments and least concentrated over the San Marcos Arch.

Upper Yegua Layer

The boundary between the Yegua and Jackson intervals is expressed in well logs as a low-resistivity shale, commonly above a 100 feet thick or thicker shaly section containing thin interbedded sands of upward-decreasing thickness (see well DPB-13R, section 17, Plate 8). It may also occur as a prominent break between upward-coarsening sands below and upward-fining sands above. This surface often marks a boundary between sand-dominated deposition below and shale-dominated deposition above (see well DP13-6, section 14, Plate 7).

The Upper Yegua Layer varies in thickness from less than 500 feet at the updip limit of well control up to more than 1,200 feet at the downdip study edge (Figure 5-2). Sand deposition is most prevalent in the middip to downdip parts of the study area. Shales in the updip area may contain thin (5 feet) to thick (50 feet) upward-fining sand interbeds, whereas downdip shales commonly occur in the upper part of the layer, may be several hundred feet thick, and may contain thin (<10 feet thick) isolated sand interbeds (compare wells DP9-8R and DP9-12, section 9, Plate 6). In a strike orientation, sandy deposition is significant in the Houston embayment and in a part of the San Marcos Arch, but is pervasive in the Rio Grande embayment.

Lower Jackson Layer

The upper boundary of the Lower Jackson Layer is a maximum flooding surface that commonly lies above a 100 feet thick or thicker upward-fining silty shale and below 100 feet thick or thicker sandy to silty shale. The boundary is often expressed in logs as a low-resistivity marker overlain by an abrupt-based silt of very slightly higher resistivity than the underlying section (see well DP3-8, section 4, Plate 4).

Another significant maximum flooding surface with very low resistivity occurs locally within the Lower Jackson Layer. This surface may have lower resistivity than either the top boundary of the Upper Yegua Layer or the top boundary of the Lower Jackson Layer (see well DP3-8, section 4, Plate 4). This surface might be mistaken for, or used by other workers as, the maximum flooding surface marking the Yegua/Jackson formational boundary. However, vertical distribution of sands across the study area is more effectively divided by the top Yegua boundary as described herein.

The Lower Jackson Layer ranges in thickness from less than 400 feet at the updip limit of well control to nearly 600 feet at the downdip edge of the study area (Figure 5-3). Sand is a minority lithology in the Lower Jackson Layer and occurs in the lower part of the unit, rarely in updip areas and more commonly in middip areas. Localized downdip areas are dominated by sand deposition (see DP19-14, section 20, Plate 9). In strike orientation, sand deposition was minor in the Houston embayment, almost nonexistent over the San Marcos Arch, and common in the Rio Grande embayment (see Plate 18).

Upper Jackson Layer

The top of the Jackson Group is here taken as a maximum flooding surface below an upward-coarsening interval containing thick (20 to 50 feet thick or more) abrupt-based sandstones suggestive of fluvial incision surfaces. In the subsurface, the Jackson Group is overlain by the Vicksburg Formation (Coleman, 1990). In the outcrop, the Jackson Group is considered to be overlain by the Catahoula, which is a combination of the Vicksburg and Frio Formations (Galloway, 1990) dominated by thick fluvial sands and gravels.

In well logs, the top of the Upper Jackson Layer is marked by low-resistivity shale above an upward fining shale commonly exceeding 100 feet in thickness and often several hundred feet thick (see wells DP13-9 and DPB-17, section 14, Plate 7). It is overlain by an upward coarsening silty shale or abrupt-based sand. Where this surface occurs within a shale interval, it is a distinct ‘neck’ on the logs, with a low resistivity combined with a pronounced shale response on the spontaneous potential log (see DP16-6, section 17, Plate 8).

The Upper Jackson Layer varies in thickness from less than 500 feet at the updip limit of well control to more than 1,000 feet at the downdip study edge (Figure 5-4). Shale dominates this interval, with thin sands (most less than 30 feet thick) occurring in the middle or upper parts of the layer. In strike orientation, sands are uncommon in the Houston embayment, more common over the San Marcos Arch, and are roughly equal to shales in abundance in the Rio Grande embayment.

5.1.2 Minor Subdivisions

The four major subdivisions of the Yegua-Jackson Aquifer defined above are at a scale appropriate to regional numerical groundwater flow modeling. Previous work (Galloway and others, 1991; Fang, 2000; and Harland and others, 1990) suggests that both the Yegua and Jackson intervals each span a depositional period of about 2 to 3 million years (Figure 2-4 and Figure 2-5), suggesting that the four major layers identified span roughly one million years each. These are categorized as third-order depositional cycles; the controls on which are not well understood. It is known that these longer cycles can be influenced by variations in the rate of basin subsidence and sediment supply, as well as tectonically driven changes in global sea level. However, periodicities of these factors are not well quantified.

Within each of the identified layers are depositional subcycles that are evident on a regional scale. These subcycles are driven by fluctuations in global sea level that tend to have periodicities ranging from 100,000 to 400,000 years (referred to as fourth-order cycles) down to 20,000 to 40,000 years (referred to as fifth-order cycles). Preliminary indications from correlations within the study area suggest that the Lower Yegua Layer may have at least five such cycles, the Upper Yegua Layer may have as many as three cycles, the Lower Jackson Layer may have three cycles, and the Upper Jackson Layer may have as many as five such cycles. These subcycles (fourth-order) are generally on the order of 100 feet thick, and change laterally in lithologic character. Where subcycles are sand-rich, they might form individually traceable features in outcrop such as a line of low sandy hills. Because surface mapping is dependent upon lithology, lateral changes in sand content of two adjacent layers might cause miscorrelation at the outcrop. In other words, surface mapping may follow a sand in one subcycle until it begins to pinch out. If it is replaced laterally by a sand-rich interval in the subcycle above or below, surface mapping might begin to follow this new sand as the boundary of the map unit, having only a small discrepancy in stratigraphic position of one hundred feet or less. Thus do lithostratigraphic boundaries come to cross or diverge from chronostratigraphic boundaries.

Although these subcycles are thin in comparison to typical layers in current numerical groundwater models, they are potentially separate flow units within an aquifer and are consequently of note. In the future, given the increasing socioeconomic role of water resources, models may require stratigraphic resolution consistent with these fourth-order chronostratigraphic packages.

5.2 Structure

The Yegua-Jackson Aquifer lies on the rim of the subsiding Gulf of Mexico basin. Aquifer layers slope toward the coast (southeast) from the outcrop with dips gradually increasing toward the coast. Large-scale tectonic features such as the Houston Embayment, San Marcos Arch, and Rio Grande Embayment also impact dip. Dips are generally gentler in the embayments and steeper across the arch. Dips steepen south of the Rio Grande Embayment, as indicated by the narrowing of the outcrop belt near the Mexican border.

The overall gulfward-dipping layers of the Yegua-Jackson Aquifer are offset by normal faults that trend parallel to the coast and are down-dropped to the southeast. Such faults in the Gulf Coast are often ‘growth’ faults because faulting was active during deposition and sediment layers can thicken dramatically across these features. In the Yegua-Jackson Aquifer, little mention is made in the literature of significant expansion across growth faults. Offsets on down-to-the-coast faults and minor growth faults can range from imperceptible to almost 1,000 feet (Quick and others, 1977; Dodge and Posey, 1981; Figures 4-1 through 4-6). This pattern is locally reversed by small up-to-the-coast faults with throws typically less than a few hundred feet (see Figures 4-1 through 4-6).

Salt domes, diapirs, and other salt-related structures occur within the study area, but are restricted to the Houston and Rio Grande Embayments. Another Gulf Coast feature which may potentially have an impact on Yegua-Jackson structure is the Cretaceous shelf margin. This margin had significant bathymetric relief prior to Tertiary clastic sedimentation. Sediment loading and differential compaction across this boundary may result in faulting of the overlying Tertiary section, which includes the Yegua-Jackson interval. In fact, many of the Yegua-Jackson faults mapped in South Texas by Quick and others (1977) lie just south of this old shelf margin.

Plates 12 through 16 present structural information from this study as structural contour maps (relative to sea level) for the:

- Top of the Upper Jackson Layer
- Top of the Lower Jackson Layer
- Top of the Upper Yegua Layer
- Top of the Lower Yegua Layer, and
- Base of the Lower Yegua Layer (base of Yegua-Jackson Aquifer).

Interpreted measured depths to these surfaces in each well, along with the correlation certainty grade (see Section 4.2.3) are provided in Appendix C. Data are machine contoured, with a contour interval of 1,000 feet. Relevant fault traces and fault throw values from Quick and others (1977) and fault intercepts and throws from Dodge and Posey (1981) are overlaid on the contour maps. Additionally, the locations of salt features and the Cretaceous shelf edge from Salazar and others (1997), who converted the Tectonic Map of Texas (Ewing, 1986) into digital GIS Format, have been overlaid on the structure maps. Detailed, hand-drawn contour maps were precluded by the data spacing of this study and the lack of published fault traces for the northern part of the study area. Most of these mapped faults occur downdip of the outcrop, but where throws are significant, faults may still have importance for hydrogeological modeling as fluid flow barriers or baffles. Data spacing and computer contouring also precluded incorporation of salt-related features into structure maps.

Structure contours are generally smooth and follow the directional trends of the outcrop belt. Cross sections of the interpreted structure (Plates 3 through 11) demonstrate that layer boundaries closely parallel one another except in far downdip parts of the study area where thickening of layers results in divergence. Some up-to-the-coast faults, or small rollover structures are indicated in cross sections. For example, in cross section 9 (Plate 6), structure surfaces at well DP9-12 are shallower than at the updip neighbor, DP8-8. This can also be seen as a data anomaly in all of the structure maps except that of the Base Yegua-Jackson Aquifer in the southern part of Austin County. A significantly thickened stratigraphic interval in the updip well, DP8-8, suggests the presence of a growth fault, with the downdip well, DP9-12 possibly being located on the rollover anticline downdip of the main growth fault. Salt features also affect the contours of each surface in the same location, as seen in southern Waller County on Plates 12 through 16.

In some cases, dips may flatten gradually or abruptly in the updip direction (see sections 3 and 6, Plates 3 and 5, in contrast to sections 4 and 20, Plates 4 and 9). A general flattening of dip in the direction away from a basin such as the Gulf of Mexico Basin is expected. The Earth's crust is pushed downward by the weight of sediment delivered by rivers to the margin of the basin. Dips may increase from nearly flat away from the basin to slightly dipping at the basin margin, becoming steeper below the area of major sediment accumulation. More abrupt changes in dip on cross sections (Plates 4 and 9) may be a consequence of cross section construction. Where wells are spaced farther apart, and dips between wells are simplified as straight lines, more gentle curves are forced into just two line segments - one steeper and one shallower. Apparent abrupt changes can also occur as a result of changes in the direction of cross section segments, such as in cross section 20 (Plate 9). Here one cross section segment is aligned away from the direction of dip, more closely paralleling strike, and consequently, creating the appearance of a decreased dip.

Updip structure is important in placing the outcrop of a structural surface. Structure maps of the five bounding surfaces used hand-drawn outcrop traces to define the elevation of the updip termination. These outcrop traces were prepared on the basis of positions interpreted from structural cross sections. Projection of surfaces from the last point of subsurface control to the ground surface assumed reasonable dips as established by the two most updip wells correlated. If flexures or faults occur in the outcrop area, this assumption may, locally, be invalid, leading to minor errors in outcrop traces. A review of the geology map (Plate 2) shows no major faults. However, abrupt lateral shifts of the outcrop boundaries perpendicular to trends, such as in La Salle and Duval counties in the southern area, and at the junction of Houston, Leon, and Madison counties in the northeastern area, suggest unrecognized folding or faulting, possibly including subtle strike-slip faulting. Lateral motion along faults might be a consequence of movement of deep salt or of subtle movement of transfer faults (Figure 2-1) that project onshore and produce dispersed or discrete faulting. A strongly indented feature of the basal Yegua boundary in Zapata County appears to be caused by a plunging fold axis. If such features exist in the outcrop area, where the bulk of the Yegua-Jackson Aquifer is located, they may impact regional or subregional fluid flow within the aquifer.

Projections of layer boundaries from the shallowest well intercept to outcrop were not bent or forced to reach formation outcrop boundaries. As a consequence, discrepancies exist between outcrop boundaries from Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, and 1992) and those used as surface elevations at layer boundary outcrops in structure mapping for this study.

5.2.1 Comparison of Layer Boundary Outcrops and Formational Outcrops

As just discussed, outcrop locations of chronostratigraphic surfaces bounding aquifer layers do not always coincide with outcrop locations of lithostratigraphic formation boundaries of surface geological mapping, such as in Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). Reasons for this are associated with the different techniques used in surface mapping (lithostratigraphy) and in the subsurface mapping of this study (chronostratigraphy). Section 2.2.1 provides a more thorough discussion of this topic. Below are discussed the variances between outcrop locations of the formation boundaries from geologic maps and approximately equivalent layer boundaries from this study.

The chronostratigraphic Base Yegua surface (Bottom Yegua), as shown in cross sections (Plates 3-11), occurs at or below the lithostratigraphic Base Yegua-Jackson Aquifer, and thus commonly outcrops farther inland (north and west) than the base of the Yegua Formation (same as Base Yegua-Jackson Aquifer) as mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). The chronostratigraphic surface represents a maximum flooding surface between the Sparta and Yegua depositional cycles and commonly occurs within the shales of the Cook Mountain Formation. It is expressed in well logs in updip and middip positions as a low resistivity, high spontaneous potential ‘neck’ overlying an upward-decreasing resistivity profile (upward-fining grain size) and underlying an upward-increasing resistivity profile (upward-coarsening) (for example, well DP2-7R on cross section 3, Plate 3). In South Texas the interval between the chronostratigraphic Base Yegua and the Base Yegua-Jackson Aquifer contains significant sands that are potentially water-bearing (see well DP19-7 on cross section 20, Plate 9, and well Richardson McKendrick on cross section 24, Plate 10). These sands were excluded from this study and thus lie between the Sparta and Yegua-Jackson Aquifers. Any future reconsideration of existing formal aquifer boundaries might best place these sands in the Yegua-Jackson Aquifer because they are probably most closely linked, hydrologically, with this aquifer.

The chronostratigraphic top of the Lower Yegua Layer typically outcrops at or below the middle of the Yegua Formation as mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992), with the possible exception of far South Texas where it may occur within the lower part of the Jackson Group (See cross section 29, Plate 11). However, dips in this southern tip of the aquifer are steep, and well control is sparse, increasing uncertainty in projection of boundaries from subsurface to outcrop.

The chronostratigraphic top of the Upper Yegua Layer outcrops in varying relationship to the mapped lithostratigraphic Yegua/Jackson boundary of Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). In East Texas it commonly lies below the top of the Yegua Formation. In Central Texas it coincides often with either the base of the Caddell or base of the Manning Formation. In South Texas the outcrop of the chronostratigraphic surface lies within the upper part of the Yegua Formation or the lower part of the Jackson Group.

The top of the Lower Jackson Layer outcrops in varying relationship to boundaries of the Jackson Group or Jackson formations as mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). In East Texas the chronostratigraphic surface lies below the base of the Yazoo Formation (lateral equivalent of the Wellborn and overlying Manning Formations), or coincides variously with an interval from the base of the Caddell Formation to the top of the Wellborn Formation. In Central Texas the outcrop coincides with the middle to top of the Manning Formation. In South Texas the top of the Lower Jackson Layer lies within the undivided Jackson Group outcrop, varying from the lower part to slightly above the middle part of the Jackson Group.

The top of the Upper Jackson Layer, and consequently, the top of the Yegua-Jackson Aquifer, generally corresponds to the top of the Jackson Group/base of the Catahoula Formation, as mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). However, from the Brazos River eastward, the top of the upper aquifer layer diverges, varying from a correspondence with the upper Manning to the lower Wellborn Formations, ultimately returning to the top of the Jackson Group near the Texas/Louisiana border. In the water resource report for Sabine and San Augustine counties, Anders (1967) states that it is not possible to separate the Jackson from the overlying Vicksburg Formation, resulting in Vicksburg sediments being mapped as part of the Jackson. Coleman (1990) correlated and mapped the Vicksburg

Formation from South Texas to eastern Louisiana. Three wells in cross section 6 (Plate 5) correspond with or are very near wells correlated by Coleman (1990). Her Top, Middle, and Base Vicksburg chronostratigraphic surfaces appear slightly inconsistent with correlations arising from this study (see cross section 6, Plate 5). To resolve inconsistencies, three major flooding surfaces in the 1,000 feet of interval overlying the approximate Top Jackson were correlated in wells throughout the eastern half of the study area. Results are shown in cross sections 3, 4, 6, 9, 14, 17, and 20 (Plates 3 through 9) but are not recorded in the geodatabase because of their preliminary nature. In sections 3, 4, and 6 (Plates 3 through 5), the chronostratigraphic surface from this study that most often matches the Top Vicksburg of Coleman (1990) projects to an outcrop location that closely corresponds with the Top Jackson Group from Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992). A maximum flooding surface several hundred feet above that surface projects to an outcrop location at or near the top of the Catahoula Formation and lateral equivalents (for example, the Frio Formation) in cross sections 6, 9, 14, 17, and 20 (Plates 5 through 9), and to a point below the top of the Catahoula Formation in cross sections 3 and 4 (Plates 3 and 4).

The above discussion suggests that the Vicksburg Formation was mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) as part of the Jackson Group from approximately the Brazos River eastward and mapped as part of the Catahoula Formation and lateral equivalents from the Brazos River southward. Inspection of Sheet 2 from Jackson and Garner (1982), a map of environmental geology covering the northern part of the Yegua-Jackson Aquifer outcrop, suggest that low sandy hills corresponding with the Whitsett Formation of Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) are interrupted by the Brazos River and not exposed because of alluvial cover for more than 10 miles. Between the Brazos River and the Navasota River, to the north another 8 miles, the area of expected Whitsett outcrop is a broad region of low sandy hills and the Whitsett/Catahoula contact might be difficult to determine. North of the Navasota River, two distinct bands of sandy hills emerge. The top of the Jackson Group as mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) follows the southern hills, and the northern set of hills corresponds with the chronostratigraphic top of the Upper Jackson Layer (Top Yegua-Jackson Aquifer) from this study. This conflict between interpretations from this study and those of Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) are important, unexpected, and not resolvable within the scope of this study. Before this structural framework of the Yegua-Jackson aquifer is incorporated into a numerical model, it is suggested that sufficient investigation resolves stratigraphic inconsistencies and logically places the 'region in conflict' within either the Yegua-Jackson Aquifer or the overlying Gulf Coast Aquifer.

In summary, the inconsistency described above and the potential explanation, related to difficulties in surface mapping, highlight the reliance of surface mapping on lithostratigraphy and the limitations of that mapping process induced by interruptions of surface exposures by natural features and by alluvial cover. Additionally, across an outcrop belt spanning a broad range of climates, key parameters used to locate formation boundaries, such as weathering relief, may change, as indicated by Jackson and Garner (1982), furthering hindering uniform outcrop boundaries.

It is important to realize that both surface-mapping and subsurface-mapping techniques have limitations. Comparison of results from both techniques will often yield conflicts, small or large. Consequently, although a chronostratigraphic framework for aquifers produces a better product for incorporation into numerical groundwater models, some level of conflict with surface mapping can be expected.

5.3 Lithology

As discussed previously in Section 2.2.1, the Yegua-Jackson Aquifer is composed of interbedded sand, silt, and clay. Sand-rich intervals form the high-conductivity framework of the aquifer, and the percent of interbedded fine-grained material is critical to numerical modeling for apportioning hydrologic properties across model grid cells. Mapping of both net sand thickness and sand percent are used to evaluate the map-view distribution of aquifer properties.

Net sand values were determined as discussed in Section 4.4, and are listed by well and layer in Appendix D. Net sand thickness and sand percent maps have been prepared for each of the four aquifer layers. The distribution of sand for each layer and a comparison to distributions determined by previous studies follows. Layers are addressed in the order of shallowest to deepest (Upper Jackson through Lower Yegua).

Before this discussion however, it is important to note the capacity for sand quality to vary across the breadth of the aquifer. Studies by Loucks and others (1986) suggest that the composition of sand grains changes from southeast Texas to South Texas. Bockoven (1985) presents data specific to the Yegua, and Meckel (1993) summarized Yegua results from both studies. Figure 5-5 provides a quartz-feldspar-lithic diagram presented in Meckel (1993). A quartz-feldspar-lithic diagram is a ternary plotting technique used to classify clastic sedimentary rocks. The percentage or feldspar, quartz, and lithic or rock fragments are plotted in these diagrams. These diagrams help both classify sedimentary rocks but also provide a means to study variability in sediment source. Ratios of quartz, feldspar, and rock fragments change progressively from southeast Texas to South Texas. The dominant change is a reduction in quartz content and an increase in feldspar and rock fragments in South Texas, most likely associated with volcanism in the Big Bend area during deposition. The sand grain composition is pertinent to aquifer studies because rock fragments, dominantly volcaniclastic grains, and feldspar grains, are less physically and chemically stable than quartz. Even compaction from shallow burial and chemical changes from early diagenesis can result in significant porosity loss compared to more quartz-dominated sands, impacting both storativity and hydraulic conductivity.

5.3.1 Upper Jackson Layer

Net sand thickness values for the Upper Jackson Layer are posted with computer-generated contours on Plate 17. Net sand thickness ranges from over 300 feet in two locations to 0 feet in isolated or downdip areas in the south-central and northeastern parts of the study area.

5.3.1.1 Outcrop Region

Sand thickness in the updip region, where fresh water is likely to be present, is greatest in north Central Texas, in Grimes, Brazos, and Burleson counties, where sand thickness can exceed 300 feet. Mapping also suggests that thick sands may be encountered near the outcrop in far southern Texas in Starr County. Intermediate sand thickness of 100 feet or more in the outcrop region can be found Central Texas and slightly south, stretching from Fayette County southeastward to McMullen County (Plate 17). Outcrop regions where less than 100 feet of sand can reasonably be included East Texas (Sabine County westward to Trinity County), and South Texas (southern McMullen County to Zapata and northern Starr counties). Thicker sands can be found farther downdip in the latter area but are likely below any fresh water.

Sand content of the Upper Jackson Layer (Figure 5-6) in the outcrop region exceeds 30 percent in north Central Texas. Sand content in excess of 20 percent can be expected in the outcrop area over a broad area from Walker County in the northeast to Live Oak County in the south.

5.3.1.2 General Study Area

The area of thick sand in the northeast part of the study map extends from Walker County through Grimes and southern Brazos counties. The sand thins rapidly from over 300 feet at the northern edge of data control near the outcrop to less than 100 feet at about 20 miles downdip of the outcrop. Sand thickness then tapers more slowly to ‘0’ values at a line running from central Tyler County through northern Liberty and northern Harris County. Areas of thicker sand, greater than 100 feet thick, occur in patches south of the main northeast accumulation. One such patch extends from southern Austin County to northern Ft. Bend County, trending southeast. Another region trends southward to southwestward from southern Colorado County to southern DeWitt County.

An area of sand accumulation greater than 100 feet, and locally perhaps more than 200 feet thick, extends southwest along the outcrop belt from northeast Fayette County to central Karnes County. This trend turns more southerly in Karnes County, extending to central Duval County. Wells between this southerly trend and the outcrop belt contain markedly less sand, with thickness of 40 feet or less.

A southern area of thick sand accumulation occurs downdip of outcrops in Starr and Hidalgo counties. Mapping suggests that a large area of sand thickness greater than 150 feet exists across these counties, extending to include the southern edge of Brooks County. One well near the center of Jim Hogg County with over 150 feet of sand may indicate that a northern branch of this ‘southern’ thick. This indication is supported by a sand thickness map for the whole Jackson from Fisher and others (1970). The Fisher and others (1970) map further suggests that this branch of the ‘southern’ thick is continuous in central Duval County, a region of data paucity in this study.

With the exceptions noted above, sand accumulations generally thin downdip (southeastward) away from the outcrop, with an absence of sand recorded in wells from northern Goliad through southern Live Oak counties. An absence of sand is also noted in some updip locations near the outcrop, such as in southeastern Webb County.

The percent-sand map for the Upper Jackson Layer (Figure 5-6) shows that even in areas of significant sand thickness, sand is only slightly more than 30 percent of the interval. In some cases the associated fine-grained material occurs as layers more than 100 feet thick (see well DP16-6, section 17, Plate 8), but in other areas fine material occurs interspersed with sand (see well DP23-7, section 29, Plate 11).

Figure 5-6 contains annotations (arrows) taken from Fisher and others (1970) indicating interpreted axes of fluvial sediment input for the combined upper and Lower Jackson. Larger arrows indicate major inputs. These fluvial axes correspond to areas of thick sand accumulation, although axes in the northeastern part of the study area tend to correspond with southeast trending areas of thickness, whereas those in the southern half of the study area correspond with more south- to slightly southwest-trending areas of thickness.

5.3.2 Lower Jackson Layer

Net sand thickness values for the Lower Jackson Layer are posted with computer-generated contours on Plate 18. Net sand thickness ranges from almost 300 feet in one area to 0 feet in much of the downdip (southeast) extent of the study area. Thickest sand accumulations occur in the south-central and southern part of the study area.

5.3.2.1 Outcrop Region

Sand thickness of the Lower Jackson Layer in the outcrop region is less than that of the Upper Jackson Layer, and is more erratically distributed (Plate 18). Areas where sand thickness exceeds 100 feet include: (1) northern Central Texas, in Grimes, southern Burleson, northern Washington, and northeastern Fayette counties; (2) Central Texas, in eastern Gonzales and northern Karnes counties; southern Central Texas, along the boundaries of Atascosa and Live Oak counties and perhaps in southern central McMullen County; and South Texas, in southeastern Webb County, around the junction of Webb, Zapata, and Jim Hogg counties, southeastern Zapata County, and southwestern Starr County.

Sand content in the Lower Jackson Layer (Figure 5-7) can exceed 30 percent in the areas of thick sand accumulation described above. Values above 20 percent are more common in these thick sand areas, and additionally in a region of thinner sand in Trinity County. Regions of less than 10 percent sand are small and include, in South Texas, eastern Webb/western Duval counties, and in East Texas, the area surrounding the junction of Angelina, Trinity, and Polk counties.

5.3.2.2 General Study Area

In the northeastern part of the study area, two isolated areas of sand thickness exceeding 150 feet occur in Washington County and around the intersection of Montgomery, Walker, and Grimes counties. Each is surrounded by county-sized regions where sand thickness exceeds 50 feet. In the central and southern part of the study area, three regions of thickness reaching or exceeding 200 feet occur in: central Live Oak County; near the junction of Live Oak, Duval, and McMullen counties; and in the southern parts of Starr and Hidalgo counties. These thick sand accumulations are surrounded by narrow regions where sand thickness exceeds 50 feet. These regions extend southward from Lavaca and Gonzales counties to western Jim Wells County. The region turns abruptly, heading southeast from southern Jim Wells to southern Starr and Hidalgo counties. It should be noted that areas of sand accumulation less than 50 lie between the south-trending sand thick and the outcrop.

The percent-sand map for the Lower Jackson Layer (Figure 5-7) shows that maximum sand percentage exceeds 40 percent in only one small area, and is generally between 20 and 40 percent in areas of thick sand accumulation discussed previously. Fine-grained material (silt and clay) occur in the Lower Jackson as layers 300 feet or more thick, in some cases overlying a thick sand at the base of the layer (see well DP9-8R, section 9, Plate 6). Non-sand intervals greater than 200 feet thick may also encase a significant sand, as seen in well DP13-6 where a sand at the top of the Lower Jackson is underlain by Lower Jackson mud/shale and overlain by mud/shale of the Upper Jackson (see section 14, Plate 7). In areas of highest sand percentage, muds/shales occur as beds less than 30 feet thick between sands (see well DP19-14, section 20, Plate 9).

Generalized fluvial axes from Fisher and others (1970) for the combined upper and lower Jackson do not match Lower Jackson sand thicknesses (Figure 5-7) as well as they match Upper Jackson sands (Figure 5-6). Large input axes in Fayette and La Salle counties do not appear to be associated with significant Lower Jackson sand accumulations. A major axis in Wilson County and lesser axes in Atascosa and Wilson counties appear to connect to the most significant Lower Jackson sand-rich areas. The southern-most sand-rich area, in Starr and Hidalgo counties, might be fed by an undocumented axis in Starr County and southern Mexico.

5.3.3 Upper Yegua Layer

Net sand thickness values for the Upper Yegua Layer are posted with computer-generated contours on Plate 19. Net sand thickness exceeds 400 feet in small areas, and is greater than 100 feet across approximately one-half of the study area. Absence of sand occurs rarely in the outcrop area, but is more widespread in the downdip region, at the southeast edge of the central and southern parts of the study area.

5.3.3.1 Outcrop Region

Sand thickness of the Upper Yegua Layer in the outcrop region is greatest in narrow regions of McMullen, southeastern Webb, eastern Zapata, and southwestern Starr counties, likely exceeding 300 feet and locally reaching nearly 500 feet (Plate 19). Sand thickness commonly exceeds 100 feet over most of the outcrop region with the exception of Trinity, McMullen, Webb, and northern Zapata counties.

Sand content in the Upper Yegua Layer (Figure 5-8) commonly exceeds 20 percent in areas of thick sand accumulation mentioned above, being less than 20 percent elsewhere along the outcrop. Locally, sand percent exceeds 40 in eastern Angelina, southern Brazos and Burleson, Gonzales and eastern Fayette, and McMullen counties.

5.3.3.2 General Study Area

In the northeastern part of the study area, a large region exists where sand accumulation exceeds 200 feet. This region trends southwestward from Polk through Austin counties, reaching a maximum of more than 400 feet near the junction of Liberty, Montgomery, and San Jacinto counties. Most of the northeastern part of the study area contains more than 100 feet of accumulated sand. Areas of less than 100 feet sand thickness occur updip (northwest) of the large area of thick accumulation, and may extend to the outcrop. These (relatively) sand-poor areas include regions: from central Brazos County through Grimes and into Waller counties; a north-south oriented zone in Trinity County extending into Polk County; and an area surrounding the junction of San Augustine, Angelina, Tyler, and Jasper counties.

In the central and southern parts of the study area, a long southwest-trending region of more than 100 feet of sand thickness extends from outcrops in Gonzales and Fayette counties through Zapata and Webb counties. This region contains large areas exceeding 200 feet in sand thickness, with localized areas exceeding 400 feet. Thicknesses decrease toward the outcrop belt, to the northwest, with sand being absent in parts of Webb and Zapata counties. Another area of thick sand accumulation in this part of the study area extends east or southeast from Starr County to Hidalgo County where sand thickness is greater than 200 feet and locally reaches 575 feet.

The percent-sand map for the Upper Yegua Layer (Figure 5-8) shows that maximum sand percentage exceeds 60 percent in a small area near the outcrop in southern Houston County, but elsewhere is generally between 20 and 50 percent in the previously noted areas of thick sand accumulation. Intervals of fine-grained sediments in the Upper Yegua occur as layers as thick as 200 feet that can encase sands (see well DP22-13, section 24, Plate 10). Fines also occur as thin layers less than a few tens of feet thick interbedded with high-quality sands (see well DP19-14, section 20, Plate 9).

Arrows on Figure 5-8 represent fluvial axes for the Upper Yegua Formation compiled from Meckel (1993). One large axis in the north corresponds with the high percent-sand area of Houston County. Other major inputs correspond to thick sandy areas in Fayette/Lavaca and in Wilson/Karnes counties. Other lesser inputs occur updip of sand-rich trends that are separated from the outcrop by sand-poor regions. This suggests that narrow sand-rich areas in these regions may not have been encountered and mapped because of the sparser data coverage of this study compared to that of Meckel (1993).

5.3.4 Lower Yegua Layer

Net sand thickness values for the Lower Yegua Layer are posted with computer-generated contours on Plate 20. Net sand thickness exceeds 400 feet in small areas, and is greater than 100 feet across three-quarters of the study area. Absence of sand occurs rarely in the outcrop area, but is more broadly distributed downdip at the southeast edge of the central and southern parts of the study area.

5.3.4.1 Outcrop Region

Sand thickness of the Lower Yegua Layer in the outcrop region is generally greater than 100 feet (Plate 20), except in northern Central Texas (Burleson, Lee, and eastern Fayette counties). Sand thickness exceeds 200 feet in isolated areas of East Texas (San Augustine and Trinity counties). Values also exceed 200 feet in Central Texas, in Fayette County, and over about one third of the outcrop area south of Karnes County. Thicknesses approaching or exceeding 300 feet in South

Texas include LaSalle, southern McMullen, eastern Webb, eastern Zapata, and western Starr counties (Plate 20).

Sand content in the Lower Yegua Layer (Figure 5-9) exceeds 20 percent over much of the outcrop area with the exception of small areas in Central and South Texas. One area of greater than 40 percent sand occur in East Texas from the Louisiana border westward to Brazos County, with values in Madison County that exceed 80 percent. A region of more than 40 percent sand occurs in Central Texas, from Fayette County south to Wilson and Live Oak counties – peak values here exceed 60 percent. Isolated areas of more than 40 percent sand also occur in eastern Webb and southwestern Starr counties.

5.3.4.2 General Study Area

A great majority of the northeastern half of the study area contains more than 100 feet of sand thickness, with a small area of less than 100 feet thickness extends southwest from Burleson County to the southern-central area of Fayette County. A small region of greater than 200 feet of sand occurs in Houston, Walker, Trinity, and Polk counties, and includes a value of almost 400 feet of sand encountered in one well. In Polk County, a much larger region of sand thickness in excess of 200 feet covers about one-half of the northeastern half of the study area just downdip (southeastward) of the outcrop. This region extends from northern Jasper County southwest to the boundary of Lavaca and Colorado counties. Within this region are small to moderately sized areas where thickness exceeds 300 feet, reaching almost 400 feet in some wells. These areas are located in Tyler and Jasper counties, and dotted across Montgomery, Waller, Austin, and Colorado counties.

In the central and southern half of the study area, a broad southwest-trending region of more than 100 feet of sand thickness covers the updip half, or more, of the area. Only small areas of less than 100 feet of sand occur within this region, in Dimmit, Webb, and Zapata counties. Several large subregions occur within the larger region of thick sand accumulation in which thickness exceeds 200 feet, with some large areas exceeding 300 feet. These subregions include: (1) an area along the outcrop belt from Gonzales County to central Live Oak County; (2) a large area from southern La Salle, McMullen, and Live Oak counties that extends south to southeastern Webb County, and then turns west, intercepting the outcrop in southern Webb County (one well within this area contains over 400 feet of sand); (3) a small area in central Zapata County;

(4) small areas in northwestern and southwestern Starr County, with one well having greater than 600 feet of sand; and (5) an area along the Starr/Hidalgo County border. An area of less than 100 feet thickness lies downdip of the sand-thick trend, extending along a line from central Starr County through southeast Live Oak County and up to the southern half of Lavaca County. Southwest of this line, sand thicknesses quickly decrease to zero.

The percent-sand map for the Lower Yegua Layer (Figure 5-9) shows that, in the downdip area, maximum sand percentage often exceeds 40 percent in the previously noted areas of thick sand accumulation with many small isolated areas of greater than 60 percent sand. Fine-grained material (silt and mud) occurs as a layer up to 100 feet thick between or above Lower Yegua sands (see well DP2-7R, section 3, Plate 3, well DP5-8, section 6, Plate 5, and well DP22-13, section 24, Plate 10), and as thin layers less than 30 feet thick between good sands or as even thinner silty layers interbedded with thin sands (see Richardson well, section 24, Plate 10).

Fluvial axes specific to the Lower Yegua (arrows, Figure 5-9) were compiled from Meckel (1993). Major axes exist across the study area, including the northern area (Nacogdoches County), southern central area (Atascosa County) and southern area (central Webb County). However, many large sand-rich areas correspond best to collections of lesser axes, such as in the Houston/Leon County area. A small axis noted by Meckel (1993) corresponds with a localized sand thick in this study at the Starr/Hidalgo County border that is not mentioned by previous workers.

5.4 Depositional Systems

Net sand thickness and sand percent provide information regarding the distribution of sand within an aquifer layer. However, parameters such as conductivity (vertical and horizontal) and storativity are not uniform for all sand in a given aquifer layer. These hydrologic characteristics are a function of the grain size, sorting, mineralogy, and degree of interbedding or interlamination of silt and clay. These properties are dependent on the sediment source area and the energy of the depositional setting. For example, sand from a given source area that is deposited in a fluvial environment will have a relatively coarse grain size, moderate sorting, and a moderate amount of interbedded fine material. It will have good storativity and a high contrast between vertical and horizontal hydraulic conductivity. Whereas, sand from the same source area that is deposited in a barrier bar/strandplain setting might have a finer grain size, but has better sorting, fewer compactable grains, and far fewer interbedded silt and clay layers, resulting in better aquifer characteristics. It will have good to very good storativity and a low contrast between vertical and horizontal conductivity. Thus, a modification of aquifer characteristics on the basis of depositional facies may improve the accuracy of the resulting numerical model.

Depositional facies for each aquifer layer are discussed in the following sections, in the order in which the layers were deposited (Lower Yegua through Upper Jackson). Interpretation of facies at each wellbore was based on log curve shape and was generalized for the layer. This generalization must be done because a layer may contain many sand bodies, each deposited in different settings. In this case, a well is assigned the facies that is most abundant in the mapped layer at that well. Facies boundaries are hand-drawn based upon facies and log curve profiles in individual wells and surrounding wells, in addition to sand thickness trends. Facies boundaries may often follow sand thickness contours, such as when distinguishing between proximal and distal deltaic settings. However, if, during creation of an overall understanding of the deposition of a layer, computer-generated sand thickness contours appear inconsistent with the depositional model, they are disregarded for the purposes of mapping facies boundaries.

5.4.1 Lower Yegua Layer

In the updip regions (northwestern edge of study area) log curves are dominated by upward-fining sands and shaly intervals containing thin spikey sands and silts. Along the middle region of the study area, log curves contain a mixture of upward-fining and upward coarsening sands, but upward coarsening sands dominate. In parts of this region, spontaneous potential curves appear blocky and the corresponding resistivity curve increases upward (upward-coarsening) or is also blocky. In mud-rich interval of the downdip region (southeast) of the study area, sand is generally absent, replaced by thin silt beds. In some downdip areas, thick upward-coarsening to blocky sands occur.

The interpreted facies map for the Lower Yegua Layer is shown in Figure 5-10. Updip sand-rich intervals dominated by upward-fining sands are interpreted as dip-oriented fluvial deposits. Intervening areas of less than 100 feet of sand are marginal to these fluvial axes and are here considered floodplain deposits, even though these areas may contain some individual thick upward-fining fluvial sand bodies. Sand-rich regions across the middle of the study area that are dominated by upward coarsening or blocky sand bodies are interpreted as deltaic facies fed by updip fluvial systems. In the northern and southern part of the study area, these deltas prograde out to the shelf-edge position as interpreted by Galloway and others (1983). Areas between the fluvial deposits and the shelf edge that contain less than 100 feet of net sand are interpreted as delta margin deposits. The area downdip of the shelf edge is dominated by shale, but a sandy interval in a well in South Texas contains an upward-fining sand body approximately 100 feet thick. This suggests that sandy sediment bypassed the deltas and was carried by channels across the slope.

5.4.2 Upper Yegua Layer

In the updip regions of the Upper Yegua Layer, log curves are again dominated by upward-fining sands and shaly intervals containing thin spikey sands and silts. Along the axis of the study area, as in the Lower Yegua Layer, log curves contain a mixture of upward-fining and upward coarsening sands, but upward coarsening sands dominate. In parts of this region, spontaneous potential curves appear blocky and the corresponding resistivity curve increases upward (upward-coarsening) or is also blocky (this shape is very common in the southern part of the Upper Yegua Layer). In mud-rich intervals of the downdip region (southeast) of the study area, net sand thickness is markedly decreased, and log curves indicate the presence of shale and thin (10–30 feet thick) sands that are symmetrical, upward coarsening, or upward fining. In downdip regions in the northern and southern parts of the study area, thick upward-coarsening to blocky sands and thick, overall upward coarsening intervals of interbedded sand and shale occur.

The interpreted facies map for the Upper Yegua Layer is shown in Figure 5-11. As in the Lower Yegua, updip regions are interpreted as fluvial axes separated by floodplain deposits (defined as having less than 100 feet of net sand). Sand-rich regions across the middle of the study area are interpreted as deltaic deposits fed by the updip fluvial systems. Deltaic centers in the southern part of the study area are likely more wave-dominated as suggested by strike alignment and the dominance of blocky sand bodies. Thick sand accumulations at the shelf edge containing blocky sands or interbedded sand and shale are interpreted as shelf-edge deltas constructed as deltas built to the shelf edge. These deltas received sustained volumes of sediment, resulting in aggradational stacking of sand as delta progradation was slowed by having to fill increasing depths of water on the slope. It is extremely likely, assuming the shelf-edge position is accurate, that abundant sand bypassed deltas near the shelf edge and was deposited on, and carried across, the slope.

5.4.3 Lower Jackson Layer

In the updip regions of the Lower Jackson Layer, log curves are again dominated by upward-fining sands and shaly intervals containing thin spikey sands and silts. Along the axis of the study area, as in the Yegua layers, log curves contain a mixture of upward-fining and upward coarsening sands, but upward coarsening sands dominate. In parts of this region, spontaneous potential curves appear blocky and the corresponding resistivity curve increases upward (upward-coarsening) or is also blocky (this shape is very common in the southern part of the Upper Yegua Layer). In mud-rich intervals of the downdip region (southeast) of the study area, sand is nearly absent, and intervals contain thick shales with thin silt beds. In downdip regions in the southern part of the study area, thick upward-coarsening to blocky sands and thick, overall upward coarsening intervals of interbedded sand and shale occur in a few wells.

The interpreted facies map for the Upper Yegua Layer is shown in Figure 5-12. As in the Yegua, updip regions are interpreted as fluvial axes separated by floodplain deposits (defined as having less than 50 feet of net sand). Sand-rich regions across the middle of the study area are interpreted as deltaic deposits fed by the updip fluvial systems. Areas between fluvial axes, updip of deltaic settings, but containing less than 50 feet of net sand and dominated by thin upward-coarsening sands were interpreted as delta margins. Areas downdip of deltaic regions and containing from less than 50 feet of net sand to zero sand are interpreted as distal deltaic facies. Deltaic centers in the southern part of the study area have been interpreted by Fisher and others (1970) as being more wave-dominated deltas, or even strandplain/barrier bar systems, as suggested by strike alignment and the dominance of blocky sand bodies. A similar interpretation is made here, and it is noted that more strike-aligned sandbodies result in thinning or decrease of sand in the outcrop direction. Downdip shale dominated intervals are more abundant in the Lower Jackson than in either of the Yegua layers, indicating a significantly higher relative sea level, possibly related to decreased sediment supply. Thick sand accumulations at the shelf edge containing blocky sands or interbedded sand and shale are again interpreted as shelf-edge deltas, which feed sand down across the slope in narrow dip-oriented channels.

5.4.4 Upper Jackson Layer

In the updip regions of the Upper Jackson Layer, log curves are again dominated by upward-fining sands and shaly intervals containing thin spikey sands and silts. In middip regions of the study area, as in the Yegua layers, log curves contain a mixture of upward-fining and upward coarsening sands, but upward coarsening sands dominate. In parts of this region, spontaneous potential curves appear blocky and the corresponding resistivity curve increases upward (upward-coarsening) or is also blocky (this shape is very common in the southern part of the Upper Yegua Layer). In mud-rich intervals of the downdip region (southeast) of the study area, sand is nearly absent, and intervals contain thick shales with thin silt beds. In downdip regions in the southern part of the study area, thick upward-coarsening to blocky sands and thick, overall upward coarsening intervals of interbedded sand and shale occur in a few wells.

The interpreted facies map for the Upper Jackson Layer is shown in Figure 5-13. As in the Yegua, updip regions are interpreted as fluvial axes separated by floodplain deposits (defined as having less than 50 feet of net sand). Sand-rich regions across the middle of the study area are interpreted as deltaic deposits fed by the updip fluvial systems. Areas between fluvial and deltaic settings but containing less than 50 feet of net sand and dominated by thin upward-coarsening sands were interpreted as delta margins. Areas downdip of deltaic regions and containing from less than 50 feet of net sand to zero sand are interpreted as distal deltaic facies. Areas updip of the shelf edge but lacking sand are mapped as ‘shelf’ facies.

Deltaic centers in the southern part of the study area, as in the Lower Jackson Layer, appear strongly wave-influenced, especially compared to deltas in the northern part of the study area in which patterns of thick sands are more dip-oriented and which are likely more fluvially dominated. Downdip shale-dominated intervals are less abundant in the Upper Jackson Layer than in the Lower Jackson. This reinvigorated progradation (although still weaker than the Lower Yegua) indicates a lower relative sea level, possibly related to increased sediment supply. Thick sand accumulations at the shelf edge containing blocky sands or interbedded sand and shale are again interpreted as shelf-edge deltas, which feed sand down across the slope in narrow dip-oriented channels. However, in the upper Jackson, the southern wave-dominated delta has built to, or past, the shelf edge, creating a strike-aligned shelf-edge sand body.

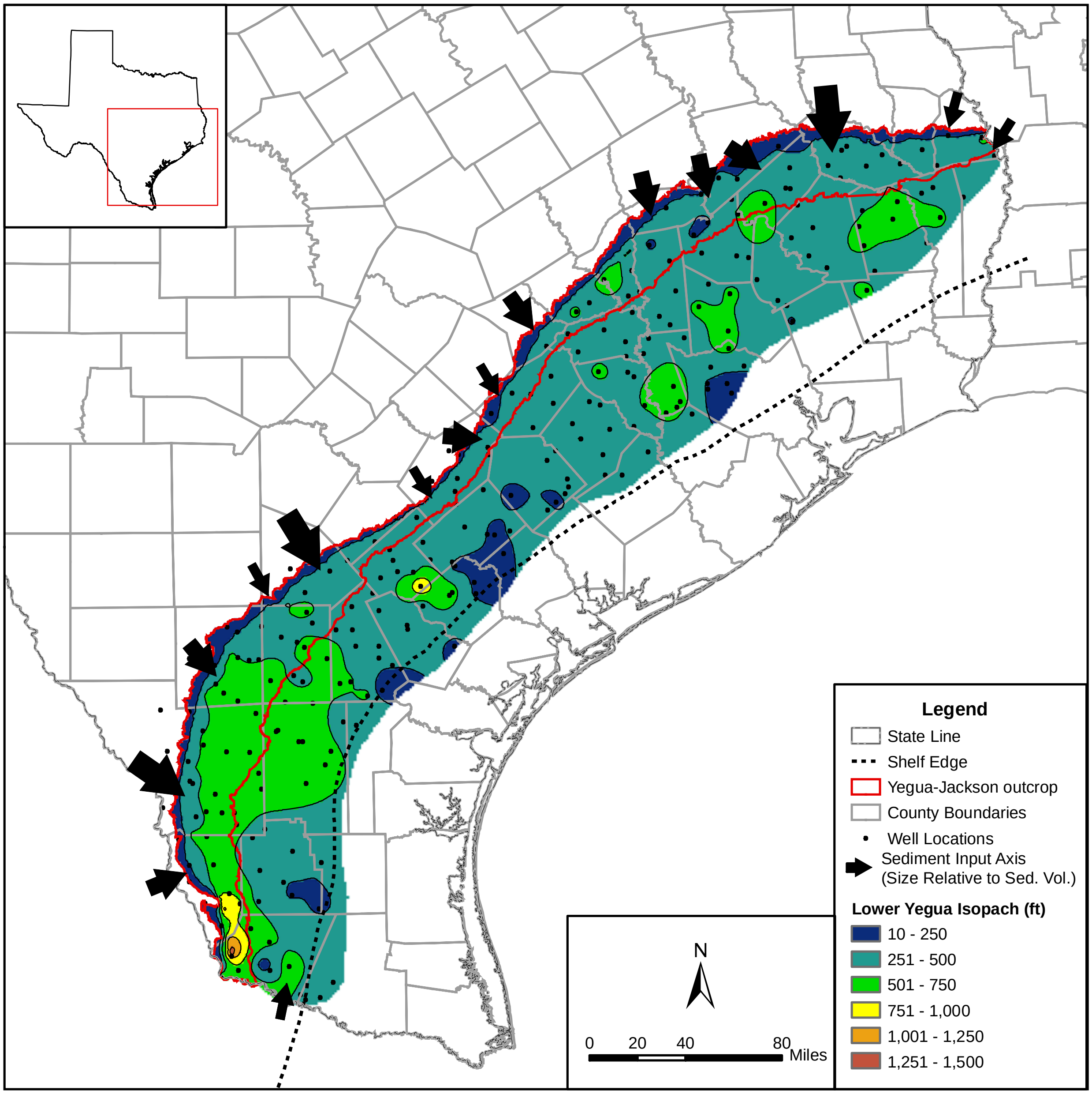


Figure 5-1. Lower Yegua isopach map.

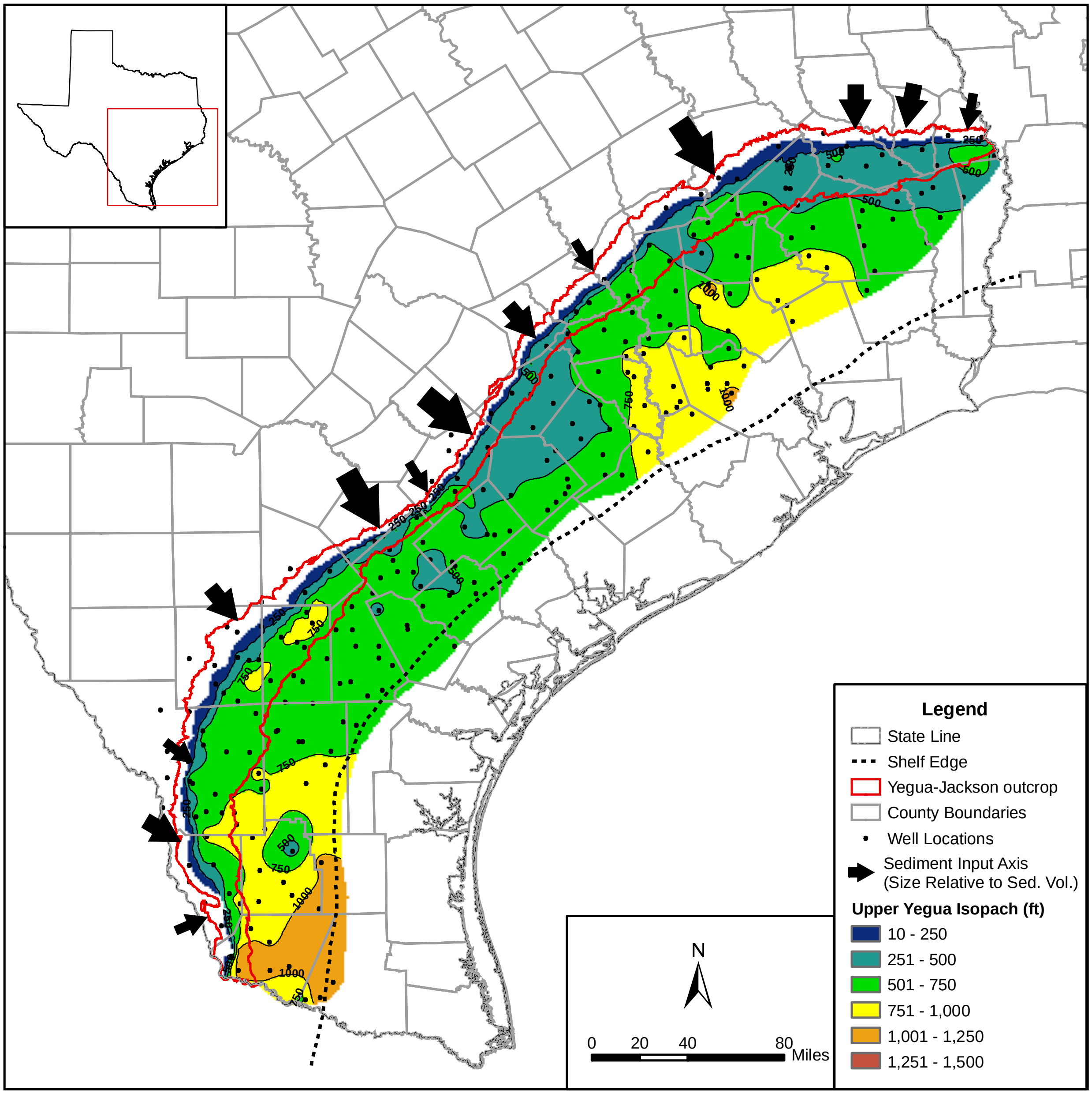


Figure 5-2. Upper Yegua isopach map.

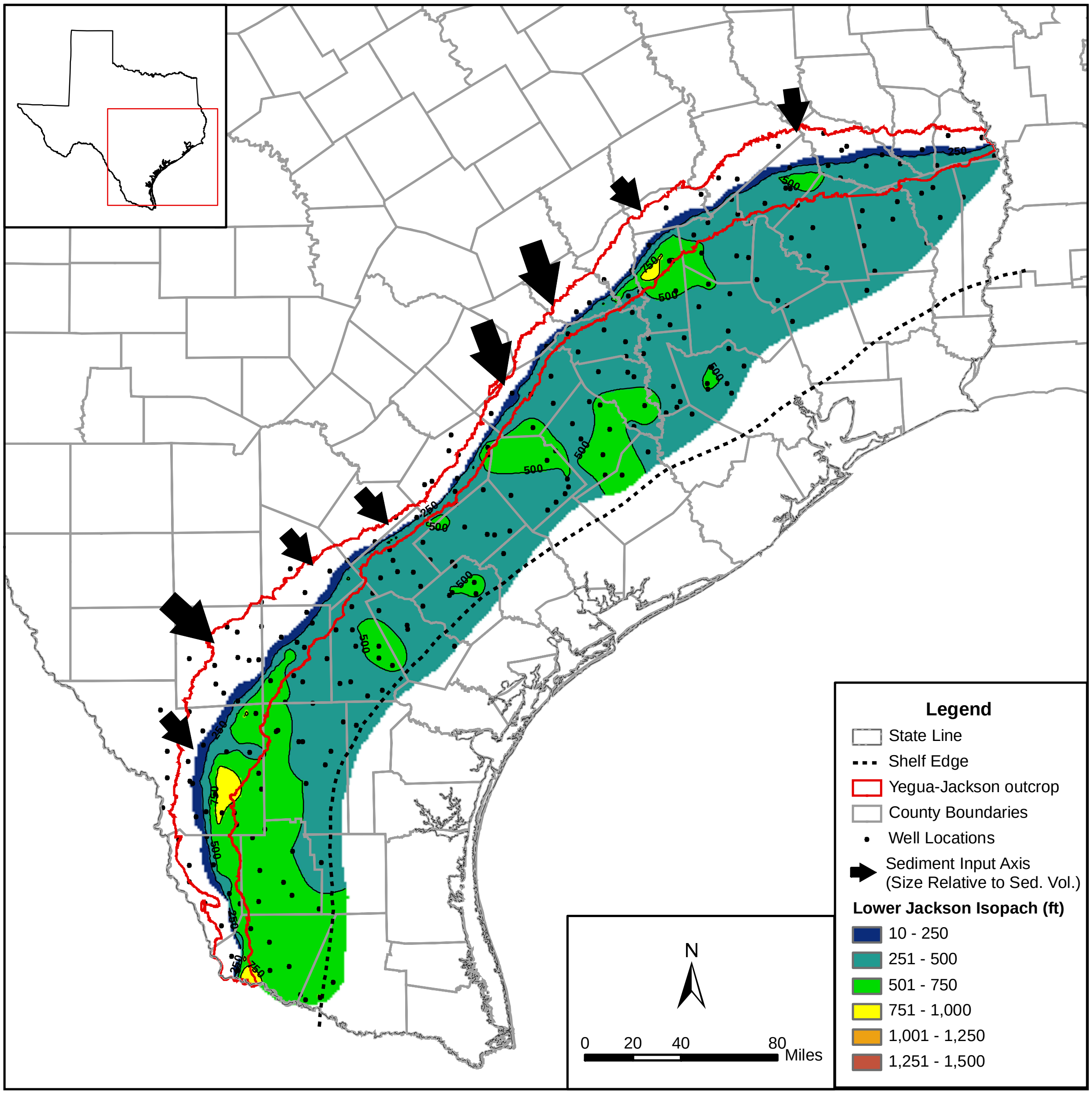


Figure 5-3. Lower Jackson isopach map.

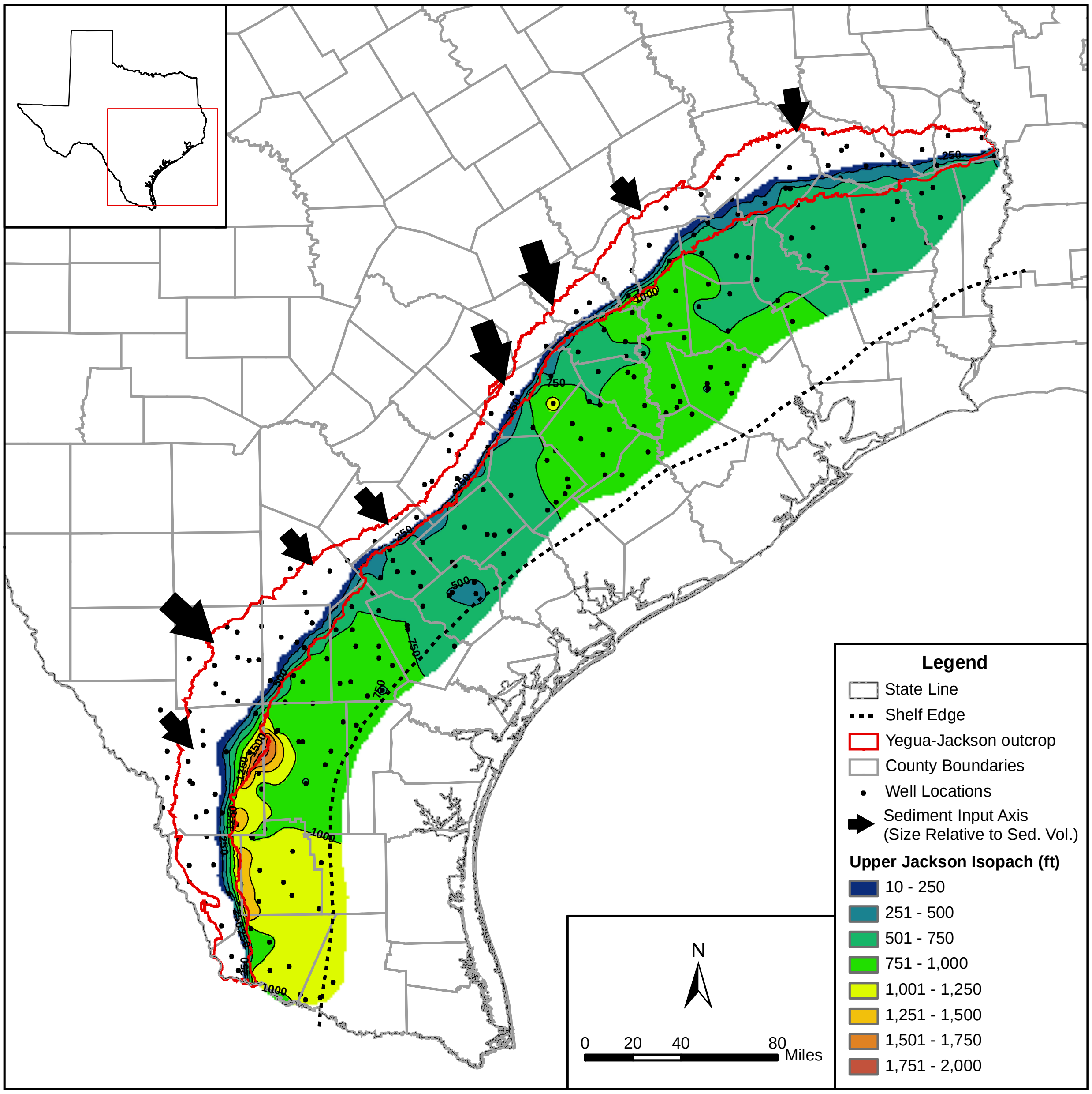


Figure 5-4. Upper Jackson isopach map.

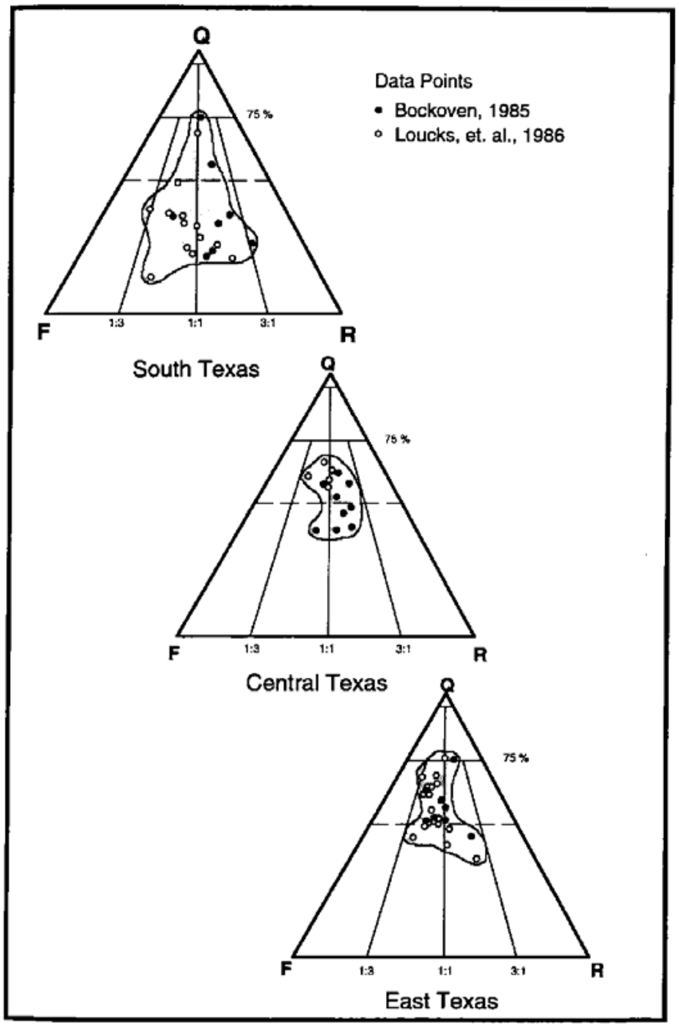


Figure 5-5. **Quartz-Feldspar-Lithic diagram showing sand grain composition for samples in the Yegua-Jackson Aquifer (after Meckel), 1993. Original data from Bockoven (1985) and Loucks and others (1986).**

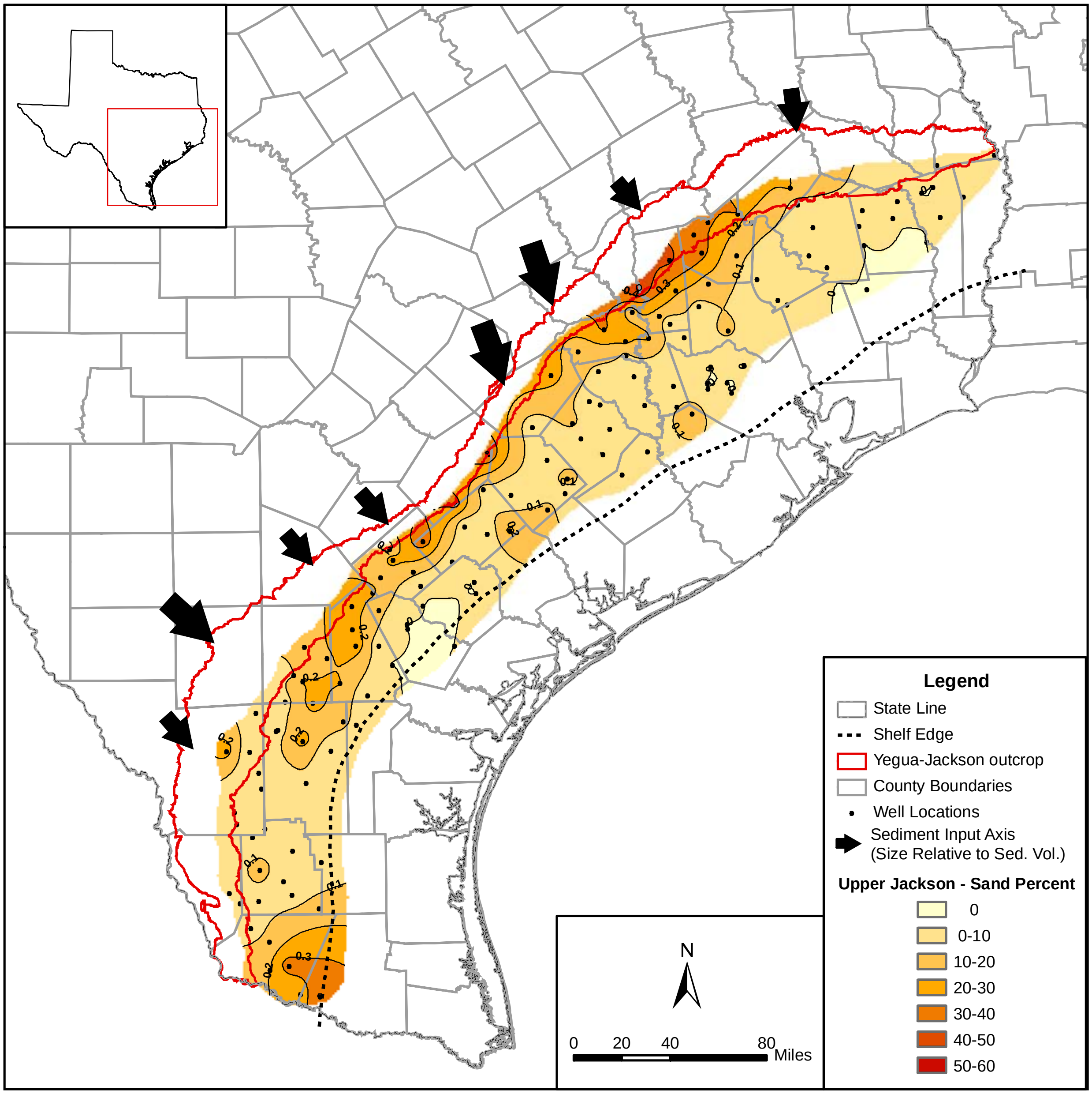


Figure 5-6. Upper Jackson sand percent map.

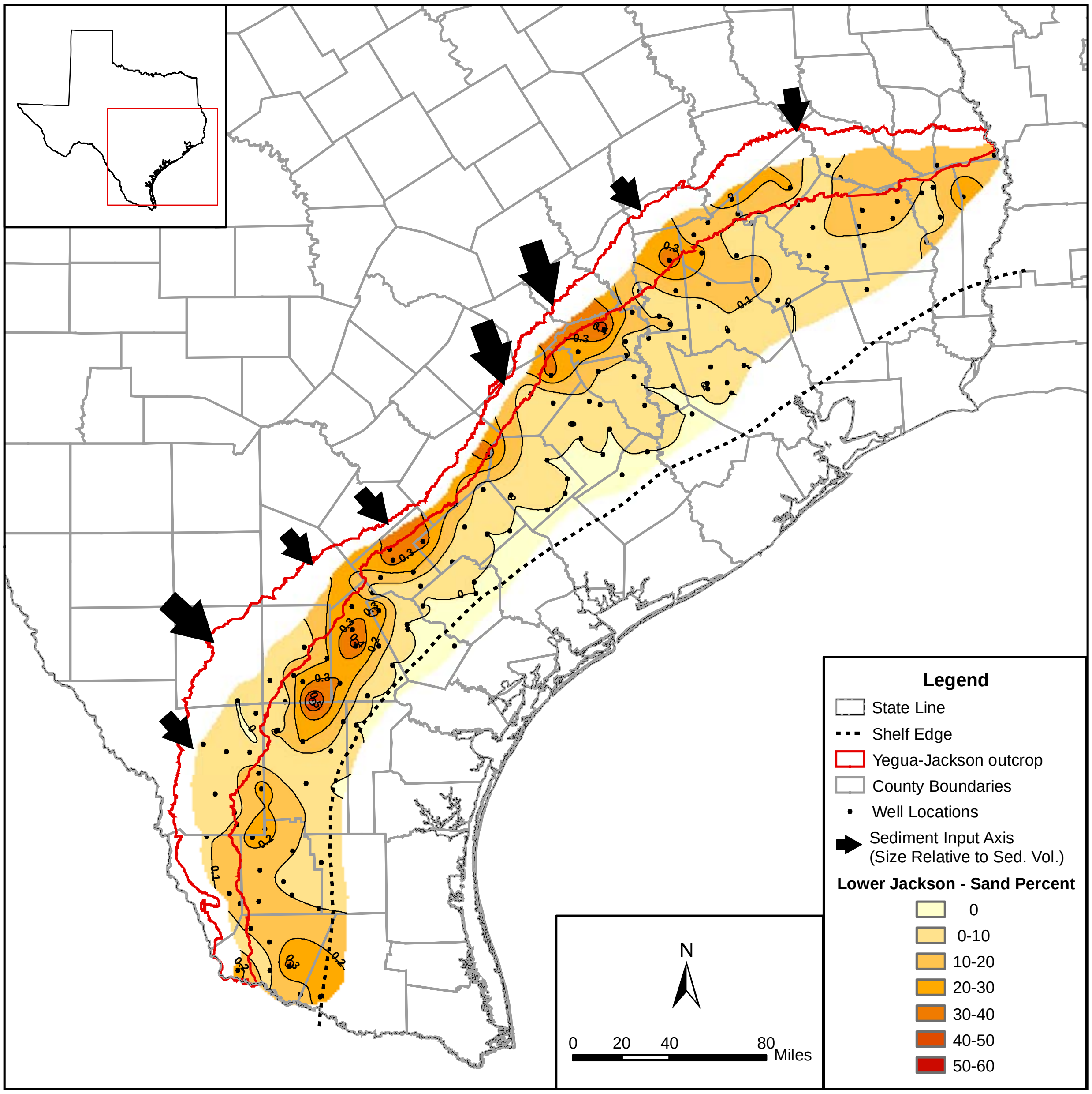


Figure 5-7. Lower Jackson sand percent map.

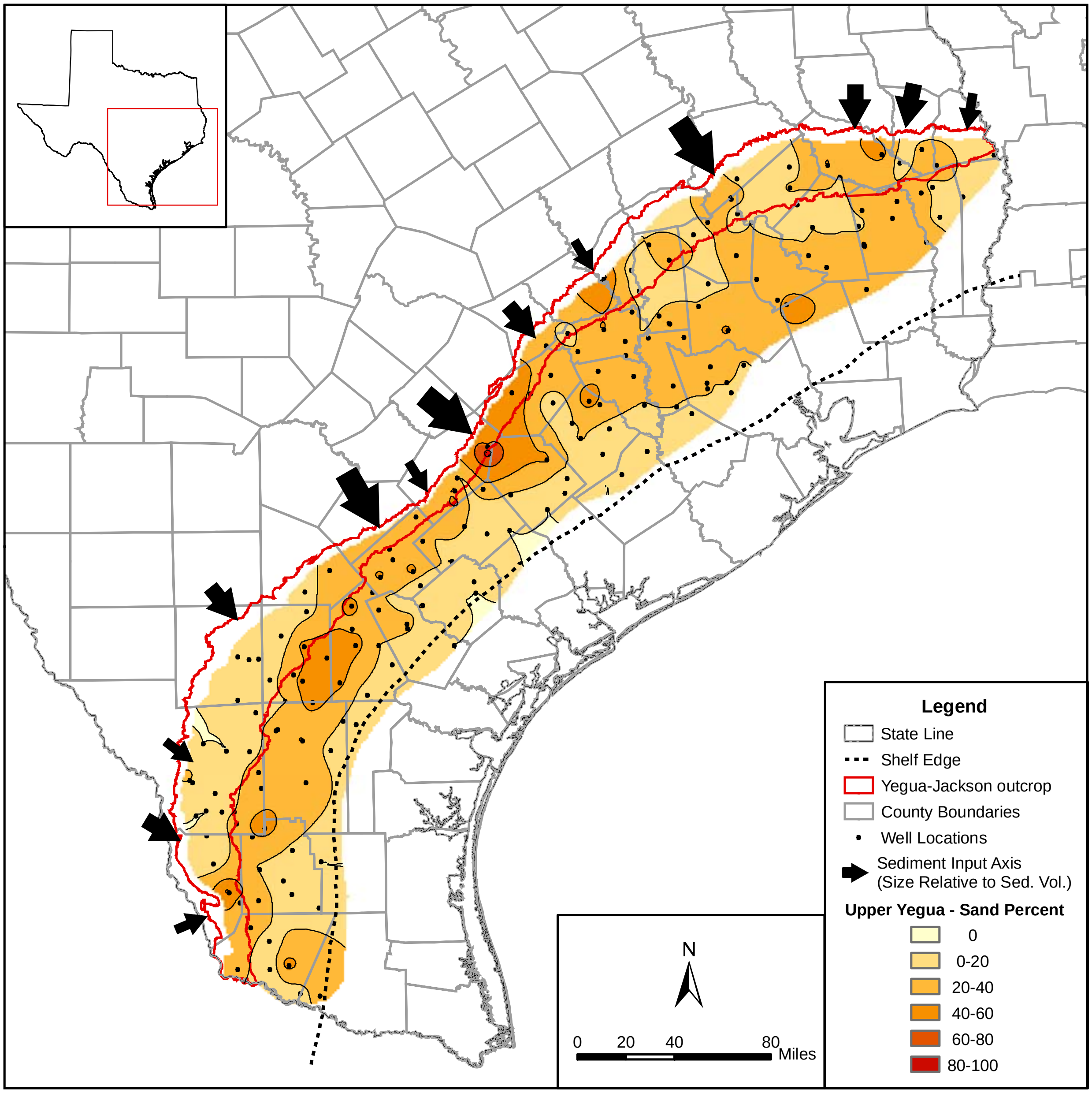


Figure 5-8. **Upper Yegua sand percent map.**

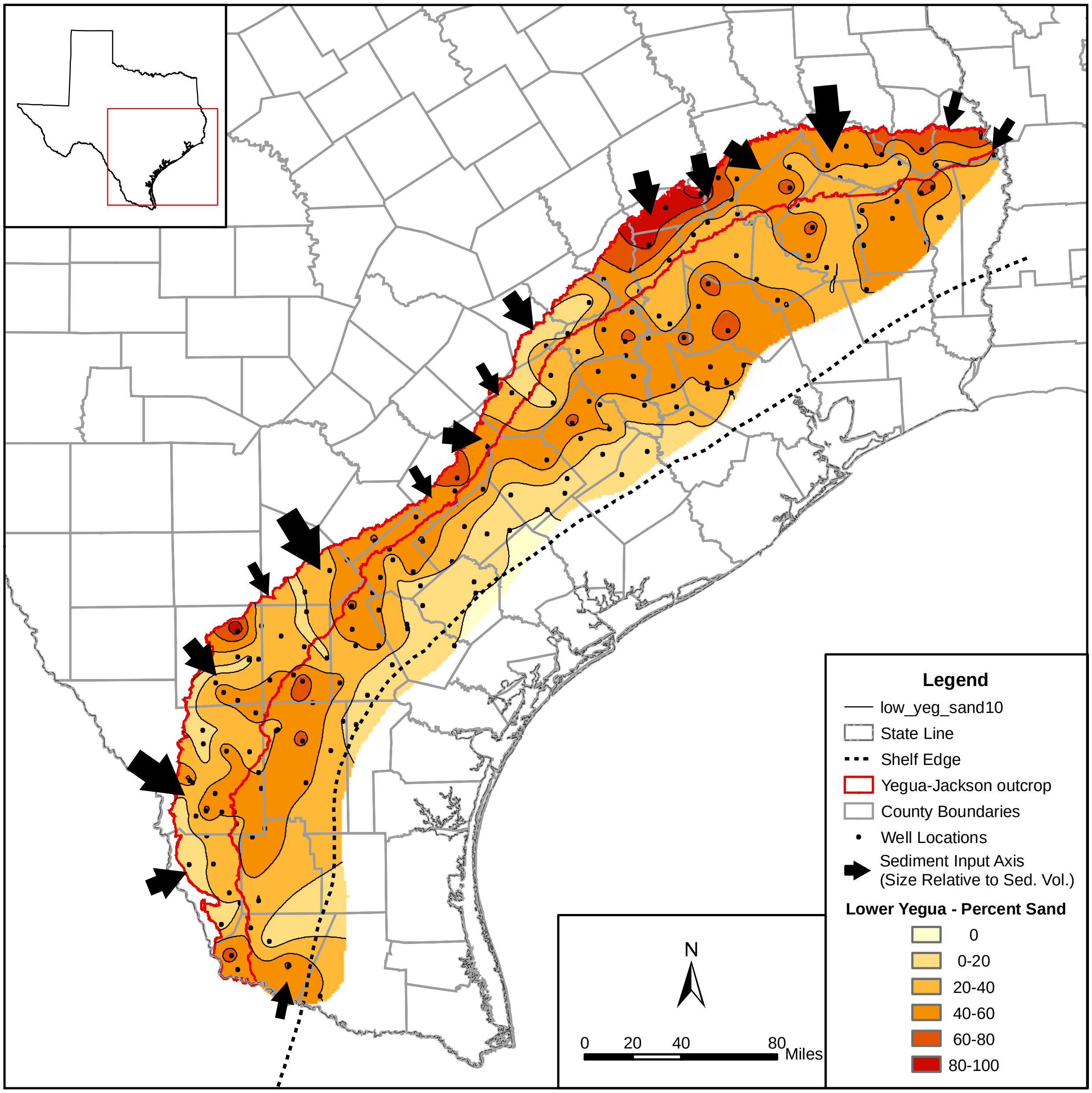


Figure 5-9. **Lower Yegua sand percent map.**

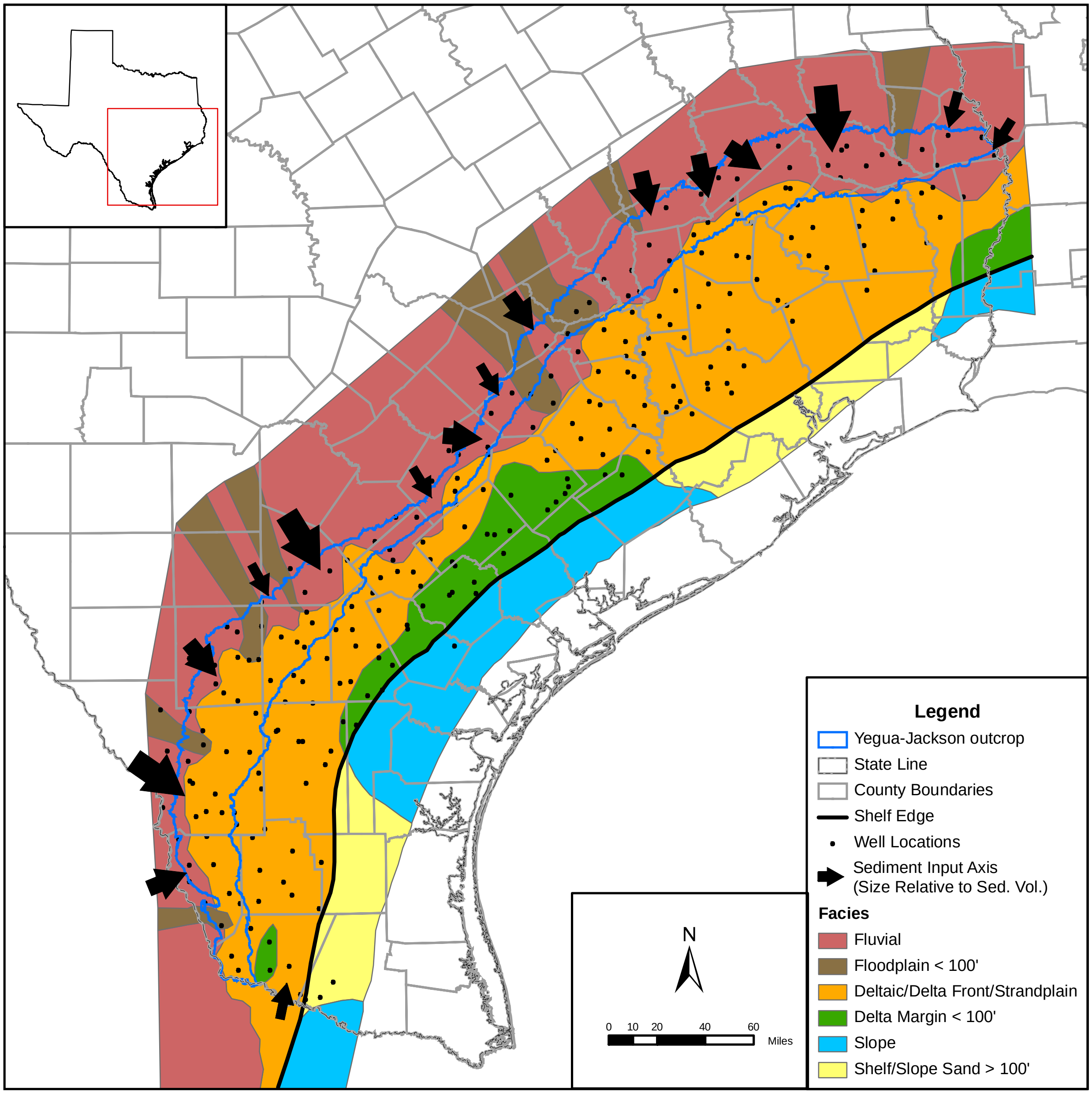


Figure 5-10. Lower Yegua depositional facies map.

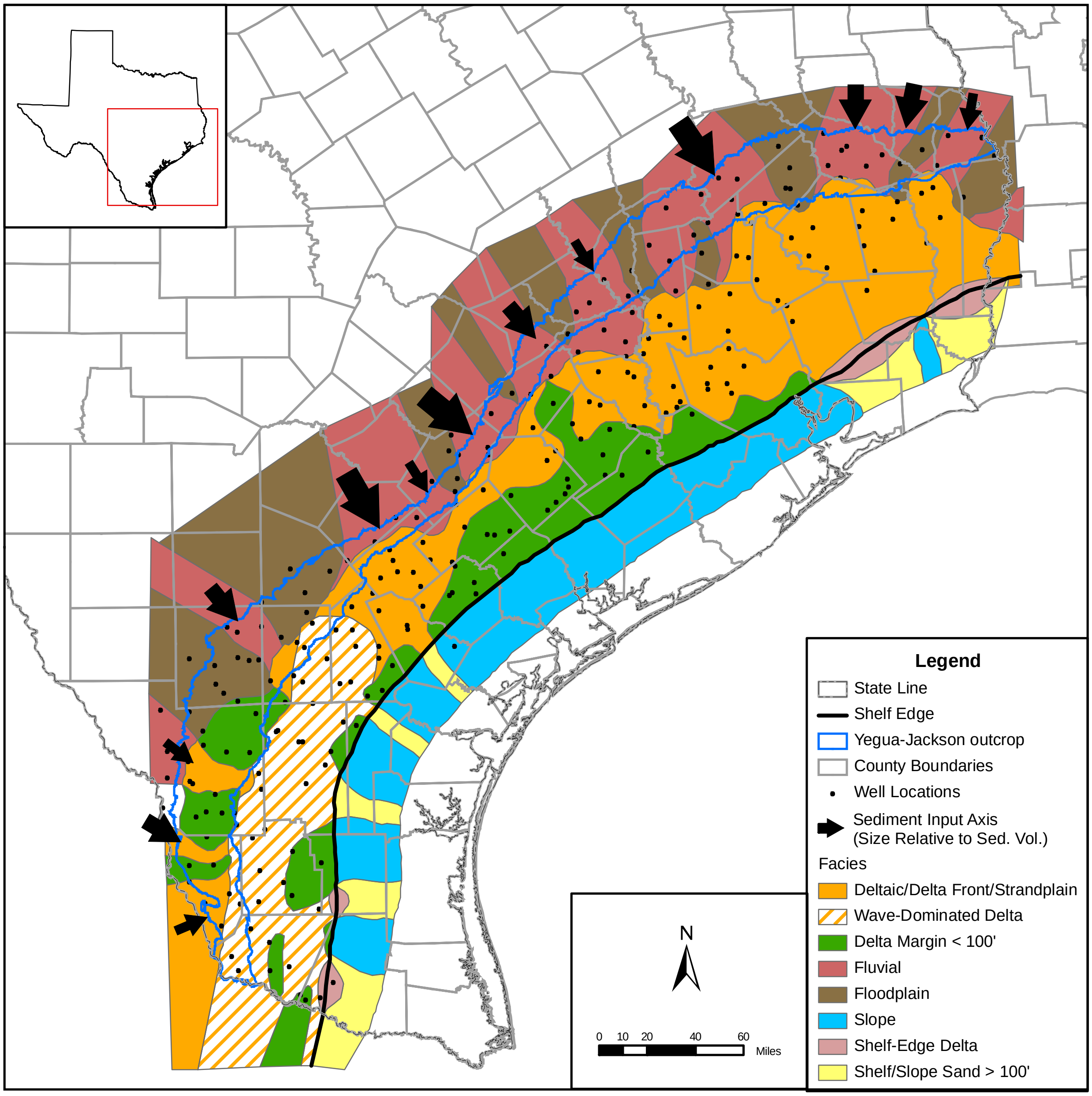


Figure 5-11. **Upper Yegua depositional facies map.**

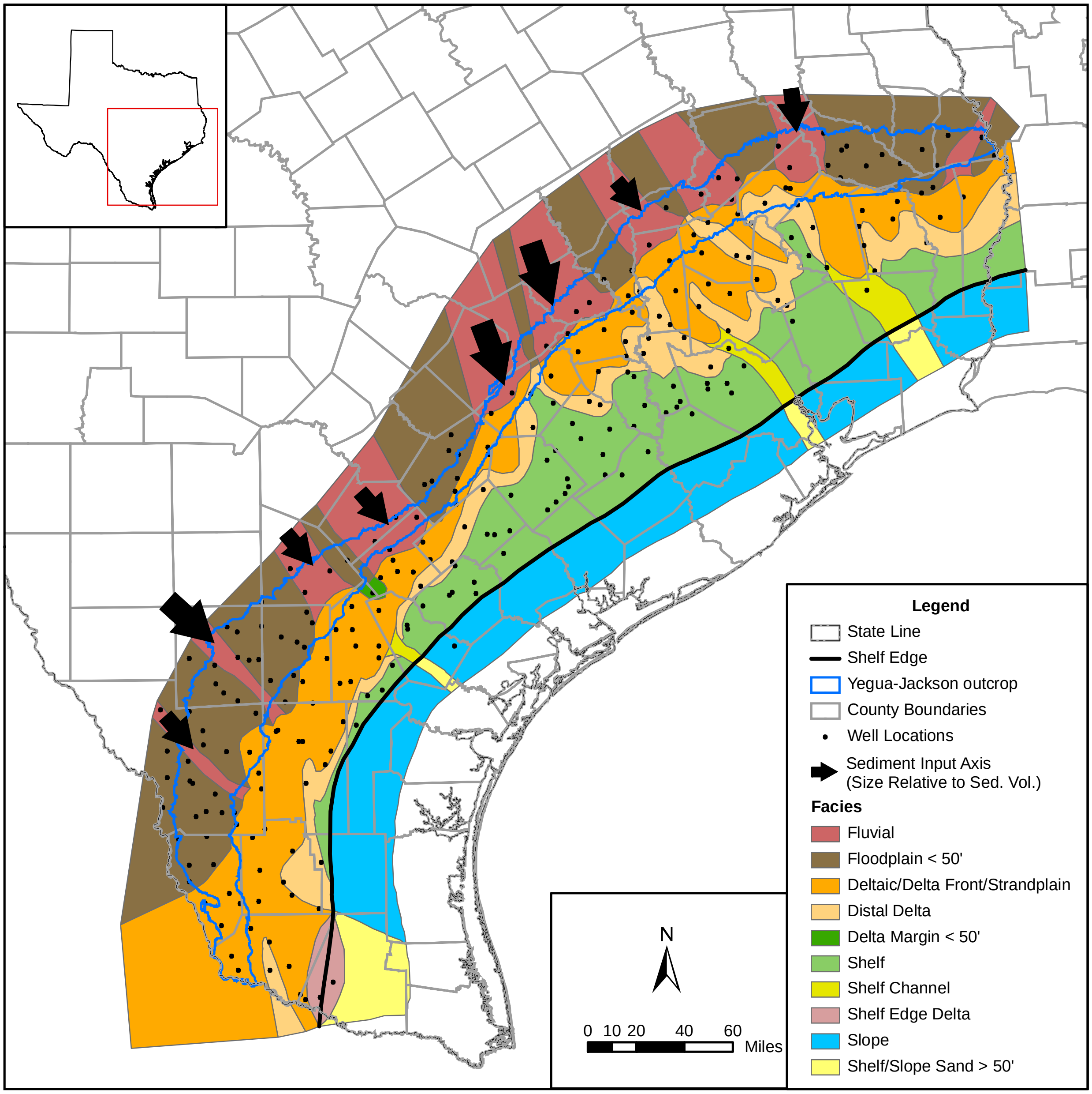


Figure 5-12. **Lower Jackson depositional facies map.**

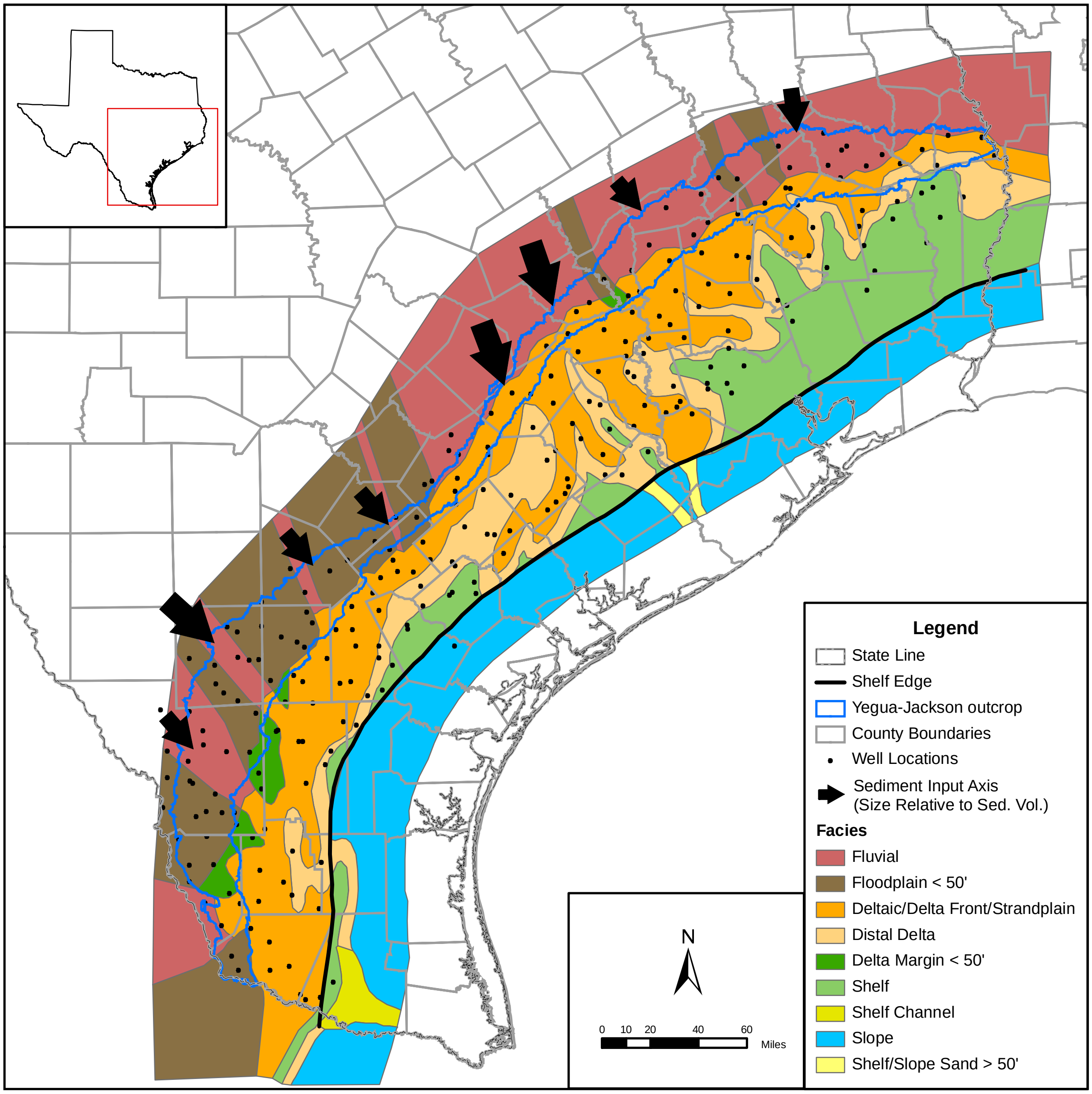


Figure 5-13. **Upper Jackson depositional facies map.**

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6. Conclusions and Recommendations

This report documents the development of the structure and depositional framework for the Yegua-Jackson Aquifer in Texas. The Eocene-age Yegua-Jackson interval is designated as a minor aquifer by the Texas Water Development Board. The Yegua-Jackson Aquifer is reported to have an estimated available groundwater supply of 25,000 acre-feet per year. The purpose of this study is to provide the basic data regarding aquifer structure and depositional framework capable of supporting the future development of a Yegua-Jackson Aquifer Groundwater Availability Model.

The Yegua-Jackson Aquifer exists predominantly in the outcrop or near-outcrop areas of the Yegua Formation and Jackson group. In Texas, this outcrop area stretches in a relatively thin band approximately parallel to the coastline, from Starr County in the Rio Grande Valley to Sabine County in East Texas, and is thus bracketed by the Rio Grande River to the south, and the Toledo Bend Reservoir (along the Sabine River) to the east. The width of this outcrop varies from less than 10 miles in Gonzales County to near 40 miles in La Salle County, with an area of approximately 11,000 square miles.

The Yegua Formation overlies the Cook Mountain Formation and is uppermost in the Middle Eocene Upper Claiborne group. This group is overlain by the Upper Eocene to Oligocene Jackson Group. In Texas, the Jackson Group consists of the Whitsett, Manning, Wellborn, and Caddell formations (and lateral equivalents). The Yegua-Jackson interval continues across the Sabine River into Louisiana, where the Yegua Formation is called the Cockfield Formation, and the Jackson Group is undifferentiated.

This study created a chronostratigraphic framework for the Yegua-Jackson Aquifer that spans its entire extent in Texas. A chronostratigraphic approach to mapping provides a consistent depositional framework for the geologic intervals comprising the aquifer. The dominant controls on aquifer framework in terms of fluid flow characteristics result from the distribution of sedimentary processes, both geographically and through geologic time. Estimating aquifer framework and heterogeneity on the basis of outcrop and limited subsurface data requires a predictive approach founded on an understanding of the activities that built the aquifer. The concepts of chronostratigraphy and depositional systems provide that predictive capability.

Unlike lithostratigraphic correlation, which relies on lithologic changes to subdivide sedimentary intervals, chronostratigraphic correlation relies on recognition of depositional surfaces formed at critical times in a depositional cycle. At these relatively brief periods of time, broad areas of the coast are undergoing similar depositional processes. At sea-level highstand times, deposition of fine-grained deposits (an aquitard) cover a large portion of the sand-rich sediments deposited during the last lowstand (an aquifer). These highstand times are represented by maximum flooding surfaces, and their associated fine-grained deposits are especially useful in defining aquifer framework because they often have a characteristic signature on geophysical logs from wellbores. Thus these deposits can be traced across a regional extent in the subsurface. The intervals above and below these fine-grained deposits are sand-rich packages deposited under a common set of conditions, including positions of major sediment input. Predictive methods for evaluating the geographic distribution of sand-rich areas within the package can then be applied. These predictive methods are based on observations of modern depositional processes and systems such as rivers and deltas. These methods rely on the commonality of depositional conditions within the time frame of the package, and the location and style of sand-rich deposition will vary from package to package.

The following bullets will summarize the key findings or conclusions from this study.

- The general chronostratigraphic correlation approach used in this study is based upon the correlation of maximum flooding surfaces within fine-grained highstand deposits as defined in geophysical well logs arranged in dip-oriented cross sections, connecting low-resistivity markers in downdip shale sections with shales or abrupt-based sands in updip sandy and silty intervals.
- Correlation was based upon the use geophysical logs from 250 wells. These wells were used to develop a grid of 30 dip-oriented cross sections and 3 strike-oriented cross sections for correlation purposes. Dip sections extend from the Yegua-Jackson outcrop area downdip (southeast) more than 50 miles and to depths exceeding 6,000 feet subsea to allow a more complete stratigraphic analysis. Strike sections extend from the Mexico to Louisiana borders. Two sections roughly parallel the outcrop and, depending on their location, show either mostly the Jackson interval or mostly the Yegua interval. A third

strike section was created from selected wells such that coverage of both intervals was optimized.

- Four major chronostratigraphic units (third-order genetic units) were defined for the Yegua-Jackson Aquifer. These include, from the bottom upward, the Lower Yegua, Upper Yegua, Lower Jackson, and Upper Jackson Units, which each span one to two million years of deposition (third-order genetic units) and are of appropriate scale for regional groundwater availability modeling (generally 400 to 800 feet thick, thickening in the downdip direction).
- Each of the four major chronostratigraphic units is bounded above and below by time-synchronous maximum flooding surfaces dominated in the sedimentary record by fine-grained (clay-rich) deposition. Such surfaces and associated fine-grained sediments impede vertical fluid flow, forming low-flow units within the aquifer. Maximum flooding surfaces also bound laterally contiguous sand-rich sediments, which form high-flow units within the aquifer.
- These four aquifer chronostratigraphic units are comprised of 15 or more finer units which are of fourth-order scale, each spanning a period of 100,000 to 400,000 years. These minor sequence stratigraphic units represent finer-scale (fourth-order) genetic units that are also bounded by finer-scale maximum flooding surfaces.
- The four chronostratigraphic units were used as the basis for defining four operational aquifer layers within the Yegua-Jackson Aquifer; the Lower Yegua Layer, the Upper Yegua Layer, the Lower Jackson Layer and the Upper Jackson Layer. Of these four aquifer layers, only the Lower Yegua Layer differs from it’s chronostratigraphic unit equivalent. This is because the chronostratigraphic Base Yegua Unit occurs at or below the lithostratigraphic Base Yegua-Jackson Aquifer, and thus commonly outcrops farther inland (north and west) of the base of the Yegua Formation as mapped in outcrop. The chronostratigraphic surface represents a maximum flooding surface between the Sparta and Yegua depositional cycles and commonly occurs within the shale of the Cook Mountain Formation. To address this issue, the base of the Lower Yegua Aquifer Layer, which comprises the base of the Yegua-Jackson Aquifer, was defined to occur at the first significant freshwater sand and was tied to the base Yegua outcrop boundary.

- Five types of maps were developed for the four aquifer layers. These are a structure map, an isopach map, a sand thickness map, a sand percent map, and a depositional facies map. These maps provide the necessary framework for future groundwater availability model development.
- The results of this research provide direct support for the future development of the Yegua-Jackson Aquifer Groundwater Availability Model and the advancement of the understanding of the hydrogeology, and controls on availability and sustainability, of the aquifer. Through the integration of the data presented, future modelers can impose conceptual constraints on regional model parameterization and will have the depositional framework necessary to evaluate characterization data and to apply interpolation techniques during calibration.
- The following bullets will summarize recommendations from this study.
- In South Texas the interval between the chronostratigraphic Base Yegua Unit and the Base Yegua-Jackson Aquifer contains significant sands that are potentially water-bearing. These sands were excluded from this study and thus lie between the Sparta and Yegua-Jackson Aquifers. Future reconsideration of existing formal aquifer boundaries might place these sands in the Yegua-Jackson Aquifer because they are probably most closely linked, hydrologically, with this aquifer.
- This study provides significant evidence that the Vicksburg Formation was mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) as part of the Jackson Group from approximately the Brazos River eastward and mapped as part of the Catahoula Formation and lateral equivalents from the Brazos River southward. This conclusion is substantiated by this work and the work of others. This conflict between interpretations from this study and those of Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) are important, unexpected, and not resolvable within the scope of this study. Before this structural framework of the Yegua-Jackson aquifer is incorporated into a numerical model, it is suggested that sufficient investigation resolves stratigraphic inconsistencies and logically places the ‘region in conflict’ within either the Yegua-Jackson Aquifer or the overlying Gulf Coast Aquifer.

- As water resources in the state become more valuable and subject to greater use, it is expected that groundwater availability models will have to increase their accuracy, which implies an increase in understanding of the aquifer flow controls and dynamics. There are many valuable stratigraphic studies within the Texas Tertiary aquifers. However, many times these studies are at a sub-regional scale and differences in nomenclature between studies make integration of these studies into a coherent whole difficult. It is recommended that similar studies be funded for aquifers where detailed structure, lithology, and depositional facies are not defined at the relevant aquifer scale. The resulting uniformity will prove critical to future groundwater resource management.

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7. Acknowledgements

The well logs critical to this investigation could not have been gathered without open access to resources at the Bureau of Economic Geology, the Texas Water Development Board, and the Texas Commission on Environmental Quality Surface Casing Division. Friendly and helpful guidance in these respective facilities was provided by Daniel Ortuno, Deborah Schultz, and Julia Harvey. We would like to acknowledge Scott Hamlin, the TWDB Project manager for his support and guidance through this structure development project. The skills and patience of Sarah Pierson, and Michelle Tiemeier at INTERA, Incorporated, and Alex Sanders at Baer Engineering and Environmental Services, Incorporated, have transformed thoughts and ideas into geographic information system-based maps. Computer aided design-based cross section drawing was accomplished by Jorge Garza of INTERA, Incorporated and we appreciate his patience. Funding for this study was provided by TWDB under contract 0604830617.

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Plates

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Appendix A

Study Wells, Locations, Cross Section Occurrence, and Key Log Parameters

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Appendix A Study Wells, Locations, Cross Section Occurrence, and Key Log Parameters

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	KB[2]	Base of Log	Top of Log
5944109	420515544109	-96.58722	30.37278	BURLESON	9	A	N	338[3]	329	
6617614		-96.91500	29.68583	FAYETTE	12	B	N	362[3]	1090	26
AHERNHUBBARD205		-99.45234	27.61498	WEBB			N	637	2602	136
AQ-39	420050019500	-94.40840	31.24045	ANGELINA	2	A	Y	238	5054	144
AQ-52		-94.52108	31.17882	ANGELINA			N	237[3]	5466	323
AQ-78	420050022400	-94.81377	31.38711	ANGELINA	3		Y	350	8165	90
ARCOSAENZ299	424270445100	-98.98486	26.45269	STARR	29	A,C	Y	322[3]	7503	1631
ARCOTEMPLE948	422410026900	-94.06502	31.02761	JASPER		B,C	Y	214	10814	100
ATQ-228	420130082300	-98.33219	28.84983	ATASCOSA		A	Y	272	2573	100
BENTSENVIDAURRI235	425050187700	-99.37886	27.24390	ZAPATA	25		Y	389	5510	135
BLANCOJENNINGS247	425050179400	-99.14327	27.08941	ZAPATA	26	A	Y	421	11667	142
CLARKSALINAS279	424270185900	-98.89712	26.70530	STARR	28	B,C	Y	376	3914	141
CONSOLIDATEDVELA215	424793128000	-99.48432	27.43511	WEBB	24		Y	418	7660	468
CQ-343		-96.74585	29.55443	COLORADO		C	N	234	9214	2067
DP10-10N		-96.42370	29.38855	COLORADO	11		N	163	11047	
DP10-11		-96.30903	29.38330	WHARTON	10		N	143	14950	430
DP10-3R	421490006300	-97.05167	29.89721	FAYETTE	11		Y	419	6340	175
DP10-4R	421490004000	-96.92181	29.88502	FAYETTE	11	A	Y	304[3]	7037	811
DP10-5R	421490002700	-96.77888	29.99284	FAYETTE	10	B	N	479[3]	7497	787
DP10-6	421493269900	-96.76743	29.82856	FAYETTE	11	B	Y	246	13700	2054
DP10-7	420890087500	-96.63988	29.70296	COLORADO	11	C	Y	338	12733	2241
DP10-8		-96.58532	29.60938	COLORADO	11		N	307	11150	50
DP10-9		-96.43502	29.51067	COLORADO	10		N	200	11948	
DP11-10		-96.68132	29.32400	LAVACA	12		N	176	11722	2984
DP11-11		-96.70356	29.28299	LAVACA	12		N	165	10156	1242
DP11-7R	422853015200	-96.82290	29.48497	LAVACA	12	C	Y	320	10002	1802
DP11-8	422850032600	-96.68429	29.37153	LAVACA	12		Y	220	16720	188
DP12-6A	421230000300	-97.26828	29.31944	DEWITT		B	Y	345	8017	741
DP12-7	422850035800	-97.07708	29.28255	LAVACA	13	C	Y	266	10251	100
DP12-8		-96.82653	29.18642	LAVACA	13		N	164	16015	63
DP13-3		-97.61983	29.37674	GONZALES	14		N	317	7099	169
DP13-4R	421770028700	-97.46088	29.31554	GONZALES	14	A	Y	273[3]	6740	734

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	KB[2]	Base of Log	Top of Log
DP13-5	421770042400	-97.45603	29.23655	GONZALES	14	B	Y	241	13356	100
DP13-6	421230087000	-97.40049	29.09896	DEWITT	14	C	Y	238	14191	57
DP13-7		-97.24656	29.05147	DEWITT	14		N	210	14472	1717
DP13-8		-97.19685	29.04774	DEWITT	14		N	162	13000	1515
DP13-9	421233162200	-97.09277	29.06901	DEWITT	14		Y	225	15500	100
DP1-4	424050002800	-94.12601	31.25995	SAN AUGUSTINE	1	A	Y	184	10029	297
DP14-4R	421230033700	-97.69045	29.01454	DEWITT	15	B	Y	494	9012	1018
DP14-5R		-97.64167	28.90614	DEWITT			N	369	14848	1286
DP14-6	421233000500	-97.49090	28.89030	DEWITT	15	C	Y	344	12496	2066
DP14-7		-97.47293	28.86545	GOLIAD	15		N	283	14320	1799
DP14-8	421753010500	-97.34597	28.76476	GOLIAD	15		Y	240	24755	97
DP14-9		-97.33563	28.69792	GOLIAD	15		N	178	16000	100
DP1-4A		-94.28219	31.18229	ANGELINA	2		N	178[3]	1816	201
DP1-5	422410000200	-94.36998	31.03559	JASPER	2		Y	117	10108	206
DP15-10		-97.71260	28.75000	KARNES	16		N	305	11424	173
DP15-11R	421750192800	-97.70030	28.62804	GOLIAD	16		Y	365	9303	100
DP15-13		-97.48775	28.38284	BEE	17		N	121	16335	824
DP15-5	424930153600	-98.02026	29.02221	WILSON	16	A	Y	390	8168	492
DP15-6R	422550068900	-97.92059	28.97352	KARNES	16		Y	360	11367	667
DP15-7	422550063400	-97.89902	28.90755	KARNES	16	B	Y	344	8346	90
DP15-8		-97.86759	28.83833	KARNES	16		N	336	8799	1648
DP15-9	422553022800	-97.76062	28.83507	KARNES	16	C	Y	277	14070	56
DP1-6	424570005400	-94.31878	30.95545	TYLER	2	B,C	Y	364	12019	70
DP16-3	424930174700	-98.21063	28.91319	WILSON	17	A	Y	319	6214	398
DP16-5A	422970001100	-98.04020	28.71429	LIVE OAK	17	B	Y	396	7699	807
DP16-5R	422550084200	-97.98382	28.80270	KARNES	17		Y	472[3]	7998	38
DP16-6	420250047400	-98.00049	28.60813	BEE	17	C	Y	363	16988	52
DP16-8		-97.80807	28.51742	BEE	17		N	344	12850	2016
DP1-7	424570025700	-94.12650	30.69987	TYLER	2		Y	75	7512	970
DP17-10	422973000200	-98.00635	28.39298	LIVE OAK	18		Y	232	14051	100
DP17-11		-98.00464	28.32379	LIVE OAK	18		N	177	10905	1523
DP17-13		-97.98677	28.12696	LIVE OAK	19		N	194	6707	899

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	KB[2]	Base of Log	Top of Log
DP17-3R		-98.60384	28.86719	ATASCOSA	18		N	464[3]	7378	40
DP17-4	420130288700	-98.50541	28.72439	ATASCOSA	18	A	Y	336	5598	100
DP17-5	423110016700	-98.49363	28.60330	MCMULLEN			Y	295	10517	100
DP17-6		-98.45833	28.53993	MCMULLEN			N	306	12126	40
DP17-7R		-98.29380	28.49783	LIVE OAK			N	190	13794	81
DP17-8	422970082400	-98.18284	28.49566	LIVE OAK	18	B,C	Y	174	8018	85
DP17-9		-98.16226	28.39670	LIVE OAK	18		N	234	9204	1527
DP18-10	423110092700	-98.35938	28.32348	MCMULLEN	19	B,C	Y	256	15018	75
DP18-11	422973033000	-98.27295	28.17335	LIVE OAK	19		Y	428	14838	58
DP18-13		-98.20147	28.18162	LIVE OAK	19		N	412	14857	78
DP18-14		-98.16926	27.91899	JIM WELLS	20		N	305	6820	777
DP18-5	421630158200	-98.80294	28.67014	FRIO	19		Y	510	6449	200
DP18-6	422830005100	-98.80315	28.52300	LA SALLE	19		Y	366	5492	315
DP18-7R	423110123700	-98.66814	28.45819	MCMULLEN	19	A	Y	297[3]	11407	90
DP18-8		-98.56226	28.42465	MCMULLEN	19		N	313	11574	100
DP18-9	423113010800	-98.51373	28.39286	MCMULLEN	19		Y	297	12036	60
DP19-10R	422830011500	-98.82549	28.32310	LA SALLE	20		Y	413	5992	147
DP19-11	423110153200	-98.74805	28.19630	MCMULLEN	20		Y	284	24213	487
DP19-12		-98.58971	28.22565	MCMULLEN			N	296	7594	228
DP19-13	423110158000	-98.52696	28.18649	MCMULLEN		B,C	Y	351	8505	200
DP19-14	421313044500	-98.45898	28.05619	DUVAL	20	C	Y	605[3]	11023	2007
DP19-15	421310107500	-98.25392	27.94207	DUVAL	20		Y	472	5885	430
DP19-6	422830003300	-99.03809	28.52127	LA SALLE	20		Y	420	6709	239
DP19-7	422830006000	-98.97108	28.49171	LA SALLE	20		N	362	5100	160
DP19-8R	422830020400	-98.96569	28.33737	LA SALLE	20		Y	474	21992	100
DP19-9	422830012400	-98.89020	28.31834	LA SALLE	20	A	Y	408	11994	100
DP20-10	422830072500	-99.11965	28.18031	LA SALLE	21		Y	395	5753	250
DP20-11		-99.06615	28.12284	LA SALLE	21		N	313	6348	348
DP20-12	422830064600	-98.97010	28.07465	LA SALLE	21	A	Y	309	6455	100
DP20-13	424790018600	-98.84706	28.00087	WEBB	21		Y	327	7704	142
DP20-14	421310545000	-98.71045	27.89063	DUVAL	21	C	Y	543	9502	108
DP20-15R	421311060000	-98.70058	27.89749	DUVAL	21	B	Y	547	7682	100

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	KB[2]	Base of Log	Top of Log
DP20-16		-98.56152	27.82840	DUVAL	21		N	632	15439	
DP20-17	421311115900	-98.53272	27.82753	DUVAL	21		Y	601	16015	1527
DP20-18	421310188100	-98.34217	27.76519	DUVAL	21		Y	428	5999	600
DP20-19		-98.38086	27.68533	DUVAL			N	476	7011	789
DP20-8		-99.29688	28.33116	LA SALLE	21		N	557	4502	103
DP20-9	422830030900	-99.12696	28.28950	LA SALLE	21		Y	348	5337	107
DP2-10		-94.59337	30.81576	TYLER	3		N	368	10261	929
DP2-11	424570047700	-94.56500	30.70052	TYLER	3		Y	291	16005	80
DP21-10	424790062800	-99.04834	27.77170	WEBB	22	A	Y	516	20571	100
DP21-11R		-98.89453	27.76481	WEBB	22		N	509	7904	815
DP21-12	424790108500	-98.83512	27.63780	WEBB	22	C	Y	811	10506	100
DP21-13	424790141800	-98.81663	27.54443	WEBB	22	B	Y	792	12505	900
DP21-14	422470014000	-98.79554	27.30295	JIM HOGG	24		Y	748	7101	272
DP21-15	422470033000	-98.61100	27.16710	JIM HOGG	25		N	480	6085	1710
DP21-16		-98.41795	27.09679	BROOKS	25		N	338	8240	1049
DP2-12		-94.50100	30.54427	TYLER	3		N	156	12804	90
DP2-13	421993002100	-94.56125	30.43380	HARDIN	3		Y	136	10955	2006
DP21-6R	424790002000	-99.49660	28.02483	WEBB	22		Y	729	5484	100
DP21-7	424793018000	-99.29981	28.01492	WEBB	22		Y	489	6803	367
DP21-8R	424793121400	-99.20898	27.89583	WEBB	22		Y	486[3]	10401	39
DP21-9R	424790064600	-99.20671	27.81380	WEBB	22		Y	526[3]		
DP22-10R	424793084800	-99.18931	27.41102	WEBB	24	A	Y	477	10515	722
DP22-11	424793036800	-99.08253	27.40278	WEBB	24		Y	612	9510	1549
DP22-12	424790285100	-99.00048	27.40375	WEBB	24		Y	790	10019	1074
DP22-13	424790305100	-98.98547	27.33030	WEBB	24	B,C	Y	903	11510	1023
DP22-14	422470277000	-98.88081	27.25260	JIM HOGG	25	B,C	Y	840	15615	100
DP22-15	422470152900	-98.83091	27.05556	JIM HOGG	26	B,C	Y	722	3851	100
DP22-16		-98.67326	26.98270	JIM HOGG	26	C	N	513	6300	212
DP22-17	422470237200	-98.61945	26.90182	JIM HOGG			Y	465	6506	340
DP22-18		-98.43774	26.81727	JIM HOGG			N	270	8501	2042
DP22-6	424793000100	-99.45020	27.77691	WEBB	23		Y	732	15010	180
DP22-7R	424790071300	-99.31031	27.71311	WEBB	23		Y	574	7000	348

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	Kelly Bushing[2]	Base of Log	Top of Log
DP22-8	424790071601	-99.29864	27.59635	WEBB	23		Y	709	13849	327
DP22-9R	424790077300	-99.12839	27.51655	WEBB	23	A	Y	604[3]	5241	110
DP23-6	424273084000	-98.77260	26.62240	STARR	28		Y	446	9902	580
DP23-7	424270339600	-98.64231	26.47362	STARR	29	C	Y	354	8599	2046
DP23-8	422150187900	-98.35123	26.37370	HIDALGO	29		N	201		
DP24-1	424273124000	-98.56940	26.30366	STARR	30	B,C	Y	250	6493	1532
DP24-2		-98.53649	26.27119	HIDALGO	30		N	217	9030	5845
DP2-5	420050006000	-94.65510	31.30208	ANGELINA	3		Y	298	4824	185
DP2-6		-94.68980	31.27865	ANGELINA	3		N	260	5000	319
DP2-7R	420050011800	-94.78974	31.19227	ANGELINA	3	A	Y	224	2682	1277
DP2-8R		-94.70783	31.11237	ANGELINA	3		N	141	4011	123
DP2-9	424570005900	-94.56650	30.90972	TYLER	3	B,C	Y	316	9309	935
DP3-10	423730035900	-94.83250	30.57769	POLK	4		Y	223	12031	117
DP3-6A	424550003200	-95.06426	31.06521	TRINITY	4	A	Y	251[3]	3569	228
DP3-6R	424550002200	-95.06044	31.19060	TRINITY	4		Y	361	13005	100
DP3-7R	423730003000	-95.01857	30.96385	POLK	4		Y	275[3]	3908	330
DP3-8	423730002500	-94.91600	30.82266	POLK	4	B,C	Y	269	15196	76
DP3-9R		-94.95536	30.65398	POLK	4		N	149	6623	361
DP4-11		-95.18552	30.39706	SAN JACINTO	5		N	179	14006	2996
DP4-12	422910485100	-95.12251	30.36462	LIBERTY	5		Y	153	14109	3048
DP4-13		-95.09014	30.26730	LIBERTY	5		N	120	15687	1848
DP4-3	422250040000	-95.56082	31.14742	HOUSTON	5		Y	322	9518	100
DP4-4	424710020300	-95.47757	31.01410	WALKER	5	A	Y	281	9978	220
DP4-5		-95.43850	30.92474	WALKER	5		N	135	13501	136
DP4-6	424710018100	-95.34689	30.86762	WALKER	5		Y	167[3]	13820	121
DP4-7	424710018300	-95.45950	30.67405	WALKER	5	B,C	Y	385	15400	161
DP4-8		-95.37450	30.66102	WALKER	5		N	389	18158	185
DP4-9	424070013300	-95.32250	30.52700	SAN JACINTO	5		Y	400	12015	1251
DP5-10R	423390111100	-95.53685	30.22656	MONTGOMERY	6		Y	200	12347	1453
DP5-11R		-95.53885	30.12109	HARRIS			N	169	14044	3101
DP5-12		-95.43775	30.01302	HARRIS	6		N	130[3]	14011	2574
DP5-5R	423130010700	-95.93750	30.97917	MADISON	6		Y	300[3]	10276	90

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	Kelly Bushing[2]	Base of Log	Top of Log
DP5-6		-95.64900	30.87976	WALKER			N	237	14543	93
DP5-7R	421850002400	-95.92779	30.66090	GRIMES			Y	379	4802	85
DP5-8	423390000600	-95.66235	30.51081	MONTGOMERY	6	B,C	Y	249	16764	277
DP5-9		-95.51494	30.44792	MONTGOMERY	6		N	279	13060	90
DP6-10		-95.69494	29.88019	HARRIS	7		N	157	14934	207
DP6-11		-95.56200	29.91220	HARRIS	7		N	136	15508	100
DP6-12		-95.53274	29.85048	HARRIS	7		N	120	17004	80
DP6-3	420410001200	-96.19500	30.61068	BRAZOS	7	A	Y	201	6902	90
DP6-4	420410006300	-96.14550	30.48394	BRAZOS	7		Y	190	8215	150
DP6-5R	421850008300	-96.01345	30.33045	GRIMES	7	B	Y	333	6980	739
DP6-6		-95.94000	30.27768	GRIMES	7	C	N	340	11616	1723
DP6-7	424730004400	-95.84412	30.19444	WALLER	7		Y	249	12047	2535
DP6-8	422010788900	-95.66883	30.01346	HARRIS	7		Y	184	17470	2590
DP6-9		-95.69544	29.91652	HARRIS	7		N	163	16488	2600
DP7-1R	420410002700	-96.38975	30.56207	BRAZOS			Y	307	4568	330
DP7-2		-96.22450	30.45920	BRAZOS			N	292[3]	7776	30
DP7-3	424770025600	-96.20150	30.35986	WASHINGTON			Y	308	9796	999
DP7-4	424730000500	-96.09163	30.19948	WALLER		B,C	Y	254	20788	68
DP7-5		-96.13050	30.10758	WALLER			N	235	11635	96
DP7-6	424730031800	-95.93155	29.90528	WALLER	8		Y	211	13525	132
DP7-7		-95.88785	29.81272	WALLER	8		N	186	19013	3002
DP7-8		-95.91255	29.77941	WALLER	8		N	181	11344	2538
DP7-9		-95.80926	29.73611	FORT BEND	8		N	147	13521	2776
DP8-2	420510007700	-96.49550	30.42491	BURLESON	8	A	Y	323	6516[4]	
DP8-3R	424770023900	-96.40040	30.25998	WASHINGTON	8		Y	345	9424	90
DP8-4	424770027200	-96.25473	30.18294	WASHINGTON	8	B,C	Y	291	10964	1322
DP8-5	424770029400	-96.25347	30.09722	WASHINGTON	8		Y	285	10501	120
DP8-6		-96.24450	30.00022	AUSTIN	8		N	275	10005	
DP8-7	420150024200	-96.20418	29.97159	AUSTIN	8		Y	192	10513	1397
DP8-8	420150053600	-96.13645	29.79704	AUSTIN	9		Y	190	7570	610
DP8-9		-95.99058	29.74957	WALLER			N	136	13509	111
DP9-10R		-96.44600	29.80793	COLORADO	10	C	N	333	10998	2014

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	Kelly Bushing[2]	Base of Log	Top of Log
DP9-11R	420890017200	-96.38492	29.66050	COLORADO	10		Y	227	9023	1683
DP9-12		-96.21379	29.67422	AUSTIN	9		N	169	11988	115
DP9-13		-96.12599	29.51764	WHARTON	9		N	136	14701	154
DP9-5R	422870008400	-96.80379	30.17231	LEE	10	A	N	447[3]	3052	155
DP9-6	424770036500	-96.65239	30.24110	WASHINGTON	9		Y	340	10235	715
DP9-7	424770036600	-96.58665	30.13281	WASHINGTON	9	B	N	438	4108	
DP9-8R	420150001700	-96.44900	30.00825	AUSTIN	9	C	Y	335	10802	1819
DP9-9	420890001500	-96.51942	29.83247	COLORADO	10		N	320	11424	60
DPA-22	424570005700	-94.35492	30.85273	TYLER	2		Y	300	14510	100
DPB-12	422970153300	-97.91397	28.27517	LIVE OAK	18		Y	222	6310	317
DPB-13R	420250160200	-97.80663	28.49135	BEE	17		Y	326	8725	1520
DPB-15A		-97.51716	28.69141	GOLIAD			N	212	10498	100
DPB-15R		-97.49510	28.70595	GOLIAD			N	297	9726	1746
DPB-17		-97.14032	28.93555	VICTORIA	14		N	145	9226	921
DPB-2	422470225800	-98.84183	26.86635	JIM HOGG	27	B,C	Y	603[3]	5006	90
DPB-20		-96.76722	29.23481	LAVACA			N	156	10006	1026
DPB-5	421310782600	-98.51265	27.57509	DUVAL	22		Y	477	6312	425
DPB-9R	422973030100	-98.08706	28.09528	LIVE OAK	19		Y	281	7005	1635
DPC-2	422150078300	-98.43726	26.28571	HIDALGO	30	C	Y	230	10260	9887
FQ-103	421490013700	-97.19862	29.77778	FAYETTE	12	A	Y	434	5015	265
FRAZIERCOCHRAN719	422550023600	-97.73081	29.16233	KARNES	15	A	Y	333[3]	3050	95
GINTHERKILLAM206		-99.28162	27.58058	WEBB	23		N	685	4509	152
GQ-90	421770006100	-97.22768	29.53082	GONZALES	13	A	Y	409	7503	410
GRQ-29	421850009400	-95.89300	30.47692	GRIMES		B	Y	390		
GULFSNB258	425050228800	-99.03933	26.91754	ZAPATA	27	A	Y	460	11188	80
GULFURIBE246	425053148600	-99.30677	27.08803	ZAPATA	26		Y	431	11516	55
HEWITTMANFORD718		-97.87105	29.16507	WILSON	15		N	420	7023	85
HOWETHRAMIREZ288	424270226000	-99.02740	26.54007	STARR	29	A	Y	367	5206	328
HQ-31		-95.43131	31.13507	HOUSTON			N	294	8237	50
HQ-327		-95.13214	31.31909	HOUSTON	4		N	294	1892	50
HUMBLEGARCIA269	425050274200	-98.96635	26.85504	ZAPATA		A	Y	486	6502	100
JONNELLLOPEZ278	425050297300	-99.09460	26.72474	ZAPATA	28	A	Y	382	10215	117

Appendix A, continued

Unique Well Identifier	API Well Number[1]	Longitude	Latitude	County	Dip	Strike	Digitized	Kelly Bushing[2]	Base of Log	Top of Log
JQ-168	422413029300	-94.02450	30.84559	JASPER			N	178	15382	192
JQ-192		-94.14550	30.99653	JASPER		B,C	Y	145	11222	100
LOQ-1167	422970004300	-98.18356	28.63412	LIVE OAK	18		Y	267	8028	518
MAGNOLIASPAWN420	421770016300	-97.49950	29.56033	GONZALES	13		Y	369	9002	200
MAQ-9	423130006700	-95.69006	31.05083	MADISON			N	181	2102	100
MAQUIRESALINAS257	425050305400	-99.20144	26.86155	ZAPATA	27		Y	338	5422	564
MCABEGARCIA256	425050190800	-99.30959	26.99154	ZAPATA	27		Y	468	5155	116
MCQ-107	423110183400	-98.64804	28.06510	MCMULLEN	20	B	Y	371	2224	100
MERRENSB1051	424030006800	-93.62023	31.19879	SABINE		C	Y	190	4538	189
MITCHELLMANNING2910	424270287700	-98.77170	26.45112	STARR	29	B	Y	347	7014	623
MOQ-285	423390097700	-95.73606	30.37717	MONTGOMERY		C	Y	315[3]	9216	1506
PANAMBROWN850	423510004800	-93.85446	30.95964	NEWTON	1	B,C	Y	297	14111	83
PANEASTERNMALATEK521	421773013800	-97.44516	29.39286	GONZALES		A	Y	371	15499	100
PENINSULAASHWORTH420		-97.43312	29.53476		13		N	313[3]		
PONTIACSLATOR227	425050001000	-99.18846	27.26085	ZAPATA	25	A	Y	484	7805	110
PQ-157		-95.07229	30.76990	POLK		B,C	N	145[3]	5495[4]	
RICHARDSONMCKENDRICK216	424790459000	-99.26017	27.37936	WEBB	24		Y	513[3]	7016	318
ROWEBUNTING423	421770062100	-97.22768	29.57422		13	B	Y	367[4]		
SENECATATOM1149	424030004800	-93.93649	31.33594	SABINE		A	Y	266	7500	775
SMITHISBELL732	421850000900	-96.06525	30.75781	GRIMES		A	Y	320	3916	100
SQ-41	424030001700	-93.70105	31.31337	SABINE		A,C	Y	223	4401	110
SQ-96A	424033041100	-94.02697	31.15911	SABINE	1		Y	193	2627	210
TQ-15		-95.24500	30.98134	TRINITY			N	280	11908	100
TQ-21		-95.09605	31.06884			A	N	298[3]		
TURNERBOULDIN619		-97.67003	29.35938	GONZALES			N	380	6714	277
WOODRUFFHEMPHILL1150		-93.70128	31.30877	SABINE		A	N	483[3]	964	60
WQ-14	424710014800	-95.70050	30.70052	WALKER	6		Y	208		
WQ-16	424710010200	-95.75149	30.80926	WALKER	6	A	Y	272	4049	250

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[1] Unique well number as supplied from American Petroleum Institute or Reservoir Vizualization Incorporated.

[2] Datums taken from log headers, Dodge and Posey (1981) sections, and scout cards.

[3] Elevation taken from the United States Geological Survey seamless digital elevation model data set plus 14feet (average estimated height of Kelly Bushing above ground level.

[4] Driller total depth.

Appendix B

Operator, Well Name and Number, and Tobin Grid Location for Study Wells

Appendix B Operator, Well Name and Number, and Tobin Grid Location for Study Wells

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
5944109	LASALLE ENERGY		
6617614	LAYNE TEXAS COMPANY	CITY OF SCHULENBURG TEST HOLE #1-80	
AHERNHUBBARD205	T.J. AHERN	HUBBARD A-1	
AQ-39	K.L. MC HENRY	LONG BELL #1	
AQ-52	C. ANDRADE III	OTIS NERRIN #1	
AQ-78	PLACID OIL COMPANY	FAIRCHILD #1	
ARCOSAENZ299	THE ATLANTIC REFINING COMPANY	TOMAS SAENZ NO. 1	29S-9E-4
ARCOTEMPLE948	ATLANTIC-RICHFIELD COMPANY	TEMPLE INDUSTRIES 1	9N-48E-8
ATQ-228	TRI-MARK & TEXITA OIL COMPANY	JOE WILLIAMS #1	
BENTSENVIDAURRI235	BENTSEN & WHITTINGTON	JUAN VIDAURRI #1	
BLANCOJENNINGS247	BLANCO OIL CO.	JENNINGS #1	
CLARKSALINAS279	CLARK FUEL PRODUCING COMPANY	JOSE R. SALINAS #6	
CONSOLIDATEDVELA215	CONSOLIDATED OIL & GAS, INC.	VELA #1	
CQ-343	CITIES SERVICE OIL COMPANY	GOECKLER UNIT #1	
DP10-10N	STANDARD OIL COMPANY OF TEXAS	GUY F. STOVALL #4, WELL NO. 1	5S-29E-8
DP10-11	MAGNOLIA PETROLEUM COMPANY	C.R. REYNOLDS #1	5S-30E-8
DP10-3R	TRADERS OIL CO.	FLECK #1	1S-24E-7
DP10-4R	KENNECOTT COPPER CORP.	SCHWARTZ #1	1S-25E-8
DP10-5R	AMERICAN LIBERTY OIL COMPANY	BOHLOTTMAN #1	1S-26E-1
DP10-6	AMOCO	WEGENHOFT #1	2S-26E-6
DP10-7	CARTHAY LAND COMPANY	LEROY STEIN #1	3S-27E-6
DP10-8	NATIONAL EXPLORATION COMPANY	C.G. GLASSCOCK # 1	4S-28E-3
DP10-9	SHELL	KYLE EST. #1	4S-29E-8
DP11-10	SHELL	TAYLOR NO. 1	6S-27E-5
DP11-11	H.L. HAWKINS & H.L. HAWKINS JR. NORTH CENTRAL OIL	MRS. SADA BARNES #1	6S-27E-8
DP11-7R	THE SUPERIOR OIL COMPANY	L.M. KLEKAR #1	5S-25E-4
DP11-8	THE PURE OIL COMPANY	E.E. KOLAR #1	6S-27E-2
DP12-6A	O.W. KILLAM	E.F. HOCH #1	6S-22E-1
DP12-7	H.J. CHAVANNE, TRUSTEE	CARTER #1	6S-24E-8
DP12-8	SHELL OIL COMPANY	WILLIAM BORCHERS #3	7S-26E-5
DP13-3	KIRKWOOD & MORGAN	J.R. TINSLEY #1	5S-20E-9
DP13-4R	AMERADA PETR. CORP.	MORGAN-KUMETKA #2	6S-21E-4/5
DP13-5	H.L. HUNT	W.R. MILLER	7S-21E-2/3

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
DP13-6	GULF OIL CORPORATION	MUELLER #1	8S-21E-1
DP13-7	LONE STAR PRODUCING COMPANY	FELIX HILLER #1	8S-22E-6
DP13-8	TEXACO, INCORPORATED	O.G. PROBST #1	8S-23E-5
DP13-9	HUMBLE OIL & REFINING COMPANY	ADA B. PRIDGEN #1	8S-23E-4
DP1-4	LESTER & CULBERTSON	CHILDERS 1	11N-47E-7
DP14-4R	GEOCHEMICAL SURVEYS	ANTON F. TAM JR. #1	8S-19-8
DP14-5R	TEXAS EASTERN TRANSMISSION CORP.	HERMAN A. GARBE #1	9S-19E-7
DP14-6	MONSANTO COMPANY & PENNZOIL UNITED INC.	DENTLER #1	9S-21-9
DP14-7	LONE STAR PRODUCING COMPANY	EMMA HAYNES ESTATE #1	10S-21E-3
DP14-8	CHEVRON OIL COMPANY	R.G. JACOBS #1	10S-22E-9
DP14-9	SHELL OIL COMPANY	O.J. FRIEDRICHES #1	11S-22E-4
DP1-4A	TALMADGE COMBS	W.B. THORNTON EST 1	10N-46E-6
DP1-5	HUMBLE OIL & REFINING COMPANY	NONA MILLS ET AL 1	9N-46E-9
DP15-10	SHELL OIL COMPANY	C.A. ATKINSON #1	10S-19E-9
DP15-11R	VIKING DRILLING COMPANY ET AL	J.W. RAY ESTATE #1	11S-19E-8
DP15-13	PURE OIL COMPANY	O'BRIEN-HARKINS "B" #1	13S-21E-9
DP15-5	TEXON ROYALTY CO.	MOCZYGEMBA #1	8S-16E-7
DP15-6R	COASTAL STATES GAS PRODUCING COMPANY	J. KOWALIK #1	9S-17E-2
DP15-7	TEXAS EASTERN PRODUCTION CORPORATION	OTIS S. WUEST A#1	9S-17E-7
DP15-8	HARRISON	HYSAW #1	10S-18E-3
DP15-9	GENERAL CRUDE OIL COMPANY	TIPPS #1	10S-18E-1/6
DP1-6	DAVIDSON ET-AL	HERBERT NEYLAND ET-AL 1	8N-46E-1-2
DP16-3	O.G. MCCLAIN	S.V. HOUSTON #1	9S-15E-9
DP16-5A	HAMMAN OIL & REFINING COMPANY & STATE	WALTER A. GOETZE #1	11S-16E-1
DP16-5R	SEABOARD OIL COMPANY	SALLYE TREADWELL #1	10S-16E-4
DP16-6	SHELL OIL COMPANY	ALVIN L. O'NEAL #1	12S-17E-3
DP16-8	ATLANTIC-RICHFIELD COMPANY	J.R. DOUGHERTY ESTATE #2	12S-18E-8
DP1-7	GRUBB & HAWKINS	KIRBY LUMBER CO. 1	6N-47-6
DP17-10	CONTINENTAL OIL COMPANY	ALVINA MCKINNEY #1	13S-16E-7
DP17-11	H.L. BROWN JR.	G.L. HAYES #1	14S-16E-6
DP17-13	SKINNER CORP.	HOLMAN CARTWRIGHT	15S-17E-9
DP17-3R	MAGNOLIA PETROLEUM COMPANY	STEINLE #1	10S-12E-2/3
DP17-4	THOMAS DRILLING CORP.	PEELER-SHAW	11S-12E-1

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
DP17-5	HUMBLE OIL & REFINING COMPANY	GUBBELS #14	12S013E-3
DP17-6	CONTINENTAL OIL COMPANY	RICHARD HORTON #1	12S-13E-8/9
DP17-7R	STANDARD OIL COMPANY OF TEXAS	J.V. ISAACKS #1	13S-14E-1/2
DP17-8	SEABOARD OIL COMPANY	GIBBENS #1	13S-15E-2
DP17-9	HUMBLE OIL & REFINING COMPANY	A.W. WEST, ET.AL. #1	13S-15E-7
DP18-10	TEXAM OIL CORP.	HAYS-EZZELL #1	14S-14E-4
DP18-11	ATLANTIC-RICHFIELD COMPANY	EL PASO NAT'L GAS 300 #1	15S-14E-6
DP18-13	STANDARD OIL COMPANY OF TEXAS	MRS. CLAY WEST BURNS #1	15S-15E-5
DP18-14	HAAS OIL COMPANY & MELBA PRODUCTION COMPANY	B.W. COX #1	17S-15E-5
DP18-5	MILAM DRILLING COMPANY	W.R. HINDES EST. #1	11S-10E-5
DP18-6	WINDSOR OIL COMPANY	JESSE MCNEEL #1	12S-10E-8
DP18-7R	H.R. SMITH & GULF OIL CORP.	GEO. SEALY EST #1	13S-11E-5
DP18-8	STANDARD OIL COMPANY OF TEXAS	J.F. HENRY #1	13S-12E-1
DP18-9	PAN AMERICAN PETROLEUM CORP.	L.S. MCCLAUGHERTY NO. 1	13S-12E-7
DP19-10R	JACK FROST	SOUTH TEXAS SYNDICATE #4	14S-10E-5
DP19-11	PHILLIPS PETROLEUM COMPANY	NUECES "A" LEASE WELL #1	15S-11E-4
DP19-12	RUSSELL MAGUIRE	HOLLAND RANCH #1	15S-12E-3
DP19-13	W. RIDLEY WHEELER ESTATE	RIVES WELL #1	15S-12E-6
DP19-14	COASTAL STATES GAS PRODUCING COMPANY	RAGSDALE #1	16S-13E-4
DP19-15	ARGO OIL CORPORATION	JUAN R. LOPEZ #1	17S-14E-6
DP19-6	LANN AND MCCLANNAHAM	STOREY & REED #1	12S-8E-7
DP19-7	ENGEO OIL & GAS CO. & SAM LARUE ET. AL.	MARGARET ANN KIMBALL #1	13S-9E-3
DP19-8R	PAN AMERICAN PETROLEUM CORP.	A.M. FOERSTER #1	14S-9E-3
DP19-9	PHILLIPS PETROLEUM COMPANY	LA SALLE #1	14S-9E-6
DP20-10	HUGHES & HUGHES	LOUIS C. KOEHNE #1	15S-8E-4
DP20-11	ROYAL OIL & GAS CORPORATION	ROBERT COQUAT #B-1	16S-8E-2
DP20-12	COASTAL STATES GAS PRODUCING COMPANY	ST. LOUIS UNION TRUST CO. NO. 1	16S-9E-4
DP20-13	GENERAL CRUDE OIL COMPANY	ADAMI "A" WELL #2	16S-10E-9
DP20-14	MAGNOLIA PETROLEUM COMPANY	D.C.R.C. SEC. #79	17S-11E-9
DP20-15R	MOBIL OIL COMPANY	DUVAL COUNTY RANCH COMPANY, SECTION 80, WELL # 8	18S-11E
DP20-16	SHELL OIL COMPANY	L.H. PENWELL #1	18S-12E-5
DP20-17	SHELL OIL COMPANY	L.C. WEATHERBY "A" #1	18S-12E-6

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
DP20-18	TAYLOR REFINING COMPANY	PARR NO. T-2	18S-14E-9
DP20-19	THE TEXAS COMPANY	H.M. GRAVIS #1-A	19S-13E-6
DP20-8	LIGHTNING OIL COMPANY	LLOYD HURT #1-68	14S-6E-5
DP20-9	SUTTON PROD. CO.	C.N. COOKE #2A	14S-7E-7
DP2-10	JUSTISS-MEARS OIL COMPANY	W.T. CARTER & BROTHER B-1	7N-44E-4
DP2-11	GULF OIL CORPORATION	CARTER-CAMDEN 1	6N-44E-4-5
DP21-10	HUNT OIL CO.	L.O. WALKER #1	18S-8E-8
DP21-11R	THE TEXAS COMPANY	A. MOSS # B-1	18S-9E-7
DP21-12	THE ATLANTIC REFINING COMPANY	BILLINGS #1-A	19S-10E-9
DP21-13	JAKE L. HAMON, ET AL	AMADO PEREZ, ET AL #1	20S-10E-5/8
DP21-14	THE BRITISH AMERICAN PROD. CO.	ADAMS #1	22S-10E-5
DP21-15	HUMBLE OIL & REFINING COMPANY	MESTINA NO. 3 S.H.	23S-12E-4/9
DP21-16	RUSSELL MAGUIRE	SAUNDERS #1	24S-13E-2
DP2-12	SHELL OIL COMPANY	KIRBY LUMBER CO. A-352 NO. 1	5N-44E-6
DP2-13	INTERNATIONAL NUCLEAR CORP.	A.R. E 5.	4N-44-5
DP21-6R	UNIVERSAL PETROLEUM CORP.	B.B. DUNBAR NO. 1	16S-5E-9
DP21-7	MAYFAIR MINERALS INC.	R.J. MARTIN #1	16S-6E-8
DP21-8R	MOBIL OIL COMPANY	CALLAGHAN RANCH #36	17S-7E-9
DP21-9R	SUN OIL	HIRSCH #2	18S-7E-5
DP22-10R	NORTHERN NATURAL GAS COMPANY	B.M.T. #1	21S-7E-8
DP22-11	SKELLY OIL COMPANY	J.C. MARTIN #6	21S-8E-8/9
DP22-12	TEXACO, INCORPORATED	O.G. DE DA CAMARA NO. 28	21S-8E-8/9
DP22-13	THE ATLANTIC REFINING COMPANY	PUIG GAS UNIT #1	22S-9E-3
DP22-14	ATLANTIC-RICHFIELD COMPANY	MARRS MCLEAN "C" #3	22S-9E-7
DP22-15	ALLEN & BEMIS	D.O. GALLAGHER NO. 2	24S-10E-5
DP22-16	CORPUS CHRISTI OIL & GAS COMPANY	WEIL BROTHERS #4	25S-11E-2
DP22-17	SUN OIL	A.C. JONES #45	25S-12E-9
DP22-18	HUMBLE OIL & REFINING COMPANY	BASS #30	26S-13E-5
DP22-6	LAMAR HUNT	S. BENAVIDES #1	18S-5E-8
DP22-7R	RODNEY DELANGE AND O. NEATHERY JR.	CALLAGHAN LAND PASTORAL COMPANY #2	19S-6E-2
DP22-8	GINTHER, WARREN & GINTHER, GULF & HALBOUTY	O.W. KILLAM # 1-A	20S-6E-2
DP22-9R	KILLAM	KILLAM #1	20S-7E-7

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
DP23-6	FOREST OIL CORPORATION	COATES RANCH #4	28S-10E-1
DP23-7	CONTINENTAL OIL COMPANY	M.M. GARCIA "D" 25	29S-11E-1
DP23-8			
DP24-1	TEXAS OIL & GAS COMPANY	DIAZ 2	30S-12E-5
DP24-2	PHILLIPS PETROLEUM COMPANY	FLORES #1	30S-12E-8
DP2-5	J.R. MEEKER ET AL	JOHN MASSINGILL 1	11N-43E-6
DP2-6	B.G.BYARS & E.L. KURTH	SOUTHREN PINE LBR. CO. 1	11N-43N-8
DP2-7R	SOUTHERN PINE LUMBER COMPANY	SOUTHREN PINE LBR. CO. 1	10N-42E-6
DP2-8R	ARKANSAS FUEL OIL CO.	THE CARTER CO. 1	9N-43E-3
DP2-9	JUSTISS-MEARS OIL COMPANY	W.T. CARTER & BROTHER D-1	8N-44E-8
DP3-10	CONTINENTAL OIL COMPANY	W.T. CARTER 3. RO. B-1	5N-42E-5
DP3-6A	J.G. ROBERTS	BAIN 1	9N-40E-EG
DP3-6R	SHELL OIL CO.	SOUTHERN PINE LUMBER CO. NO. 1	10N-40E-EG
DP3-7R	J.Z. WERBY	SANER-RAGLEY LBR CO. SCHOOL LAND SURVEY 1	8N-40E-6
DP3-8	SHELL OIL COMPANY	E.E. ALEXANDER1	7N-41E-5-6
DP3-9R	WILLIAM K. DAVIS	DOUGLAS MCCARDELL ET-AL UNIT 1	6N-41-9
DP4-11	SHELL OIL COMPANY	CENTRAL COAL & COKE #11	4N-39E-8
DP4-12	GEORGE MITCHELL AND ASSOCIATES INC.	CHERRY 1	3N-40E-3
DP4-13	THE SUPERIOR OIL COMPANY	T.J. HIGHTOWER #1	3N-40E-9
DP4-3	REYNOLDS MINING CORP.	J.T. KNOX 1	10N-36E-8
DP4-4	MAGNOLIA PETROLEUM COMPANY	THOMPSON LONG LEAF LBR. CO. A-1	9N-37E-9
DP4-5	UNION PRODUCING COMPANY	SMITHER1	8N-37E-5
DP4-6	TIDEWATER OIL COMPANY	A.D. NEWMAN UNIT NO. 1	7N-38E-3
DP4-7	M.H. MARR & MORAN CORPORATION	GIBBS BROTHERS COMPANY #3	6N-37E-5
DP4-8	PLACID OIL COMPANY	GIBBS BROS. #2	6N-38E-9
DP4-9	J.C. BARNES	JOHNSON #1	5N-38E-8
DP5-10R	SUPERIOR OIL COMPANY	MCMAHON #1	2N-36E-1
DP5-11R	ENSERCH EXPLORATION CO.	F.G. BOONE UNIT #1	1N-36E-7
DP5-12	HOUSTON NATURAL GAS PROD. CO.	H.W. TANNEBERGER #1	1N-37E-8
DP5-5R	WOODLEY PET. CO.	FANNIN CANNON UNIT #1	8N-33E-2
DP5-6	HUMBLE OIL & REFINING COMPANY	GIBBS BROTHERS & COMPANY # C-1	8N-35E-7
DP5-7R	WOODLEY PET. CO. & SIGNAL OIL & GAS CO.	MATTIE F. WILSON #1	6N-33E-8

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
DP5-8	PHILLIPS PETROLEUM COMPANY	COKE "A" #1	5N-35E-7
DP5-9	THE SUPERIOR OIL COMPANY & CARLTON D. SPEED JR.	JAMES B. SYKES #1	4N-36E-6
DP6-10	STANDARD OIL COMPANY OF TEXAS	G.J. MELLINGER ET AL 4 #1	1S-35E-8
DP6-11	PAN AMERICAN PETROLEUM CORP.	DOROTHY D. BROWN #1	1S-36E-8
DP6-12	PAN AMERICAN PETROLEUM CORP.	HOUSTON UNIT N-6W-10 #1	2S-36E-1
DP6-3	HUMBLE OIL & REFINING COMPANY	R.P. TRANT #1	5N-31E-2
DP6-4	THE TEXAS COMPANY	ORLANDO #1	4N-31E-1
DP6-5R	LEIGH J. SESSIONS	BARRY #1	3N-32E-6
DP6-6	GULF OIL CORPORATION	WM. GARDNER #2	3N-33E-8
DP6-7	THE TEXAS COMPANY	RICE INSTITUTE #1	2N-34-4
DP6-8	TEXACO, INCORPORATED	M.M. MERGELE #1	
DP6-9	TEXACO, INCORPORATED	J.J. SWEENEY ESTATE #1	1S-35E-5
DP7-1R	VEE TIPT OIL COMPANY	N.A. STEWART NO. 1	5N-29E-6
DP7-2	PHILLIPS PETROLEUM COMPANY	RENCHIE #1	4N-31E-3
DP7-3	GULF COAST LEASEHOLDS, INC.	G.W.TATE ET UX #1	3N-31E-2
DP7-4	SHELL OIL COMPANY	G.A. CHAPMAN #1	2N-32E-4
DP7-5	MIAMI OIL PRODUCERS, INC.	ARCH H. ROWAN #1	1N-31E-1
DP7-6	MICHEL T HALBOUTY	JOHN W. HARRIS ET AL WELL #1	1S-33E-8
DP7-7	HUMBLE OIL & REFINING COMPANY	KATY GAS FIELD UNIT 1-W 3	2S-33E-6
DP7-8	EXXON COMPANY, U.S.A.	A.D. PARKER #1	2S-33E-7
DP7-9	SCURLOCK OIL COMPANY	VIRGINA J. MEEK #1	3S-34E-2
DP8-2	HAVEN OIL CO.	LEWIS EST. NO. 1	4N-29E-4
DP8-3R	TEX HARVEY OIL COMPANY	FRED W. DALLAS #1	3N-29E-7
DP8-4	UNION SULPHER COMPANY	JOE KUBECZA #1	2N-30E-6
DP8-5	MAGNOLIA PETROLEUM COMPANY	GIDDINGS EST. #1	1N-30E-1
DP8-6	SKELLY OIL COMPANY	LANDER #1	1N-31E-9
DP8-7	H.L. HAWKINS	MEWIS #1	1S-31E-2
DP8-8	LUETH & ROBISHAW	O.C. KURTZ #1	2S-31E-6
DP8-9	MOUND COMPANY	JOHN H. ENGLAND ET AL #1	3S-33E-3
DP9-10R	THE PETROLEUM CORPORATION OF DELAWARE	H.A. LEVRIER #1	2S-29E-5
DP9-11R	CITIES SERVICE OIL COMPANY	POOLE #A-2	3S-29E-7

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
DP9-12	HUMBLE OIL & REFINING COMPANY	CHARLES KAECHELE "B" #1	3S-31E-4
DP9-13	GETTY OIL COMPANY	W.C. LEVERAGE #1	4S-31E-7
DP9-5R	M.M. MILLER & SONS	SMITH NO. 1	2N-26E-5
DP9-6	R.J. WMELAN	SOLOMON #1	2N-27E-1
DP9-7	SPEED	MAKOWSKY #1	2N-28E-9
DP9-8R	DAKAMONT EXPLORATION CORP.	WEISE #1	1N-29E-8
DP9-9	SINCLAIR-PRARIE	T. GORDON #1	2S-28E-1
DPA-22	PAN AMERICAN PETROLEUM CORP.	LONG BELL 1	7N-46E-3
DPB-12	HASS BROTHERS	W.H. RANGE 1	14S-17E-7
DPB-13R	MOKEEN OIL COMPANY	AUSTIN E BROWN 1	135-18E-2-6
DPB-15A	HUMBLE OIL & REFINING COMPANY	OTTO A. NEESE #1	11S-20E-6
DPB-15R	VAQUERO PETROLEUM COMPANY	T.A. BUCKERT 1	11S-21E-4
DPB-17	MRS. JAMES R. DOUGHERTY	MURPHY 1	9S-23E-6
DPB-2	HUMBLE OIL & REFINING COMPANY	E.B. ATWOOD # D-3	26S-10E-3
DPB-20	CHRISTIE MITCHELL & MITCHELL	CRANZ 3	7S-26E-1
DPB-5	A.M. & R. CO.	J. OLIVERA #1	20S-12E-6
DPB-9R	HUMBLE OIL & REFINING COMPANY	C.L. MC CASLIN #12	16S-16E-3
DPC-2	COASTAL STATES GAS PRODUCING COMPANY	T.F. MURCHISON #1	30S-13E-8
FQ-103	RODNEY DE LANGE- O' NEATHERY, JR.	E.A. ARNIM #1	
FRAZIERCOCHRAN719	JACK W. FRAZIER	COCHRAN RANCH #1	
GINTHERKILLAM206	GINTHER, WARREN & GINTHER, GULF & HALBOUTY	O.W. KILLAM #2	
GQ-90	TEX-PENN OIL & GAS CORPORATION & SOUTHLAND DRLG. COMPANY	J.T. THOMPSON #1	
GRQ-29		KELLY #1	
GULFSNB258	GULF RESOURCES INC.	SECURITY NATINAL BANK OF LOS ANGELES CALF. #1	
GULFURIBE246	GULF OIL CORPORATION	S. URIBE #8	
HEWITTMANFORD718	HEWIT B. DOUGHERTY	T.D. MANFORD #1	
HOWETHRAMIREZ288	HOWETH	RAMIREZ #1	
HQ-31	CONTINENTAL OIL COMPANY	BYRLE E. WOOTTERS #1	
HQ-327	COOK EXPLORATION	SEEDTICK #1	
HUMBLEGARCIA269	HUMBLE OIL & REFINING COMPANY	ANASTASIO GARCIA #1	

Appendix B, continued

UNIQUE WELL IDENTIFIER	COMPANY	WELL NAME/NUMBER	TOWNSHIP RANGE SECTION LOCATION[1]
JONNELLLOPEZ278	JONNELL GAS COMPANY	LOPEZ (HEIRS) #1	
JQ-168	LAMAR HUNT	MCMAHON #1	
JQ-192	KELLY-BROOK	ARCO HULING #1	
LOQ-1167	BUZZINI DRILLING COMPANY	W.R. SEALE #1	
MAGNOLIASPAWN420	MAGNOLIA PETROLEUM COMPANY	WALTER SPAHN #1	4S-20E-6
MAQ-9	WOODLEY PET. CO.	FORREST #1	
MAQUIRESALINAS257	RUSSELL MAGUIRE	SALINAS-LOPEZ UNIT #1	
MCABEGARCIA256	J. C. MCCABE	GARCIA-TREVINO SISTERS #1	
MCQ-107	HAROLD K. BOYSEN	WALKER #1	
MERRENSB1051	K.E. MERREN	STARK & BROWN 1	10N-51E
MITCHELLMANNING2910	J.B. MITCHELL	GREEN & MANNING #1	29S-10E
MOQ-285	THE TEXAS COMPANY	SEALY SMITH #1	
PANAMBROWN850	PAN AMERICAN PETROLEUM CORP.	E.W. BROWN. JR. "A" 1	8N-50E-5
PANEASTERNMALATEK521	PAN EASTERN EXPLORATION COMPANY	MALATEK #1	5S-21E-8
PENINSULAASHWORTH420			
PONTIACSLATOR227	PONTIAC REFINING CORPORATION	SLATOR RANCH #1	
PQ-157	KOUNTZE MUD SERVICE	T.D. STANFORD #1	
RICHARDSONMCKENDRICK216	RICHARDSON PETROLEUM ENT. INC.	W.H. MCKENDRICK #1	
ROWEBUNTING423			
SENECATATOM1149	SENECA DEVELOPMENT COMPANY	LYNN TATOM #1	
SMITHISBELL732	JAMES E. SMITH	ISBELL #1	7N-32E-8
SQ-41	GOLDSMITH	SOUTHERN PINE LUMBER CO. NO. 1	
SQ-96A	SONERRA RESOURCES	BEAR CREEK #1	
TQ-15	PAULEY PETROLEUM INCORPORATED & MCCULLOCH OIL CORP.	CAMERON HEIRS #4	
TQ-21			
TURNERBOULDIN619	M.O. TURNER	C.P. BOULDIN #1	6S-19E-2
WOODRUFFHEMPHILL1150	R.S. WOODRUFF & ASSOCIATES, INC.	HEMPHILL 2	11N-50E
WQ-14			
WQ-16	**** A. JACKSON		

[1] Township, range, section location from Tobin Maps.

Appendix C

Measured Depth to Layer Boundaries by Well, Annotated with Correlation Quality Ranking

Appendix C Measured Depth to Layer Boundaries by Well, Annotated with Correlation Quality Ranking (see Section 4.2.4)

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
5944109							270	A		
6617614	440	A	1160	C						
AHERNHUBBARD205										
AQ-39					190	A	550	A	840	A
AQ-52					440	A	830	A	1150	A
AQ-78									360	A
ARCOSAENZ299									2070	A
ARCOTEMPLE948	870	A	1510	A	1810	A	2300	A	2740	A
ATQ-228							270	A	640	A
BENTSENVIDAURRI235										
BLANCOJENNINGS247							800	A	1350	A
CLARKSALINAS279	755	A	1695	A	2280	A	3190	A	3720	A
CONSOLIDATEDVELA215										
CQ-343	1750	A	2480	A	2990	A	3360	A	3790	A
DP10-10N	4660	A	5610	A	6130	A	6730	A	7040	A
DP10-11	5030	A	6020	A	6620	A	7300	A		
DP10-3R							330	A	840	A
DP10-4R			700	C	980	A	1430	A	1860	A
DP10-5R	850	B	1250	A	1590	A	1985	A	2300	A
DP10-6			2180	A	2490	A	2875	A	3280	A
DP10-7	2510	A	3340	A	3755	A	4250	A	4720	A
DP10-8	3120	A	3985	A	4440	A	4880	A	5410	A
DP10-9	4090	A	4980	A	5560	A	6180	A	6440	A
DP11-10	3850	A	4780	A	5210	A	5860	A	6170	A
DP11-11	4035	A	4955	A	5400	A	6030	A	6360	A
DP11-7R	1750	C	2530	A	3030	A	3415	A	3740	A
DP11-8	3735	A	4640	A	5160	A	5780	A	6100	A
DP12-6A	1450	A	1990	A	2390	A	2800	A	3150	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP12-7	2700	A	3295	A	3745	A	4220	A	4390	A
DP12-8	4000	A	4620	A	5040	A	5710	A	6030	A
DP13-3										
DP13-4R							950	A	1330	A
DP13-5	610	A	1090	A	1440	A	1845	A	2390	A
DP13-6	2260	A	2810	A	3250	A	3730	A	4170	A
DP13-7	3440	A	3950	A	4410	A	4890	A	5200	A
DP13-8	3710	A	4210	A	4650	A	5180	A	5270	A
DP13-9	3660	A	4250	A	4680	A	5270	A	5550	A
DP1-4							410	A	700	A
DP14-4R	1630	A	2100	A	2390	A	2960	A	3390	A
DP14-5R	2330	A	3000	A	3420	A	3850	A	4260	A
DP14-6	3460	A	4100	A	4490	A	5010	A	5330	A
DP14-7	3440	A	4080	A	4480	A	5000	A	5160	A
DP14-8	4030	A	4520	A	5050	A	5570	A	5790	A
DP14-9	4280	A	4700	A	5210	A	5745	A	5950	A
DP1-4A					447	A	820	A	1270	A
DP1-5	398	A	1072	A	1442	A	1840	A	2340	A
DP15-10	2940	A	3550	A	4070	A	4525	A	5760	A
DP15-11R	3110	A	3720	A	4200	A	4820	A	5140	A
DP15-13	5810	A	6490	A	6895	A	7470	A	7660	A
DP15-5									670	A
DP15-6R			790	A	1140	A	1580	A	2090	A
DP15-7	980	A	1500	A	1860	A	2365	A	2830	A
DP15-8			2025	A	2380	A	2890	A	3320	A
DP15-9	1785	A	2485	A	2910	A	3440	A	3720	A
DP1-6	1470	A	2160	A	2580	A	2990	A	3520	A
DP16-3							480	A	900	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP16-5A	750	C	1280	A	1710	A	2250	A	2660	A
DP16-5R	840	A	1270	A	1600	A	2215	A	2590	A
DP16-6	1280	A	2010	A	2490	A	2940	A	3380	A
DP16-8	2955	A	3730	A	4135	A	4680	A	5100	A
DP1-7	3515	A	4235	A	4520	A	5160	A	5620	A
DP17-10	2380	A	3255	A	3890	A	4540	A	4820	A
DP17-11	2775	A	3630	A	4180	A	4850	A	5130	A
DP17-13	4300	A	5030	A	5380	A	5925	A		
DP17-3R										
DP17-4							340	A	775	A
DP17-5							625	A	1170	A
DP17-6					305	A	1050	A	1500	A
DP17-7R	10	C	690	A	1080	A	1810	A	2260	A
DP17-8	505	A	1270	A	1760	A	2320	A	2810	A
DP17-9	1450	C	2250	A	2690	A	3245	A	3715	A
DP18-10	730	A	1470	A	1920	A	2570	A	3160	A
DP18-11	2110	A	2920	A	3340	A	3990	A	4510	A
DP18-13	2500	A	3370	A	3770	A	4390	A	4920	A
DP18-14	4240	A	5080	A	5555	A	6270	A	6530	A
DP18-5										
DP18-6							200	C	590	A
DP18-7R							650	A	1060	A
DP18-8			50	C	405	A	1150	A	1630	A
DP18-9			210	A	590	A	1305	A	1840	A
DP19-10R							450	A	920	A
DP19-11					610	A	1280	A	1900	A
DP19-12	300	A	1090	A	1420	A	1970	A	2420	A
DP19-13	890	A	1680	A	2110	A	2580	A	3030	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP19-14			2600	A	3065	A	3750	A	4320	A
DP19-15	3350	A	4210	A	4650	A	5350	A	5730	A
DP19-6										
DP19-7									190	A
DP19-8R							360	A	850	A
DP19-9							410	A	880	A
DP20-10							150	C	610	A
DP20-11							485	A	1160	A
DP20-12					235	A	870	A	1470	A
DP20-13			570	A	1030	A	1650	A	2350	A
DP20-14	1115	A	1915	A	2450	A	3050	A	3710	A
DP20-15R	1120	A	1930	A	2440	A	3070	A	3730	A
DP20-16	1920	A	2720	A	3210	A	3870	A	4620	A
DP20-17	2010	A	2830	A	3330	A	4040	A	4740	A
DP20-18	3140	A	3930	A	4415	A	5120	A	5690	A
DP20-19	3020	A	3840	A	4300	A	5110	A	5780	A
DP20-8										
DP20-9										
DP2-10	2350	A	3100	A	3440	A	4068	A	4590	A
DP2-11	3140	A	3835	A	4210	A	4970	A	5550	A
DP21-10			390	A	820	A	1400	A	2030	A
DP21-11R			1340	A	1770	A	2390	A	3120	A
DP21-12	1355	A	2160	A	2690	A	3480	A	4210	A
DP21-13	1520	A	2280	A	2810	A	3530	A	4240	A
DP21-14	2005	A	2910	A	3510	A	4415	A	4740	A
DP21-15	4105	A	5210	A	5720	A				
DP21-16	5320	A	6400	A	6865	A	8030	B	8280	D
DP2-12	4590	A	5280	A	5615	A	6300	A	6570	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP2-13	5382	A	6090	A	6420	A	7145	A	7740	A
DP21-6R										
DP21-7										
DP21-8R							460	C	960	A
DP21-9R					190	A	730	A	1300	A
DP22-10R							840	A	1400	A
DP22-11							1740	A	2375	A
DP22-12			1230	A	1800	A	2710	A	3400	A
DP22-13			1570	A	2140	A	3000	A	3740	A
DP22-14	1540	A	2360	A	2940	A	3820	A	4140	A
DP22-15	1900	A	2860	A	3385	A	4185	D	4485	D
DP22-16	3810	A	4800	A	5385	A	6285	D	6535	D
DP22-17	4395	A	5540	A	6065	A	7015	D		
DP22-18	5840	A	6960	A	7480	A	8580	D		
DP22-6										
DP22-7R										
DP22-8							750	A	1170	A
DP22-9R			210	A	670	A	1270	A	1850	A
DP23-6	1660	A	2570	A	3226	A	4110	A	4680	A
DP23-7	4310	A	5400	A	6035	A	7155	A	7980	A
DP23-8										
DP24-1	4200	A	5290	A	6030	A				
DP24-2										
DP2-5							160	C	520	A
DP2-6							350	A	640	A
DP2-7R					300	A	695	A	980	A
DP2-8R			400	A	690	A	1105	A	1400	A
DP2-9	1530	A	2250	A	2630	A	3160	A	3660	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP3-10	3340	A	3950	A	4370	A	5245	A	5710	A
DP3-6A			660	A	1060	A	1475	A	1740	A
DP3-6R							260	A	660	A
DP3-7R	620	A	1320	A	1740	A	2200	A	2440	A
DP3-8	1530	A	2250	A	2745	A	3270	A	3790	A
DP3-9R	2500	A	3240	A	3650	A	4495	A	4840	A
DP4-11	4030	A	4775	A	5140	A	6030	A	6400	A
DP4-12	4265	A	5070	A	5425	A	6370	A	6670	A
DP4-13	4750	A	5545	A	5960	A	6930	A	7160	A
DP4-3									450	A
DP4-4					440	A	950	A	1320	A
DP4-5			460	A	880	A	1490	A	2010	A
DP4-6	310	A	905	A	1360	A	1975	A	2600	A
DP4-7	1980	A	2650	A	3100	A	3680	A	4100	A
DP4-8	2270	A	2930	A	3350	A	4000	A	4480	A
DP4-9	3120	A	3780	A	4210	A	5010	A	5490	A
DP5-10R	4230	A	4975	A	5390	A	6145	A	6700	A
DP5-11R	4460	A	5240	A	5655	A	6340	A		
DP5-12	5040	A	5865	A	6280	A	7040	A	7340	A
DP5-5R									300	A
DP5-6			345	A	825	A	1390	A	1590	A
DP5-7R			840	A	1200	A	1755	A	2100	A
DP5-8	2200	A	2970	A	3500	A	4025	A	4250	A
DP5-9	3070	A	3805	A	4300	A	4890	A	5460	A
DP6-10	5140	A	5870	A	6380	A	7210	A	7440	A
DP6-11	5300	A	6100	A	6600	A	7480	A	7590	A
DP6-12	5630	A	6430	A	6900	A	8000	A	8055	A
DP6-3							710	A	930	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP6-4			850	A	1170	A	1840	A	2160	A
DP6-5R	2420	A	3210	A	3570	A	4250	A	4680	A
DP6-6	2950	A	3700	A	4100	A	4820	A	5320	A
DP6-7	3530	A	4310	A	4720	A	5530	A	5880	A
DP6-8	4530	A	5340	A	5840	A	6580	A	6980	A
DP6-9	5075	A	5870	A	6390	A	7240	A	7480	A
DP7-1R									750	A
DP7-2			750	A	1090	A	1770	A		
DP7-3	1200	A	1850	A	2235	A	2910	A	3180	A
DP7-4	2870	A	3650	A	4030	A	4740	A	5210	A
DP7-5	3210	A	3920	A	4310	A	5090	A	5430	A
DP7-6	5185	A	6050	A	6420	A	7180	A	7880	A
DP7-7	4720	A	5520	A	5960	A	6743	A	7380	A
DP7-8	4920	A	5760	A	6165	A	7010	A	7700	A
DP7-9	5190	A	6050	A	6360	A	7222	A	7590	A
DP8-2							630	A	920	A
DP8-3R	1080	A	1770	A	2140	A	2790	A	3060	A
DP8-4	2500	A	3250	A	3620	A	4340	A	4780	A
DP8-5	2790	A	3500	A	3880	A	4650	A	5100	A
DP8-6	3230	A	4000	A	4360	A	5145	A	5540	A
DP8-7	3380	A	4140	A	4490	A	5245	A	5660	A
DP8-8	4560	A	5550	A	6275	A	7155	A		
DP8-9										
DP9-10R	3010	A	3750	A	4280	A	4755	A	5250	A
DP9-11R	3830	A	4700	A	5245	A	5710	A	6000	A
DP9-12	4360	A	5300	A	5770	A	6570	A	6890	A
DP9-13	5300	A	6250	A	6710	A	7570	A		
DP9-5R					165	A	540	A	965	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
DP9-6					620	C	1050	A	1470	A
DP9-7	1200	A	1750	A	2150	A	2630	A	2970	A
DP9-8R	2050	A	2750	A	3250	A	3890	A	4490	A
DP9-9	2740	A	3470	A	3950	A	4410	A	4690	A
DPA-22	2150	A	2830	A	3210	A	3754	A	4340	A
DPB-12	3720	A	4515	A	5100	A	5740	A	6020	A
DPB-13R	2990	A	3745	A	4200	A	4775	A	5170	A
DPB-15A	3540	A	4025	A	4495	A	5020	A		
DPB-15R	3650	A	4135	A	4655	A	5110	A		
DPB-17	3980	A	4680	A	5160	A	5740	A	5980	A
DPB-2	1820	A	2780	A	3385	A	4285	A	4630	A
DPB-20	3990	A	4850	A	5275	A	5910	A		
DPB-5	3285	A	3970	A	4475	A	5310	A	5920	A
DPB-9R	3430	A	4200	A	4590	A	5210	A	5810	A
DPC-2	5000	A	6000	A	6760	A	8065	A	8440	A
FQ-103									280	A
FRAZIERCOCHRAN719					130	A	535	A	900	A
GINTHERKILLAM206					200	C	775	A	1190	A
GQ-90	350	C	780	A	1160	A	1500	A	1840	A
GRQ-29	1640	A	2425	A	2920	C				
GULFSNB258			810	A	1350	A	2130	A	2790	A
GULFURIBE246									260	A
HEWITTMANFORD718										
HOWETHRAMIREZ288									1200	A
HQ-31							120	A	350	A
HQ-327									230	A
HUMBLEGARCIA269		A	1490	A	2160	A	3140	A	3920	A
JONNELLLOPEZ278									170	A

Appendix C, continued

Unique Well Identifier	Top Jackson	Quality	Top Lower Jackson	Quality	Top Yegua	Quality	Top Lower Yegua	Quality	Base Yegua-Jackson Aquifer	Quality
JQ-168	2630	A	3320	A	3620	C	4125	A	4690	A
JQ-192	970	A	1620	A	1985	A	2450	A	2930	A
LOQ-1167			890	A	1355	A	1890	A	2370	A
MAQ-9									160	A
MAQUIRESALINAS257										
MCABEGARCIA256										
MCQ-107	530	A	1300	A	1795	A				
MERRENSB1051	425	A	980	A	1350	A	1750	A	2120	A
MITCHELLMANNING2910	2280	A	3300	A	3950	A	5080	A		
MOQ-285	2840	A	3550	A	3930	A	4650	A	5240	A
PANAMBROWN850	2555	A	3200	A	3512	A	3992	A	4360	A
PANEASTERNMALATEK521							400	A	780	A
PENINSULAASHWORTH420										
PONTIACSLATOR227					220	A	1040	A	1590	A
PQ-157	1540	A	2240	A	2720	A	3280	A	3740	A
RICHARDSONMCKENDRICK216							745	A	1060	A
ROWEBUNTING423					880	B	1405	A	1810	A
SENECATATOM1149										
SMITHISBELL732					150	A	695	A	790	A
SQ-41							230	A	340	A
SQ-96A			610	A	877	A	1284	A	1640	A
TQ-15			490	A	910	A	1500	A	2230	A
TQ-21	140	A	745	A	1060	A	1450	A		
TURNERBOULDIN619										
VRATISKNOX321										
WQ-14	650	A	1420	A	1930	A				
WQ-16			340	A	810	A	1400	A	1610	A

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Appendix D

Net Sand Values by Well and by Layer

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Appendix D Net Sand Values by Well and by Layer. NL – interval not logged NDE – well not deep enough

Unique Well Identifier	Upper Jackson Layer	Lower Jackson Layer	Upper Yegua Layer	Lower Yegua Layer
5944109	NL	NL	NL	NDE
6617614	>20	NDE	NDE	NDE
AQ-39	NL	NL	181.5	189
AQ-52	NL	NL	NL	140
ARCOSAENZ299	NL	>150	324.5	258
ARCOTEMPLE948	0	22.5	80	305.5
ATQ-228	NL	NL	>40	130
BENTSENVIDAURRI235	NL	NL	NL	NL
BLANCOJENNINGS247	NL	NL	>20	120
CLARKSALINAS279	58	81.5	319.5	208
DP10-11	10	0	55	0
DP10-3R	NL	NL	>90	110
DP10-4R	NL	>0	177.5	70
DP10-5R	>110	120	150	120
DP10-6	NL	0	0	37
DP10-7	110	0	100	330
DP10-8	10	0	120	170
DP10-9	90	0	40	25
DP11-11	60	0	40	40
DP11-7R	>20	0	164.5	190
DP11-8	123	0	50	40
DP12-6A	30	13.5	151	165.5
DP12-7	0	0	89.5	8.5
DP12-8	70	0	0	0
DP13-4R	NL	NL	>90	205
DP13-5	169	74	177	266
DP13-6	5	20	107	134
DP13-7	0	0	10	0
DP13-9	133	0	0	0
DP1-4	NL	NL	>30	208
DP14-4R	189.5	111	177	268
DP14-6	19	5.5	112	72
DP14-8	0	0	5	10
DP14-9	0	0	0	0
DP1-4A	NL	NL	50	90
DP1-5	20	47.5	94.5	124
DP15-10	0	0	0	0
DP15-11R	1	0	132	15
DP15-13	0	0	0	0
DP15-5	NL	NL	NL	>110
DP15-6R	>3	108	149.5	260
DP15-7	127.5	140	140	150
DP15-9	95.5	89.5	251.5	160.5
DP1-6	20	67	97	256.5

Appendix D, continued

Unique Well Identifier	Upper Jackson Layer	Lower Jackson Layer	Upper Yegua Layer	Lower Yegua Layer
DP16-3	NL	NL	NL	200
DP16-5A	120.5	26.5	120	241.5
DP16-5R	60.5	54.5	270	204
DP16-6	99	169	139	193
DP16-8	0	0	130	80
DP1-7	0	34	189	200.5
DP17-10	40	116.5	137	147
DP17-4	NL	NL	>30	102.5
DP17-5	NL	NL	>50	110
DP17-8	180.5	155	200.5	294
DP17-9	>240	200	290	180
DP18-10	130	79	333.5	107.5
DP18-11	170	130	310	260
DP18-14	50	0	80	>25
DP18-6	NL	NL	NL	>100
DP18-7R	NL	NL	>30	100
DP18-9	>20	0	319.5	130
DP19-10R	NL	NL	>15	130
DP19-11	NL	>0	102.5	250
DP19-12	70	65	150	180
DP19-13	164.5	96	231	345.5
DP19-14	>140	270	331	326
DP19-15	124	49	132	>70
DP19-7	NL	NL	NL	>30
DP19-8R	NL	NL	>5	147
DP19-9	NL	NL	>10	78
DP20-10	NL	NL	NL	143
DP20-11	NL	NL	NL	360
DP20-12	NL	>0	35	266.5
DP20-13	>10	9.5	27	368.5
DP20-14	20.5	83	232	283
DP20-15R	21.5	16	154.5	210
DP20-17	210	110	290	480
DP20-18	2.5	40	89	163
DP2-10	50	60	75	100
DP2-11	0	10	313.5	357
DP21-10	>80	35.5	0	314
DP21-11R	>10	10	50	275
DP21-12	0	79	238.5	286.5
DP21-13	0	128	229.5	310
DP21-14	60	153	464.5	141.5
DP21-15	30	60	>60	NDE
DP21-16	40	3	0	NDE
DP2-13	0	24	289.5	260
DP21-8R	NL	NL	NL	80

Appendix D, continued

Unique Well Identifier	Upper Jackson Layer	Lower Jackson Layer	Upper Yegua Layer	Lower Yegua Layer
DP21-9R	NL	>10	0	80
DP22-10R	NL	NL	>0	387
DP22-11	NL	NL	>0	261.5
DP22-12	>0	0	129.5	424
DP22-13	>10	63.5	314	190.5
DP22-14	0	144.5	333	185
DP22-15	152.5	71.5	>150	NDE
DP22-16	40	40	>30	NDE
DP22-17	50	50	>30	NDE
DP22-18	160	50	>120	NDE
DP22-8	NL	NL	>140	293
DP22-9R	NL	12.5	22	338.5
DP23-6	110	100	90	30
DP23-7	393	220	575	527.5
DP24-1	226.5	100	>50	NDE
DP2-5	NL	NL	NL	>170
DP2-7R	NL	>0	163.5	152.5
DP2-8R	NL	50	80	80
DP2-9	65	77	143.5	236
DP3-10	0	30	314	173.5
DP3-6A	>90	93	91	206.5
DP3-6R	NL	NL	>15	140
DP3-7R	39	20	70	70
DP3-8	40	40	104.5	373
DP3-9R	50	15	180	180
DP4-11	0	0	230	180
DP4-12	0	0	475.5	185
DP4-3	NL	NL	NL	>140
DP4-4	NL	>70	218.5	235.5
DP4-5	>100	50	60	140
DP4-6	70	24	122	140
DP4-7	84.5	37	131.5	101.5
DP4-9	30	83	273.5	180
DP5-10R	94.5	42.5	319.5	376.5
DP5-12	0	0	140	120
DP5-5R	NL	NL	NL	180
DP5-6	>80	50	120	70
DP5-7R	>320	140	170	125
DP5-8	119	80.5	81	168.5
DP6-10	0	0	210	80
DP6-11	0	20	210	70
DP6-12	0	0	100	10
DP6-3	NL	NL	>70	145
DP6-4	>330	13.5	40	70.5
DP6-5R	123	35	147.5	128.5

Appendix D, continued

Unique Well Identifier	Upper Jackson Layer	Lower Jackson Layer	Upper Yegua Layer	Lower Yegua Layer
DP6-6	35	50	300	115
DP6-7	60	20	322.5	235
DP6-8	0	15	219.5	190
DP6-9	0	0	200	120
DP7-1R	NL	NL	>60	100
DP7-3	85	70	226	159.5
DP7-4	170	30	160	280
DP7-6	20	0	260	320
DP7-8	70	0	180	210
DP7-9	150	0	70	80
DP8-2	NL	NL	NL	35
DP8-3R	220	171	267.5	147.5
DP8-4	180	20	167.5	274
DP8-5	60	50	260	204.5
DP8-7	30	0	297	252
DP8-8	60	6.5	163.5	>210
DP9-10R	40	30	170	160
DP9-11R	0	0	66	123
DP9-13	35	0	60	10
DP9-5R	NL	NL	120	95
DP9-6	NL	NL	>40	71.5
DP9-7	60	100	100	100
DP9-8R	58	50.5	242	323
DP9-9	30	40	250	170
DPA-22	0	54	163.5	351
DPB-12	0	0	70	20
DPB-13R	0	0	134.5	98
DPB-2	70	120	330	140
DPB-5	60	30	321.5	260.5
DPB-9R	10	0	46.5	30
DPC-2	414.5	187	359	150
FRAZIERCOCHRAN719	NL	NL	110	186.5
GINTHERKILLAM206	NL	NL	>40	200
GQ-90	>180	139.5	313.5	142.5
GRQ-29	176	72	NDE	NDE
GULFSNB258	>0	80	497.5	258
GULFURIBE246	NL	NL	NL	>30
HQ-31	NL	NL	>10	130
HOWETHRAMIREZ288	NL	NL	NL	>630.5
HUMBLEGARCIA269	63	100	349	150
JONNELLLOPEZ278	NL	NL	NL	>20
JQ-168	0	>20	>80	100
JQ-192	0	36	140.5	306
LOQ-1167	>90	133.5	249	300
MAQ-9	NL	NL	NL	>70

Appendix D, continued

Unique Well Identifier	Upper Jackson Layer	Lower Jackson Layer	Upper Yegua Layer	Lower Yegua Layer
MCQ-107	40	3	>80	NDE
MERRENSB1051	0	40	25	140
MITCHELLMANNING2910	192	40	60	NDE
MOQ-285	50	25	153	251
PANAMBROWN850	10	91	80	135
PANEASTERNMALATEK521	NL	NL	>60	305
PONTIACSLATOR227	NL	>10	10	127
RICHARDSONMCKENDRICK216	NL	NL	>0	71.5
ROWEBUNTING423	NL	NL	290	250
SMITHISBELL732	NL	NL	110	86.5
SQ-41	NL	NL	NL	90
SQ-96A	>10	43	141	130
WQ-14	279	118.5	NDE	NDE
WQ-16	>30	50	100	80

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Appendix E

Structure Draft Final Report Technical / Administrative Comments

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Structure of the Yegua-Jackson Aquifer of the Texas Gulf Coastal Plain

(TWDB Contract #0604830617)

By Paul R. Knox, Van A. Kelley, Astrid Vreugdenhil, Neil Deeds, and Steven Seni

Review of Draft Report by TWDB Staff

General comments

1. We expected that subsurface layer boundaries would tie to outcrop contacts. Please revisit and re-submit all cross-sections, isopach maps, net sand thickness maps, and structure maps as it appears the cross-sections were not tied to the geologic outcrop points. Wells that plot to the north and west of the outcrop should be discarded in the evaluation, as these locations should represent wells completed in the Cook Mountain or Sparta formations. Also Section 5 of the report should be reviewed for relevant edits to reflect the adjusted analysis of the structure. In addition, all related data in the geodatabase should be adjusted and resubmitted. If during this project research indicates that the Geologic Atlas Sheets are incorrect, sufficient documentation and proof should be provided to substantiate this claim.

   In response to the TWDB comments, we reviewed the chronostratigraphic units to understand, and potentially reconcile differences between the base of the Lower Yegua Unit (time chronostratigraphic) and the outcrop base of the Yegua and also between the top of the Upper Jackson Unit (chronostratigraphic) and the outcrop top of the Jackson in areas north and east of the Brazos River. Below we will discuss how we addressed this comment. The report has been revised per TWDB comments and the associated geodatabase has been updated.

   Outcrop descriptions of geologic units are inherently different from subsurface descriptions. Weathering of geologic units at outcrop creates differential erosion, leaving sands and more cemented lithologies standing in relief as low hills above the more easily eroded clays that commonly form lowlands and river valleys. This concept is especially applicable in areas of low rainfall, but can be negated in wetter areas such as East Texas, where sands and muds are equally eroded and dissected (Jackson and Garner, 1982). Weathering also oxidizes the sediments, creating distinctive colors, textures, and features. Conversely, subsurface observation is limited to well borings, lithologic logs, and geophysical logs of resistivity and natural gamma-ray values. This information may be less indicative of trace mineralogic content but is more sensitive to slight changes in lithology that reflect changes in depositional setting and are laterally correlative. These changes are indicative of regional or subregional time-stratigraphic, or chronostratigraphic, relationships. Subsurface data may more accurately relate sediments deposited during a certain time interval, regardless of their gross lithology. In *this way, sands that are hydrologically linked can be grouped together to constitute a 'flow layer' within the aquifer.*

The general chronsotratigraphic correlation approach used in this study is based upon the correlation of maximum flooding surfaces within fine-grained highstand deposits as defined in geophysical well logs arranged in dip-oriented cross sections, connecting low-resistivity markers in downdip shale sections with shales or abrupt-based sands in updip sandy and silty intervals. Utilizing this technique, four major chronostratigraphic units (third-order genetic units) were defined for the Yegua-Jackson Aquifer. These include, from the bottom upward, the Lower Yegua, Upper Yegua, Lower Jackson, and Upper Jackson Units, which each span one to two million years of deposition (third-order genetic units) and are of appropriate scale for regional groundwater availability modeling (generally 400 to 800 feet thick, thickening in the downdip direction).

The four chronostratigraphic units were used a the basis for defining four operational aquifer layers within the Yegua-Jackson Aquifer; the Lower Yegua Layer, the Upper Yegua Layer, the Lower Jackson Layer and the Upper Jackson Layer. Of these four aquifer layers, only the Lower Yegua Layer differs from it's chronostratigraphic unit equivalent. This is because the chronostratigraphic Base Yegua Unit occurs at or below the lithostratigraphic Base Yegua-Jackson Aquifer, and thus commonly outcrops farther inland (north and west) than the base of the Yegua Formation as mapped in outcrop. The chronostratigraphic surface represents a maximum flooding surface between the Sparta and Yegua depositional cycles and commonly occurs within the shale of the Cook Mountain Formation. To address this issue, the base of the Lower Yegua Aquifer Layer, which comprises the base of the Yegua-Jackson Aquifer, was defined to occur at the first significant sand above the Cook Mountain shales and was tied to the base Yegua outcrop boundary. In South Texas the interval between the Base Lower Yegua Unit (chronostratigraphic) and the Base Yegua Layer (base Yegua-Jackson Aquifer) contains significant sands that are potentially water-bearing. These sands were excluded from this study and thus lie between the Sparta and Yegua-Jackson Aquifers. Future reconsideration of existing formal aquifer boundaries might place these sands in the Yegua-Jackson Aquifer because they are probably most closely linked, hydrologically, with this aquifer.

This study provides significant evidence that the Vicksburg Formation was mapped by Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) as part of the Jackson Group from approximately the Brazos River eastward and mapped as part of the Catahoula Formation and lateral equivalents from the Brazos River southward. This conclusion is substantiated by this work and the work of others. This conflict between interpretations from this study and those of Barnes (1968a, 1968b, 1974a, 1974b, 1974c, 1975, 1976a, 1976b, 1976c, 1992) are important, unexpected, and not resolvable within the scope of this study. Before this structural framework of the Yegua-Jackson aquifer is incorporated into a numerical model, it is suggested that sufficient investigation resolves stratigraphic inconsistencies and logically places the 'region in conflict' within either the Yegua-Jackson Aquifer or the overlying Gulf Coast Aquifer.

2. Please update the descriptive sections of the report to provide a greater focus on the updip, near-outcrop parts of the Yegua-Jackson aquifer. For example, vertical bedding styles as described on page 5-10 paragraph 4 refer to wells that are below the base of fresh water. Also on page 5-13 paragraph 2, good detail of description but all way below the zone of interest.

   Sections 2.2.1, 5.3.1.1, 5.3.2.1, 5.3.3.1, and 5.3.4.1 have been added to provide more information relative to the shallow sections of the aquifer.

3. Please add descriptions from previous studies of Yegua-Jackson outcrops to Section 2. Please use county groundwater reports, Eargle (1972), and formation descriptions included with the GAT sheets to provide information about outcrop lithologies in Section 2.

   Section 2.2.1and many sections in Section 5 have been greatly expanded to provide more information relative to the shallow sections of the aquifer with emphasis on previous outcrop studies.

4. Please expand the Executive Summary to capture all important points and findings. This may be the only section that some people read.

   The Executive Summary has been re-written and expanded from the draft report.

5. Please seal the appropriate figures/plates and follow the protocol for geoscience related work in Texas to comply with the Texas Board of Professional Geoscientists rules and regulations per http://www.tbpg.state.tx.us/chapter-851c.html#6 §851.156. Geoscientist's Seals, subsection (i) and (j).

   Upon review and consent of the TWDB, we will seal the cover which is considered adequate by the Texas Board of Professional Geoscientists.

6. Please spell out all abbreviated phrases or symbols throughout the report and figures, such as: AFY, SP, m.y., yrs, Ky, MFS, ft, mi, ft/mi, 3D, TDS, dpi, GIS, %, QFL, GAMs, TCEQ, CAD, UWI, API, KB, and et al.

   Completed.

7. Digitized well logs are not included in the source data. Please provide us with the LAS files for all digitized logs.

   Completed.

8. All CAD files included in the electronic data will not open with Adobe Illustrator or ArcGIS. Please check these files and resubmit.

Completed. We have saved the CAD files to an older version.

9. Please recreate selected cross sections using digitized log curves. Cross sections on the Plates using scanned logs are difficult to use owing to their size. It is also difficult to see the log curves on some of the scans. On digitized sections wells could be placed closer together, and log curve scales could be standardized.

   We are in agreement that developing cross-sections with digitized logs would be of value. However, the production of this specific type of section with digitized logs are outside of the scope and would be extremely time consuming given our software. The current sections with the scanned logs are legible, representative, and consistent.

10. Sections 4.4.1.2 and 4.4.1.3 describe a Perl program for measuring net sandstone. Please provide a copy of the Perl code.

    Completed

11. Please describe in the report the contouring software and interpolation method(s) that were used to create contours of structure, net sand, and sand percent.

    A description of the contouring algorithm used has been included in Sections 4.3 and 4.4 for the structure and sand thickness mapping.

12. Please add county names to all plates, both maps and cross sections.

    Completed

13. Please consider adding a figure showing major structural elements of the Texas Gulf Coast, including Rio Grande Embayment, San Marcos Arch, and Houston Embayment. Or maybe add to existing figure(s).

    Figure 2.1 has been modified to include the major structural elements in the study area.

Technical comments

1. 2.1 Description of the Study Area, page 2-1, 2nd paragraph, 1st sentence: Please provide a reference for rainfall estimates and update Section 8. References, as needed. *Completed – the reference is Larkin and Bomar (1983).*
2. Page 2-2, 3rd paragraph, line 2: Reference to Barnes 1992. Please expand the citation to include the rest of the relevant GAT sheets. *Completed, Full references are provided.*
3. Plate 1 (and Figure 2-2): Please review, clarify, and adjust where Strike C-C’ begins and ends. The legend in Plate 1 indicates Strike C-C’ is denoted by a red dashed line; however, a blue dashed line extends from well DPC-2 to the C label in Hidalgo County and a blue-dashed line extends from well SQ-41 in Sabine County to the C’ label. *Completed*

4. Table 4-1, page 4-2: Please update contact information from McMullen Groundwater Conservation District from Lonnie to Lonnie Stewart. *Completed*
5. 4.1.2 Geophysical Log Sources, page 4-3, 2nd paragraph: Please provide a brief explanation of the significance of using Tobin basemaps and what a Tobin basemap represents. In addition, please provide a brief explanation of what a Kelly Bushing datum represents. It is unlikely that the casual reader will understand what these terms signify. *Completed.*
6. 4.2.1 Incorporation of Existing Data and Knowledge, page 4-5, 3rd paragraph, 1st sentence: Please update the References section with the Texas Natural Resource Information System (2006) reference. *Completed.*
7. Page 4-7, 3rd paragraph, line 5: “future aquifer (MFSs)” suggests that “aquifer” equals “MFSs”. Please update if necessary for correct meaning. *Accepted and the sentence has been re-written to avoid confusion.*
8. 4.3 Structure Mapping Approach, page 4-9, 1st paragraph, last sentence: Sentence states that issues with negative thicknesses were resolved by adding estimated depths for a surface to increase control for the contouring algorithm. Please clarify if virtual wells were used and included (and identified as such) in the accompanying geodatabase. *Complete.*
9. 4.4.1.3 The Algorithm, page 4-12, 2nd paragraph, last sentence: Sentence states values shown in Figure 4-10 were the final values used; however, Figure 4-10 shows the genealogical correlation work flow and does not list any values. Please adjust text to direct reader to the correct figure. *The reference was corrected to point to Figure 4-11.*
10. 4.4.2 Sand Thickness Mapping, page 4-14, 1st paragraph: Section states sand thickness values were gridded and contoured without directional bias. Please expand to include information on the process and software used to contour and more information on gridding, such as grid size and orientation. *Completed.*
11. Figures 4-1 to 4-6: Please provide a better explanation of map symbology in the Legends, including letters (“J” and “Y”), numbers without letters, orange numbers, etc. *Complete.*
12. Figures 4-7 and 4-8: Please consider also including the chart of Gulf Coast chronostratigraphic cycles (Galloway) with Yegua-Jackson cycles highlighted. *Figure 2-4 has been added as suggested.*
13. Figure 4-7: Caption cites Galloway (1989). Please update References section with this citation or possibly adjust the text, if appropriate, to agree with the citation listed in the References section of the report. *Completed.*
14. Figure 4-8: Caption cites Hays (1976) and Meckal and Galloway (1990). Please update References section with these citations or possibly adjust the text, if appropriate, to agree with the citations listed in the References section of the report. Please note the References section does list Hays and others (1976) and Meckel and Galloway (1996). Also please correct spelling of nomenclature in the header and include a footnote explanation for the Ky abbreviation shown in figure. *The references were incorrectly cited and have been corrected.*
15. Figure 4-9: Please expand caption to also include definitions for CR, CC, SBR, and BR shown in the figure or remove these abbreviations from figure, if not needed. *Complete.*
16. Figure 4-11: The text in the final decision diamond is truncated. Please resubmit with text visible. *Complete.*

17. Page 5-1, 2nd paragraph, general: “micropaleontologic information” is stated here but not described or referred to again. Please provide more details, even if it is just to state that paleo was not a significant source of data for this study.
    A complete discussion of the relevant paleo and its significance to the study is provided in Section 2.2 as well as a new Figure 2-4. Only one well on the cross-section plates had paleo information. That plate (Plate 3), has been updated.
18. Page 5-1, 2nd paragraph, general: “Comparisons with previous works” is stated here but not elaborated further. Please provide more information of the results of this comparison. A chart showing the comparison would be nice. *Previous works have been cited and comparisons to the critical Coleman (1990) study have been added to the cross-sections.*
19. Page 5-2, paragraph 2, lines 9 and 10: Description of vertical trends (fining vs coarsening) may be reversed. Please adjust if necessary. *Corrected, well citation has been corrected from DP2-12 to -2-10.*
20. Page 5-4, 1st paragraph, last sentence: Please consider referring to Plate 18 here (Lower Jackson net sand). *Complete.*
21. Page 5-4, 4th paragraph, general: It would be helpful if you point out in the text the geographic locations of high net sand near outcrop and refer to Plate 17. *The discussion of lithology in the outcrop has been greatly expanded in Section 5.3.*
22. Page 5-4, last paragraph, general: Please cite previous work (“Previous work suggests…”). *References provided.*
23. Page 5-5, 2nd paragraph, general: Please consider if some of these higher order cycle boundaries might correlate more closely with outcrop contacts or could be used as layer boundaries locally. *This discussion has been added in Section 5.1.2.*
24. Page 5-7, 2nd paragraph, general: Please explain the “structural hinge” concept a little more. The Plate 4 example seems pretty extreme for a hinge point. *The explanation has been provided in Section 5.2.*
25. Page 5-7, 3rd paragraph, 2nd half of paragraph: Strike-slip faulting is very unusual in the Gulf Coast Basin. Please support the statement about strike-slip faulting a little more or consider revising text. A formation having very low dips might display apparently dramatic outcrop convolutions that are attributable to the interaction of gentle folding and topography. *Figure 2-1 shows transfer faults offshore that trend across the Yegua-Jackson outcrop. Discussion of the structural setting in Section 2.2 and in 5.2 has been expanded.*
26. Page 5-7, last paragraph, last line: Please consider changing “boundaries from Barnes (1992)” to “boundaries from the Geologic Atlas of Texas (cite all relevant GAT sheets)”. *Complete*
27. Page 5-13, 2nd paragraph, last line: Reference to cross section well in parentheses seems wrong. You may have meant to refer to a different well. Please update if necessary. *Well reference has been updated.*
28. Page 5-14, 3rd paragraph, line 2: “axis of the study area” is unclear. Please clarify with additional text such as “mid-dip area”. *Completed.*
29. Page 5-15, 1st paragraph, line 3: Instead of “fluvial deposits” you may have meant “deltaic deposits”. Please update if necessary. *This is intentional. This refers to areas in the updip region of deltas that lack abundant sand.*
30. Page 5-17, 2nd paragraph, line 1: Instead of “Upper Yegua Layer” you may have meant “Upper Jackson Layer”. Please update if necessary. *Complete*

31. Section 5, figures: Please identify black arrows in Legends. *Complete.*
32. Section 5, figures: Wells on sand percent maps are not the same as wells on net sand plates. Please adjust as necessary. *Complete.*
33. Figure 5-5: Please provide more explanation in the text and caption on the purpose of the QFL diagram as it is unlikely that the casual reader will understand what this diagram represents. *A description of the QFL Diagram as well as their use has been added.*
34. Page 5-27 and 5-28, Figures 5-10 and 5-11: Light green color for "Shelf" should probably be labeled "Slope". Please update if necessary. *Complete*
35. Page 5-29, Figure 5-12: Some facies have a 100-ft cutoff in Legend but text states that cutoff is 50 ft. Please adjust if necessary. *Legend on Jackson Plates has been changed to 50 feet.*
36. Page 5-30, figure 5-13: Same comment about cutoff values. Also some shelf facies extend onto slope in south. Please adjust if necessary. *Completed as in previous comment.*
37. Plate 3: Please update Sheet title from "Dip Cross Section" to "Dip Cross Section 3" to agree with text on page 5-2. *Complete*
38. Plates 6: Please review layer boundary labels and verify that they are consistently labeled correctly for each unit. *Complete*
39. Plates 12-16, Structure Maps: Some salt dome locations are inaccurate, although this is probably Ewing's fault. But please take the "salt domes" out of Gillespie and Blanco Counties. Please identify Cretaceous shelf margins in the Legend and color differently from the salt domes. Also suggest citing sources for salt domes and Cretaceous shelf margins on the plates. *Complete*
40. Appendix A, Appendix B, Appendix C, and Appendix D: Suggest including an introduction or caption that document or explains the headers and data. *Complete.*

Editorial comments

1. Table of Contents, page vii, Plates: Please label plates 12, 13, and 16. *Complete.*
2. Section 1. Introduction, page 1-1, 2nd paragraph, 1st sentence: Suggest rewording, "Because *of* the Yegua-Jackson has been designated…" to "Because the Yegua-Jackson has been designated…" *Complete.*
3. Section 2.1 Description of the Study Area, page 2-1, 1st paragraph, 6th sentence: Please adjust capitalization of "counties" to lower case. *Complete.*
4. Section 2.1 Description of the Study Area, page 2-1, 1st paragraph and 3.2 Hydrogeology, page 3-2, 2nd paragraph, 2nd sentence: Please remove the word "River" when referring to the Rio Grande since when translated "River" is redundant. *Complete.*
5. Section 3.2 Hydrogeology, page 3-2, 1st paragraph, 1st partial sentence: Suggest rewording, "…evidence of recovering heads *during from* the 1980s…" to clarify if intending to convey that heads recovered during the 1980s or that heads recovered from sometime in the 1980s to present. *Complete.*
6. Page 4-2, last paragraph: "Evergreen" and "Fayette County" should probably be "Evergreen GCD" and "Fayette County GCD". Please adjust. *Complete.*
7. Page 4-3, 3rd paragraph: Please correct the spelling of "Visualization".
8. Page 4-4, 1st paragraph, line 7: Suggest that "were" should be "was". *Complete.*

9. Section 4.2.2.1 Concepts, page 4-6, 2nd paragraph: Paragraph describes depositional cycles beginning with shoreline progradation, stabilization, and then aggradation. However, Figure 4-7 shows the cycle in reverse. Suggest adjusting text so sequence in figure is consistent with text. *Text and figure caption have been made consistent.*
10. Section 4.2.2.1 Concepts, page 4-6, 3rd paragraph, last line: Please replace the word “seal” with “sea”. *Complete.*
11. Page 4-7, last paragraph, line 10: Please put a period after “input”. *Complete.*
12. Page 4-8, 3rd paragraph, line 4: “(C-C’, Plate 1)” should probably be “(C-C’, see Plate 1 for location of section line)”. *Complete.*
13. Page 4-12, 2nd paragraph, line 4: “Figure 4-10” should be “Figure 4-11”. *Complete.*
14. Page 5-2, last paragraph, line 6: “most” should be “mostly”. *Complete.*
15. Page 5-3, 2nd paragraph, line 5: “a” at end of line should be “and”. *Complete.*
16. Section 5.3.1 Upper Jackson Layer, page 5-8, 1st paragraph, 2nd sentence: Please replace the word “inn” with “in”. *Complete.*
17. Page 5-10, 3rd paragraph, line 3: “Each are” should be “Each is”. *Complete.*
18. Page 5-10, 4th paragraph, last line: “Plate 8” should be “Plate 9”. *Complete.*
19. Page 5-11, 3rd paragraph, last line: “Angeline” should be “Angelina”. *Complete.*
20. Page 5-11, 4th paragraph line 4: “Thickness decrease” should be “Thicknesses decrease”. *Complete.*
21. Page 5-11, 4th paragraph, last line: “County. Sand thickness” should probably be “County, where sand thickness”. *Complete.*
22. Page 5-13, 1st paragraph, last line: “thickness” should be “thicknesses”. *Complete.*
23. Page 5-13, 2nd paragraph, line 4: “occur” should be “occurs”. *Complete.*
24. Page 5-13, 2nd paragraph, line 5: “Plate 9” should be “Plate 5”. *Complete.*
25. Sections 5.4 Depositional Systems, pages 5-13 to 5-14 and Section 5.4.1 Lower Yegua layer, pages 5-14 to 5-15: Please adjust paragraph from hanging to no indentation. *Complete.*
26. Page 5-17, 2nd paragraph, line 1: “Upper Yegua Layer” should be “Upper Jackson Layer”. *Complete.*
27. References, page 8-2: Please verify spelling of Biostratigrahic and adjust as needed. *Complete.*
28. References, pages 8-2 and 8-3: Please confirm if the following were cited in the text of the report: Fisher and others (1969), Hays and others (1976), and Mace and others (2005). If they were not cited, please remove from reference list. Fisher and others should be Fisher (1969) in the references. *Mace and others was not cited in the text and it has been removed from the reference list. The references has been checked and corrected where needed.*
29. References, page 8-3: Galloway and others (1991) contains [Flag italicize in], please verify if this was intentional or if “in” should be italicized and the reminder removed. *Complete.*
30. References, page 8-3: Galloway (1990) is listed twice and “annual” is misspelled in the first listing. Please review and either delete the possible duplication or correctly list as two references from the same author in the same year. *Complete.*
31. References, page 8-4: Galloway and others (2000) is listed twice. Please review and either delete the possible duplication or correctly list as two references from the same author in the same year. *Complete.*

32. References, page 8-5: Preston (2006) contains [Flag: italicize in], please verify if this was intentional or if "in" should be italicized and the reminder removed. *Complete.*
33. References, page 8-5: Renick (1926) and Renick (1936), please clarify if the same article was reprinted in 1936 or the author gave the same title to two different publications. *These references are correct*.
34. References, page 8-6: Please redo reference for Texas Water Development Board (2006) as the reference is actually Texas Water Development Board Report 365. See http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R365/AGCindex.htm
    Complete.

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