Final Report - Conceptualization of Groundwater in the Glen Rose Formation, Maverick Basin, Texas

Texas Water Development Board Report 2300012710-2

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Mr. Grisak supervised INTERA geologists/hydrogeologists involved in the report development, and prepared sections on published data of the groundwater aquifers in the Maverick Basin, the Texas groundwater Conservation Districts in the area, and general geologic setting. He also provided discussion on aquifer characterization methods and the proposed hydrogeologic conceptual model of the Maverick Basin aquifer and aquifer boundaries in Texas, including groundwater recharge conceptualization supported by the stable isotope data collected by the Texas Water Resources Institute (Rosario Sanchez) and James Harcourt and Royce Massey and the available on the Glen Rose Formation groundwater quality.

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1 Introduction

1.1 Discovery of the Maverick Basin aquifer

In November 2021, there was a press release from the Railroad Commission of Texas that brought attention to freshwater production from Glen Rose Formation wells in Maverick County (Railroad Commission of Texas, 2021b). Later presentations from the Railroad Commission of Texas detailed this release was in response to a series of oil-to-water well conversions that showed these oil wells would produce freshwater. Given the dearth of water resources in Maverick County, it was a significant discovery.

The information presented by the Railroad Commission of Texas showed that the wells were completed in the Glen Rose Formation of the Trinity Group in the southern Maverick Basin. The Maverick Basin is a hydrocarbon province in South Texas (Figure 1.1-1), and these anomalous wells were originally completed to produce oil.

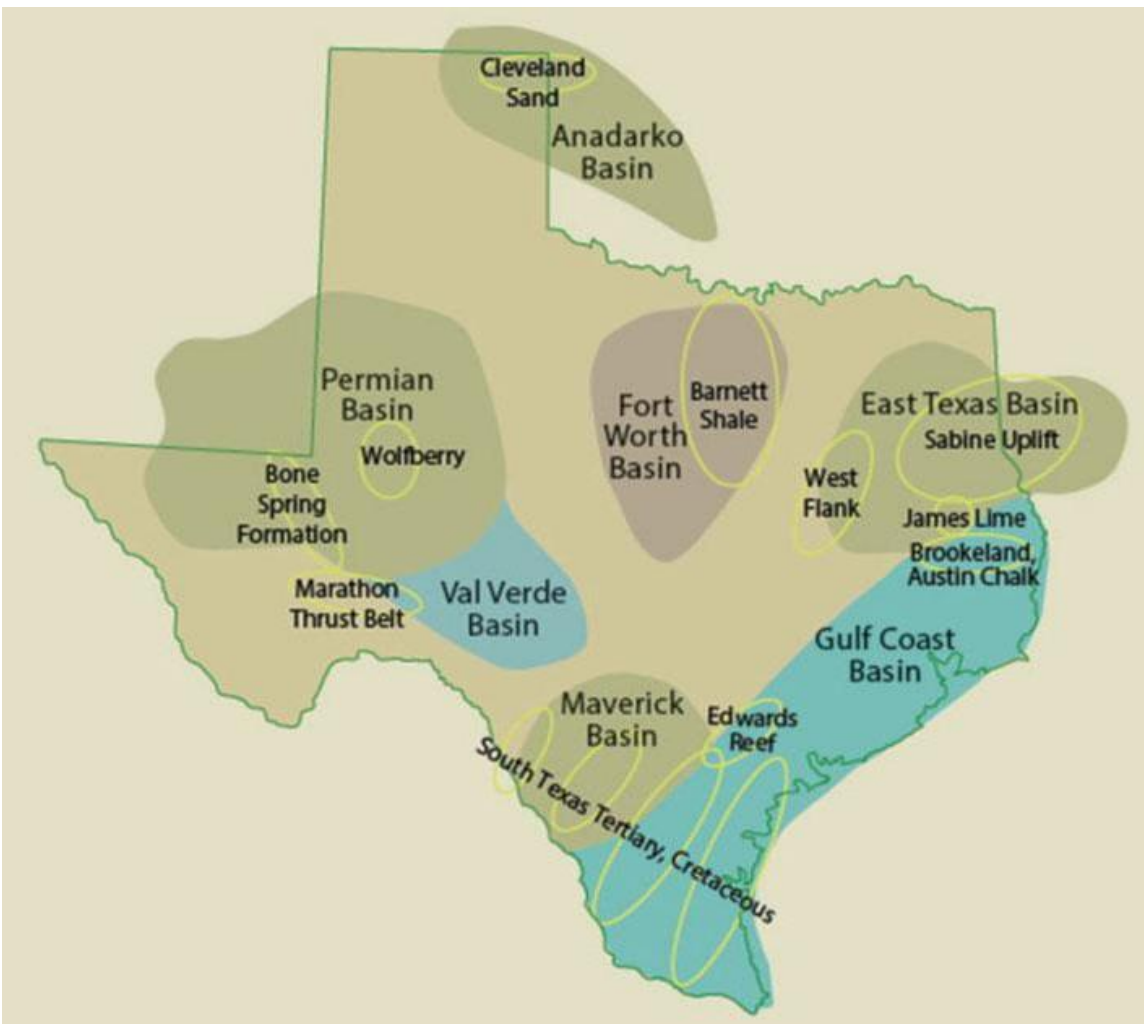

Figure 1.1-1. The Maverick Basin shown in relationship with other Texas basins (Brown, 2008).

However, upon completion in the early 2000s, the wells began to coproduce anomalously high volumes of water along with the oil, also known as a high water cut. The locations of the relevant permitted wells are shown in Figure 1.1-2. The P-13 wells are applications to convert from an oil well or dry hole to a water well, and the R-2 wells are where there is surface discharge of fresh to slightly saline produced water. Researchers also found the produced water ranged between 130- and 150-degrees Fahrenheit.

O'Brien (2002) showed initial wells were drilled by Saxet Petroleum based on a 3D seismic survey that gave indications of reef facies but when drilled, the rock was found to be reworked forereef facies that were hydrothermally altered by deep-seated fluids that created secondary porosity. An article from the Oil and Gas Journal (2002) shows low total dissolved solids water being produced (200 to 300 milligrams per liter total dissolved solids) and was researching possible uses for the water, including irrigation.

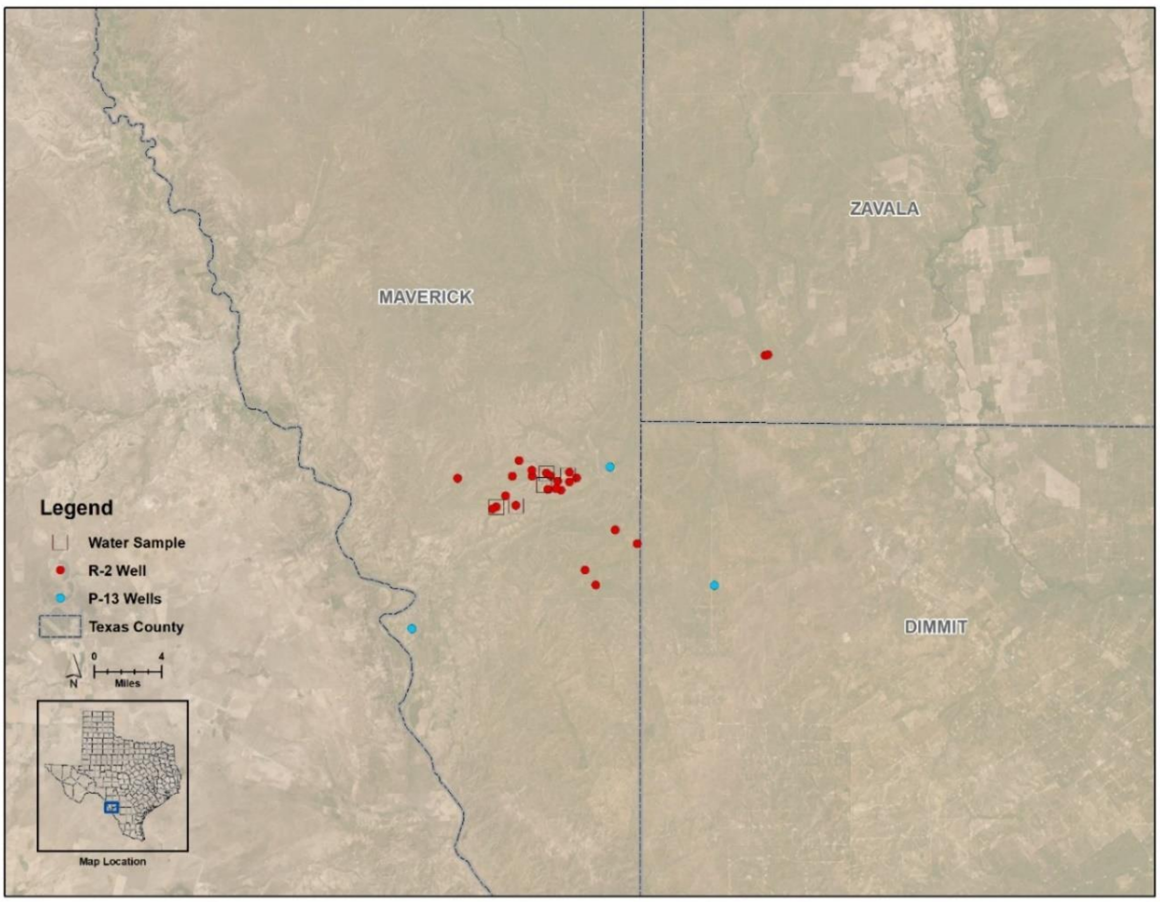

Figure 1.1-2. Location of relevant wells. R-2 wells are oil wells permitted to discharge to surface. P-13 wells are abandoned wells conditioned for water production.

The "Maverick Basin aquifer" was included in the Texas Water Development Board's brackish groundwater study of the Edwards-Trinity (Plateau) Aquifer, as the Glen Rose Formation is continuous from the Edwards-Trinity Plateau down into the Maverick Basin. Following this study and any associated future work, the Texas Water Development Board will consider whether the Maverick Basin aquifer should be designated as a new minor aquifer, incorporated into another official aquifer, or neither.

The Glen Rose Formation (also known as the Aurora Formation in Mexico) has been identified as a potential transboundary aquifer at depth in Sanchez and others (2018), referencing the Mexico National Water Commission (CONAGUA, 2015a, 2015b, 2015c). CONAGUA (2006, 2011, 2015a, 2015b, 2015c, 2015d, 2015e, 2015f, 2015g, 2015h) refers to secondary porosity due to fractures in the Aurora/Glen Rose Formation and report confining to semi-confining conditions.

Research and evaluation of the Glen Rose/Aurora Formation as a potential source of freshwater is being undertaken by the Texas Water Development Board, the Railroad Commission of Texas, the Texas Water Resources Institute, the Texas Bureau of Economic Geology, and CMR Energy LP.

1.2 Publications

The Railroad Commission of Texas' Groundwater Advisory Unit gave several presentations on the Maverick Basin aquifer, including for INTERA Incorporated in January 2022, for the Texas Water Development Board in September 2021, and for the American Groundwater Trust in 2022 (Railroad Commission of Texas, 2022a, 2022b, 2022c). In addition to the November 2021 press release, there was another article published by the Railroad Commission of Texas in June 2022 detailing a trip to sample groundwater from wells completed into the Glen Rose Formation (Railroad Commission of Texas, 2022d).

An interview with Natalie Ballew of the Texas Water Development Board discussing the Glen Rose Formation was released in Texas Water Development Board (2022). Larry French of the Texas Water Development Board also discussed the potential aquifer with the Texas Standard (Marks, 2022).

1.3 Available Data

1.3.1 Geophysical Well-logs

This study benefited from access to geophysical well logs as a result of the Maverick Basin aquifer being located within a hydrocarbon province. These well logs were interpreted to identify the top and base of the Glen Rose Formation as well as to allow determination of the various structural and stratigraphic components of the Glen Rose Formation. This is further discussed in Section 3.

1.3.2 Water Samples

Groundwater samples from a hypothesized recharge location in Mexico along with Glen Rose Formation oil wells in the Maverick Basin were utilized in this study. Reported analyses from these samples include hydrogen and oxygen isotopes, water quality parameters, and temperature data.

1.3.3 Outcrop Data

The Cretaceous deposits of southwest Texas, and the Glen Rose Formation in particular, have been the subject of much study, and there are numerous publications about the Cretaceous carbonates north of the Maverick Basin that provide context about the formation in the deep subsurface (Bebout and Loucks, 1977; Aconcha and others, 2008; Smith, 2013). These geologic studies are summarized in Section 2 Geologic Background.

1.3.4 Seismic Data

There has been extensive seismic exploration in the Maverick Basin. Some operators have provided seismic data to research consortiums for study. Aconcha and others (2008), Scott (2004), and Smith (2013) published seismic lines and cross sections detailing their interpretation of the structure and stratigraphy of the Glen Rose Formation.

1.3.5 Production Data

Oil, gas, and water production data from wells completed in the Glen Rose Formation has been made available to the study, allowing for the determination of water cuts from various geologic formations in the area of investigation. The relatively large number of wells available for interpretation helped to map the aerial and vertical extent of the water bearing portions of the geologic units.

1.4 Local Groundwater

1.4.1 Groundwater in Maverick, Dimmit, and Zavala counties

To the east in Zavala and Dimmit counties, groundwater demands are almost exclusively met by the Carrizo-Wilcox Aquifer, which is designated a major aquifer by the Texas Water Development Board (Figure 1.4-1). With the adequate availability of groundwater from the much shallower and better water quality Carrizo-Wilcox Aquifer throughout Zavala and Dimmit counties, utilizing the deeper Glen Rose Formation was not a consideration to individuals drilling groundwater supply wells.

Maverick, Zavala, and Dimmit counties are in Texas' Groundwater Management Area 13. Groundwater Management Areas are comprised of members from groundwater conservation districts within their boundaries and guide the protection and management of groundwater in their regions. Groundwater Management Areas determine desired future conditions for aquifers in their constituent groundwater conservation districts. Desired future conditions describe the desired condition of groundwater resources within a Groundwater Management Area in terms of quantifiable aquifer properties such as water levels, spring flows, or volumes. Zavala and Dimmit counties are subject to the rules and constraints of the Wintergarden Groundwater Conservation District. The Wintergarden Groundwater Conservation District's desired future conditions are zero drawdown throughout the entire Carrizo-Wilcox aquifer, recognizing that the desired future conditions are an average over the entire aquifer which covers numerous counties and extends to considerable depth (deeper than 2,000 – 3,000 feet in Zavala and Dimmit

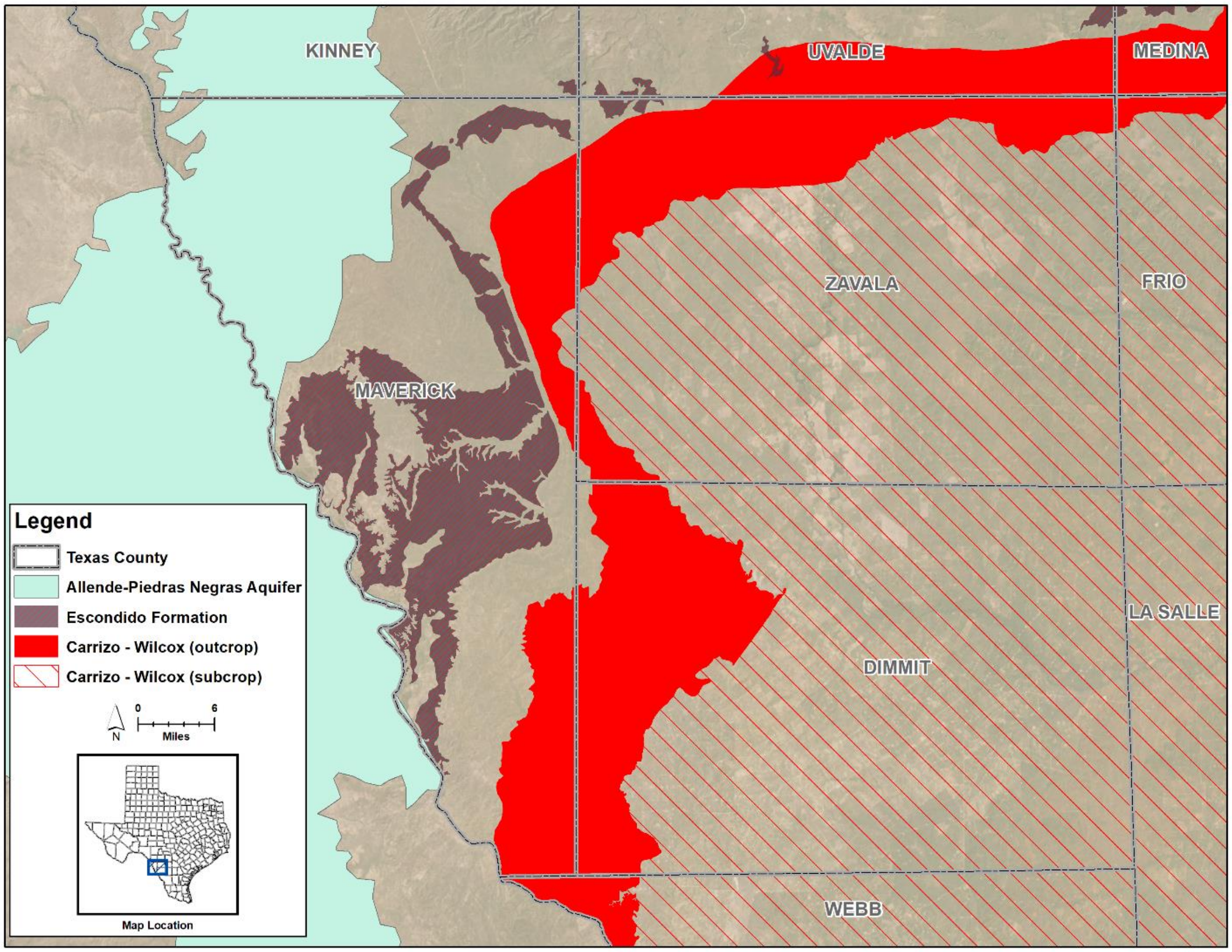

Figure 1.4-1. Local groundwater resources available to Maverick, Dimmit, and Zavala counties.

counties). Although geographically within Groundwater Management Area 13, Maverick County has no groundwater conservation district, and as such there are no groundwater use or production rules. Under the Rule of Capture, no permit is required for a landowner to drill a well, install a pump, and extract as much groundwater as can be beneficially used. Landowners may also sell the water for use at any location.

1.4.2 Allende Piedras-Negras Aquifer (Neogene-Recent Alluvium)

The Allende-Piedras Negras aquifer in Texas occurs north and west of Eagle Pass. The Texas portion is comprised of permeable recent to Quaternary alluvial deposits near the Rio Grande and is overlain to the east and north by the late Neogene/Pleistocene Uvalde gravel. The majority of the Allende-Piedras Negras Aquifer occurs in Coahuila, Mexico. It is comprised of Quaternary alluvial deposits and conglomerates, as mapped by the Servicio Geologico Mexicano (Servicio Geologico Mexicano, 2008a, 2008b). The Allende-Piedras Negras Aquifer and its potential recognition as a transboundary aquifer is discussed by Rodriquez and others (2020) and Sanchez and others (2018). Previous studies (as reported by Rodriquez and others, 2020) have focused discussion of the Allende-Piedras Negras Aquifer on the larger, central portion of the aquifer located in

Mexico. The Allende-Piedras Negras Aquifer is an unconfined alluvial system and is described by CONAGUA (2014) as highly permeable, with transmissivities more than 400 feet squared per day. The aquifer is relatively thin with a maximum thickness at 130 feet (Rodriquez and others, 2020). Total dissolved solids measurements from the Texas Water Development Board database for Allende-Piedras Negras Aquifer wells on the Texas side of the Rio Grande range from 650 to 1,500 milligrams per liter, indicating fresh to slightly brackish groundwater.

1.4.3 Escondido Formation (Cretaceous Sandstone)

The Cretaceous Escondido sandstone is an eastward-thickening gray/yellow sandstone situated near the top of the Navarro Group (see Figure 2.1-2) with thicknesses estimated between 50 and 100 feet based on submitted driller's reports from the Texas Water Development Board database. The same formation name is used in both Texas and Mexico. The Escondido is located at a depth of 100 to 200 feet below ground surface in eastern Maverick County. With water levels 50 feet below ground surface, the unit is assumed to be under confined conditions. Yields from a limited number of groundwater wells completed in the Escondido or other similar sands near the top of the Cretaceous range between about 5 to 20 gallons per minute. Water quality remarks noted in a few driller's logs are 'fresh' or 'good,' with two chemical analyses indicating total dissolved solids concentrations less than 1,000 milligrams per liter. The Escondido Formation is recognized as a minor groundwater source in Texas and Mexico, with marginally fresh or slightly saline, high sulfate water quality (Boghici, 2002).

1.4.4 Carrizo-Wilcox Aquifer (Paleogene Sandstones)

The Carrizo-Wilcox Aquifer is designated as a major aquifer by the Texas Water Development Board. It outcrops in a north-trending belt extending from the Rio Grande River at the southern end of Maverick County, along the western Dimmit and Zavala County boundaries to approximately the Uvalde County line at the northern end of the eastern border of Maverick County (Figure 1.4-1). The Carrizo-Wilcox Aquifer supplies water to wells throughout the Wintergarden Groundwater Conservation District. The primary uses of the groundwater within the Wintergarden Groundwater Conservation District are for irrigation, municipal use, and oil and gas activities. Water wells in Zavala and Dimmit counties generally target the Carrizo sand which is the upper transmissive section of the Carrizo-Wilcox Aquifer. The Carrizo-Wilcox Aquifer is unconfined in outcrop areas along the Maverick, Zavala, and Dimmit County lines and confined further downdip to the east and southeast. Transmissivities of the Carrizo-Wilcox Aquifer are geographically variable across Texas and intraformational, but are generally high (Mace and Smyth, 2003). Water quality is generally fresh (<1,000 milligrams per liter total dissolved solids) in the outcrop areas with brackish concentrations further downgradient to the east.

1.5 Local Groundwater Regulators and Needs

1.5.1 Local Water Regulators

Maverick, Dimmit, and Zavala counties are in Groundwater Management Area 13 and include the Carrizo-Wilcox, Sparta-Queen City, and Yegua-Jackson Aquifers. Current desired future conditions for each of these aquifers are designed to consider drawdowns in water level for each aquifer through 2080. Maverick County has no groundwater conservation district, but Dimmit and Zavala are in Wintergarden Groundwater Conservation District.

1.5.2 Local Water Needs

Maverick County is in Regional Water Planning Group Region M, and Dimmit and Zavala counties are in Region L. These Water Planning Groups publish regional water plans detailing future water supplies and needs in excess of supplies. Table 1.5-1 shows water needs for Maverick, Dimmit, and Zavala counties exceed 18,000, 9,473, and 21,235 acre-feet per year, respectively. Water needed for irrigation is the greatest need in each of these regions.

Table 1.5-1. Water needs in excess of water supplies for the relevant counties.

County	2020	2030	2040	2050	2060	2070
Maverick	18,686	17,630	17,041	15,750	14,477	13,514
Dimmit	9,473	9,561	8,901	7,393	5,888	5,330
Zavala	21,235	21,350	21,209	20,733	20,148	19,865

Note: Units are listed by acre-feet per year.
Source: Black and Veatch (2020a, 2020b)

The nearest municipality to the Maverick Basin aquifer is Eagle Pass in Maverick County. An article from the Railroad Commission of Texas in June 2022 indicates Eagle Pass Water Works would like to use this water resource for future water needs (Railroad Commission of Texas, 2022d).

2 Geologic Background

2.1 Introduction

The Maverick Basin is a Cretaceous intra-shelf basin overlying an earlier Mesozoic rift feature (Figure 2.1-1). It is bounded by the San Marcos arch to the northeast and the Mexican uplifts to the southwest (Ewing, 2016). The basin was formed by differential subsidence beginning in the mid-Albian stage. Middle and Upper-Cretaceous units are relatively thin and shallow over the San Marcos arch and thicken and deepen into the Maverick Basin. (Figure 2.1-2). In the Jurassic and early Cretaceous Periods, the basin was dominantly clastic, then transitioned to carbonate deposits until the Late Cretaceous Period, where it was again dominated by clastic deposition (Scott, 2004).

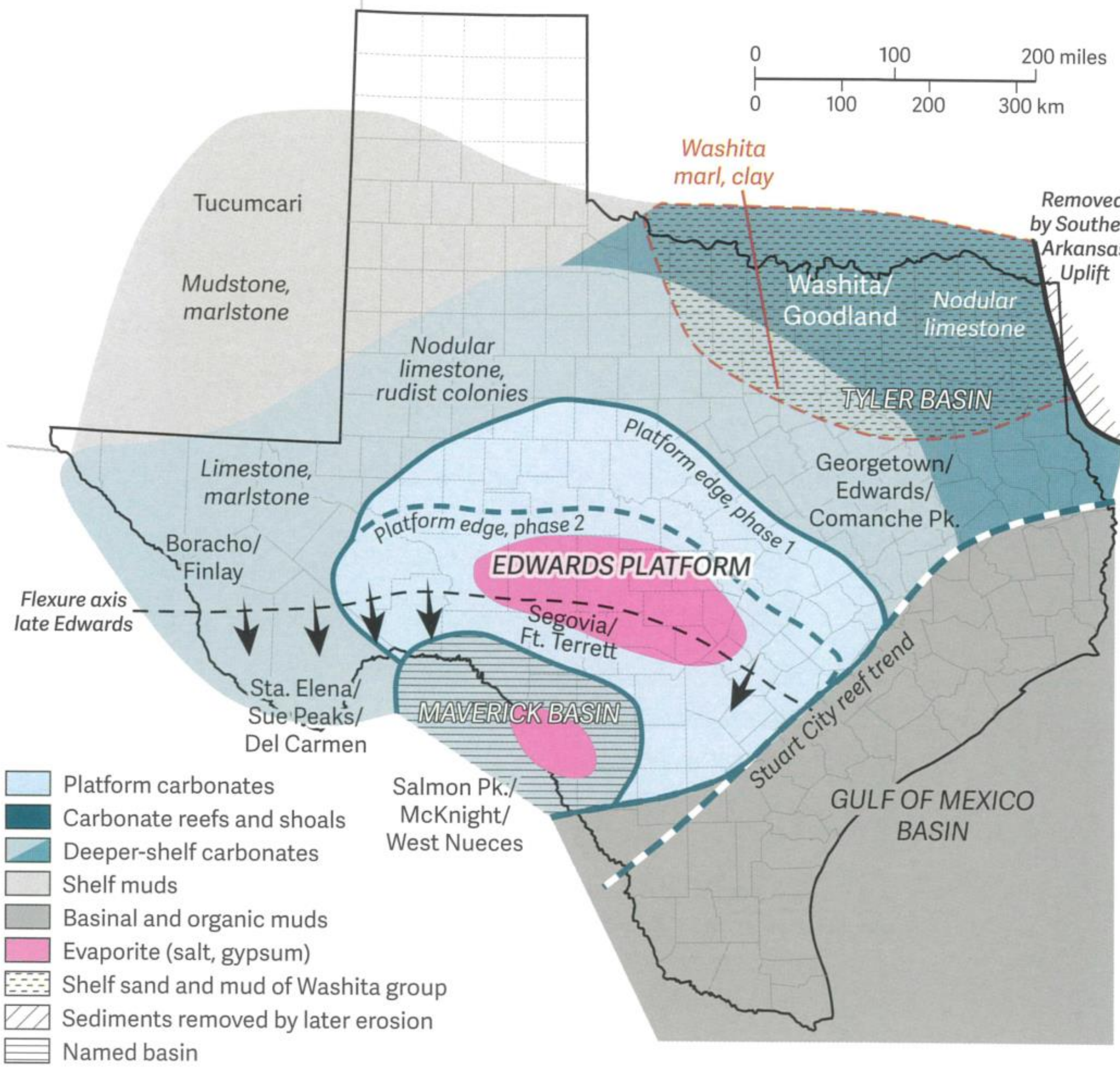

Figure 2.1-1. Overview of the Maverick Basin and Edwards Platform during the Middle Albian (Ewing, 2016).

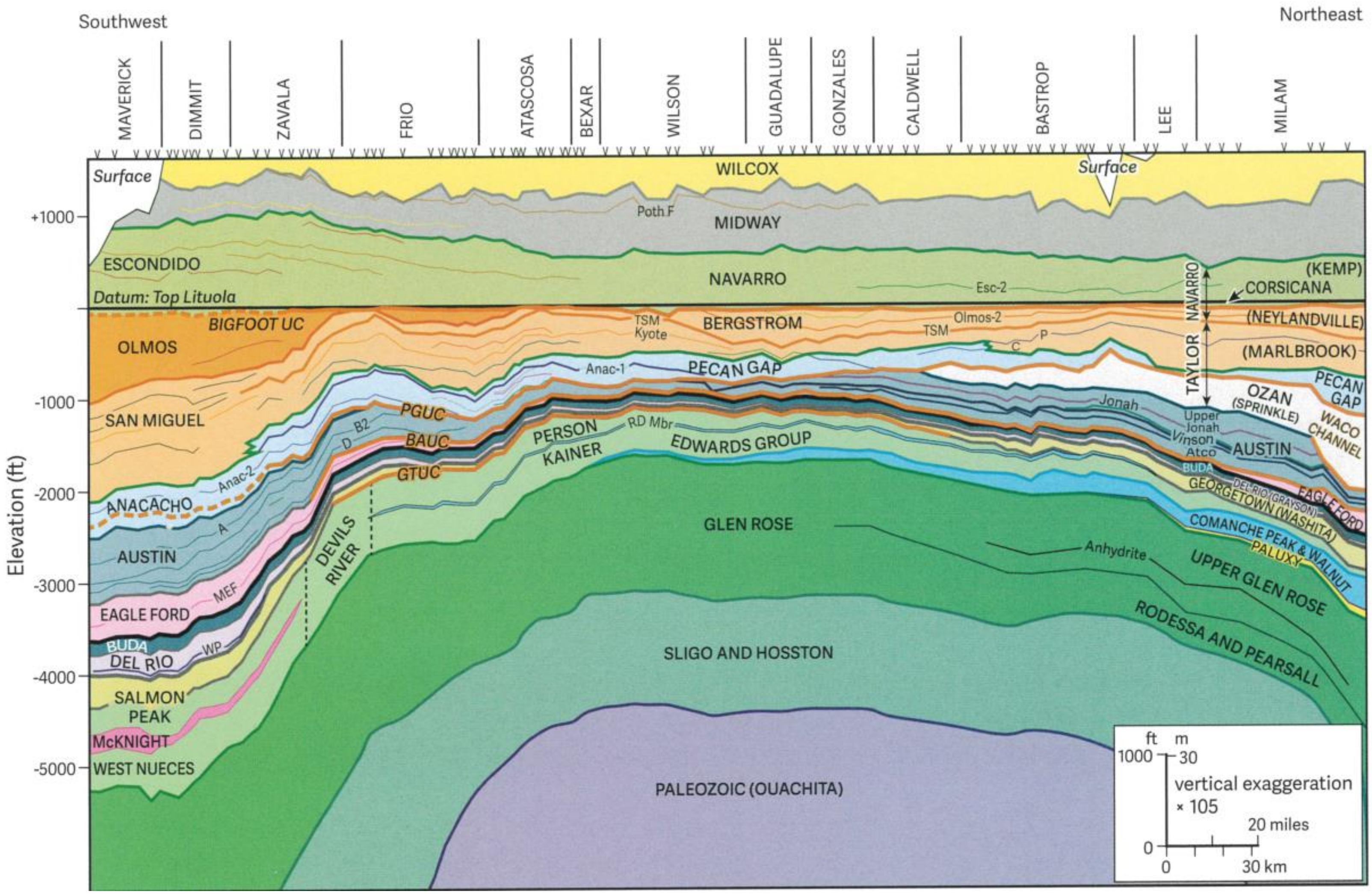

Figure 2.1-2. Cross section of the San Marcos Arch; vertical datum on base of Escondido or middle Navarro. This stratigraphic section highlights the thickening of units in the Maverick Basin, and the timing of the thickening from West Nueces to Olmos deposition (Ewing, 2016).

2.2 Geologic History

2.2.1 Paleozoic

The orientation of dominant structures in South Texas was initially set by Paleozoic and earliest Mesozoic Era events. The Ouachita Orogen (Ouachita front depicted in Figure 2.2-1) marks the closure in the late Paleozoic Era of a deep, possibly oceanic basin that once rimmed the southern margin of the Precambrian craton of North America, now exposed in the Ouachita Mountains in Oklahoma and the Marathon Uplift and Solitario domes in the Trans-Pecos region of Texas. The Paleozoic basinal strata were thrust northwestward over the Precambrian craton, forming a “frontal thrust belt.” This thrust belt covers most of the southern United States. Little is known about the Paleozoic rocks underlying the Maverick Basin (Ewing, 2016).

2.2.2 Mesozoic

Within the Maverick Basin, depositional timing is categorized into the Chittim Rift, Pre-Maverick Basin, Syn-Maverick Basin, and Post-Maverick Basin. This separation guides the dominant accommodation space creation mechanism associated with each sediment package deposited.

Chittim Rift

Coarse clastic “redbed” strata are known or inferred to overlie the deformed Paleozoic Ouachita rocks over a large area of South Texas. A specific section of these redbed strata were deposited within the "Chittim rift" (Figure 2.2-1), a northwest-trending graben or half-graben complex formed during Triassic-Jurassic rifting, which is overlain by a thick Mesozoic section in Maverick County (Scott, 2004), as shown in Figure 2.2-2. Faults of the Chittim Rift were later reactivated by Paleogene (Laramide) compression to form the broad Chittim Anticline (Figure 2.2-2). The Chittim Anticline predates the Maverick Basin, which encompasses a greater area, including the entire Chittim Rift. On the seismic line presented in Figure 2.2-2, the fill of the half-graben exceeds 500 milliseconds (approximately 3,500 feet) in thickness. Scott (2004) recounts that the Blue Star Taylor, a 22,400-foot stratigraphic test well, encountered reddish sands, shales, and anhydrites resting on a metamorphic basement. This Chittim rift is associated with other northwest-trending grabens in Mexico, which are hypothesized to contain Triassic and Lower Jurassic Rocks. These grabens may be related to crustal extension that occurred behind a Mesozoic volcanic arc located on the Pacific side of Mexico (Figure 2.2-3) (Pindall and Kennan, 2009). The Chittim Rift was filled by the beginning of the Cretaceous, and there is no expression of the Maverick Basin, as defined by the thickening of stratigraphic units, until partway through the Albian Stage, when Maverick Basin associated subsidence increases (Ewing, 2016).

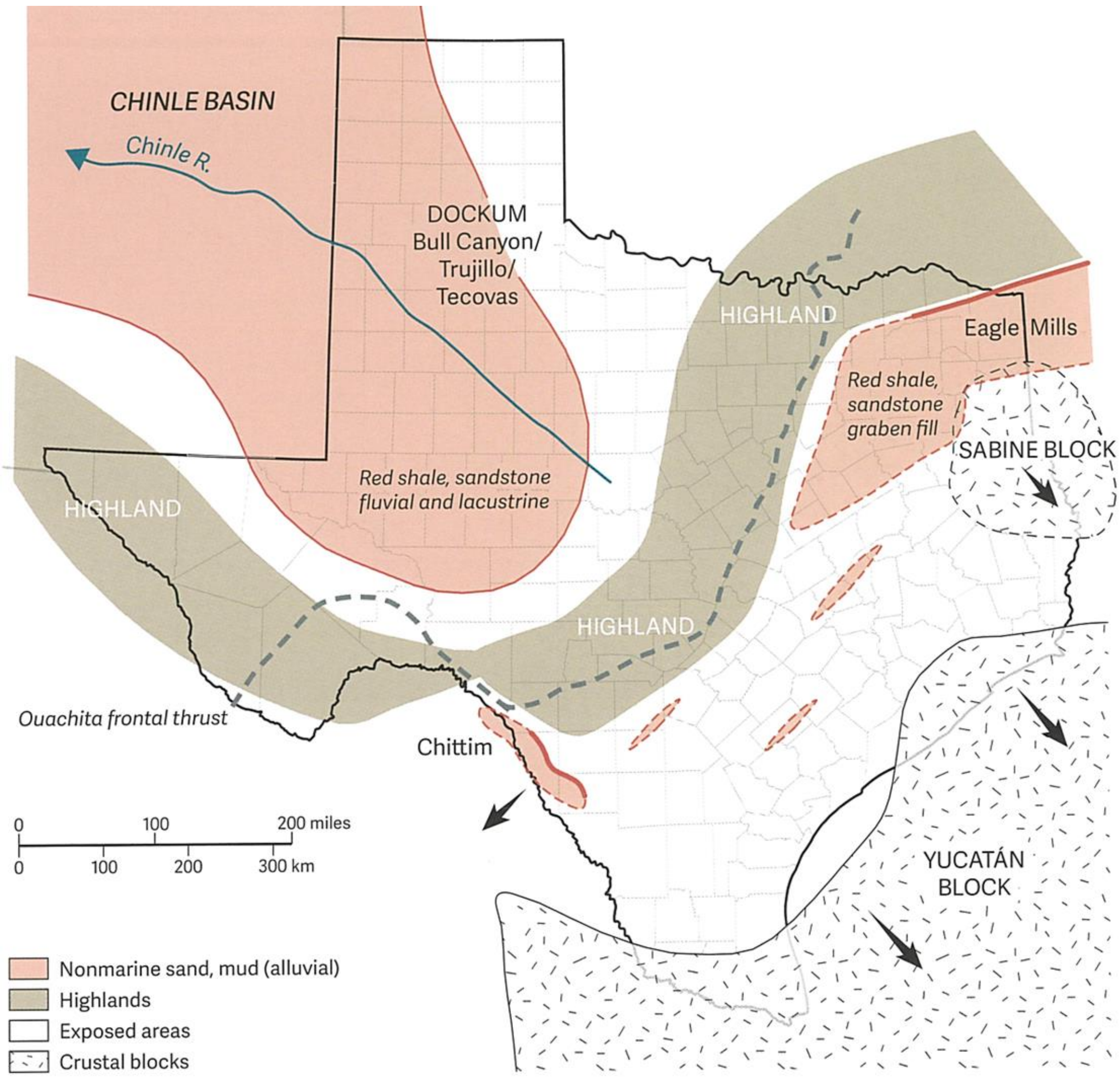

Figure 2.2-1. Texas in the Late Triassic, showing the Chittim Rift and directions of extension. The Ouachita frontal thrust is labeled to the west of the Texas-Mexico Border and is approximated by the Highland area. (Ewing, 2016, modified from Scott, 2004).

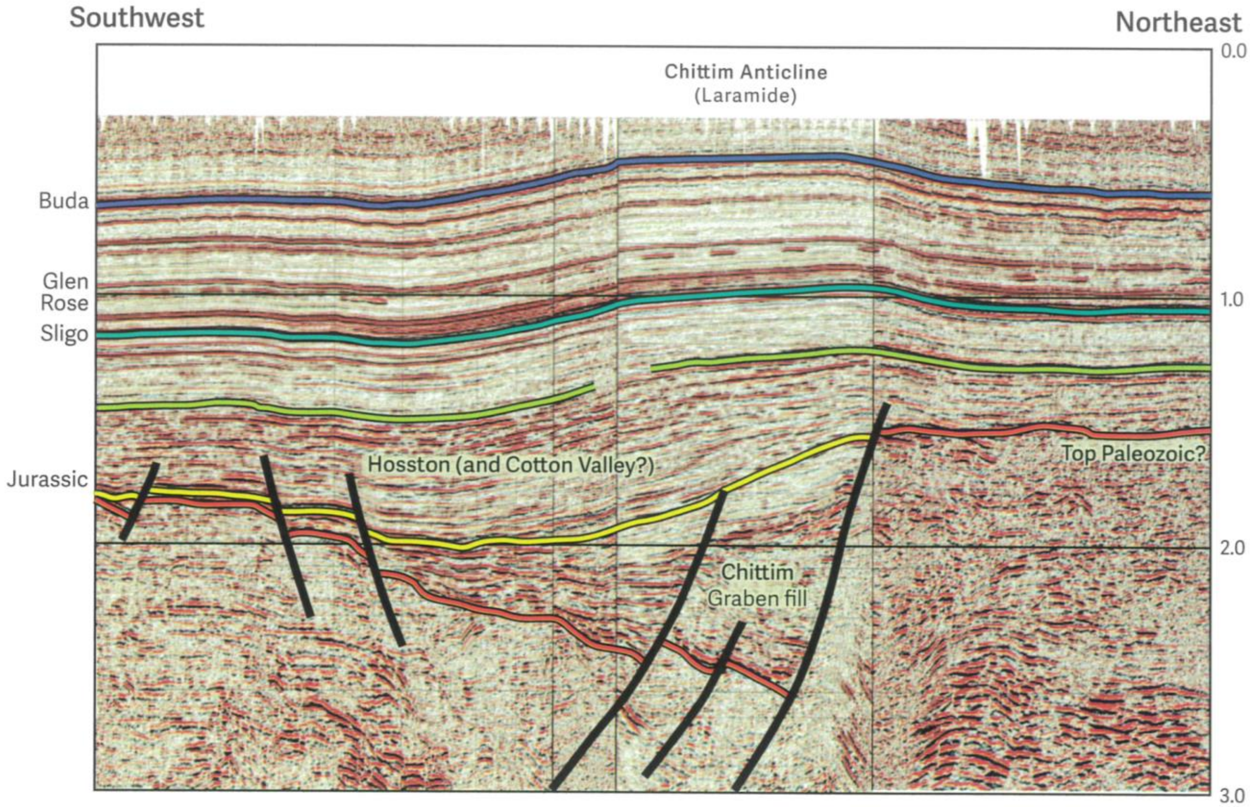

Figure 2.2-2. Seismic line from within the Maverick Basin showing the Chittim Rift, a feature that predates the development of the basin. (Ewing 2016, modified from Scott 2004)

Pre-Maverick Basin

The pre-Maverick Basin grouping includes Cotton Valley through lower Edwards Group strata (Figure 2.2-4). The upper part of this set of strata comprises the Trinity Group and lower Edwards Group of the Edwards-Trinity (Plateau) Aquifer (George and others, 2011). The Glen Rose Formation is part of the Trinity Group.

The Cotton Valley Group is an Upper Jurassic-Lower Cretaceous sandstone that was deposited over the filled Chittim Rift (Figure 2.2-5). The overlying Hosston Formation is the lowest unit in the Trinity Group and was deposited in the study area as non-marine sands (Figure 2.2-6). Following the deposition of the Hosston Formation sandstones, the rest of the Cretaceous units deposited in the Maverick Basin were predominantly carbonate in origin (Ewing, 2016). Clastic sediment delivery to the Gulf of Mexico basin waned in the Aptian Stage, and the carbonates that previously developed downdip of the Hosston Formation transgressed across the entire Gulf of Mexico Shelf (Ewing, 2016). These carbonate environments were assisted by a global sea level rise and a paucity of clastic deposition, making the ideal conditions for significant carbonate deposition and buildup. The first carbonate unit following the deposition of the Hosston Formation is the Sligo Formation (Figure 2.2-4, Figure 2.2-7).

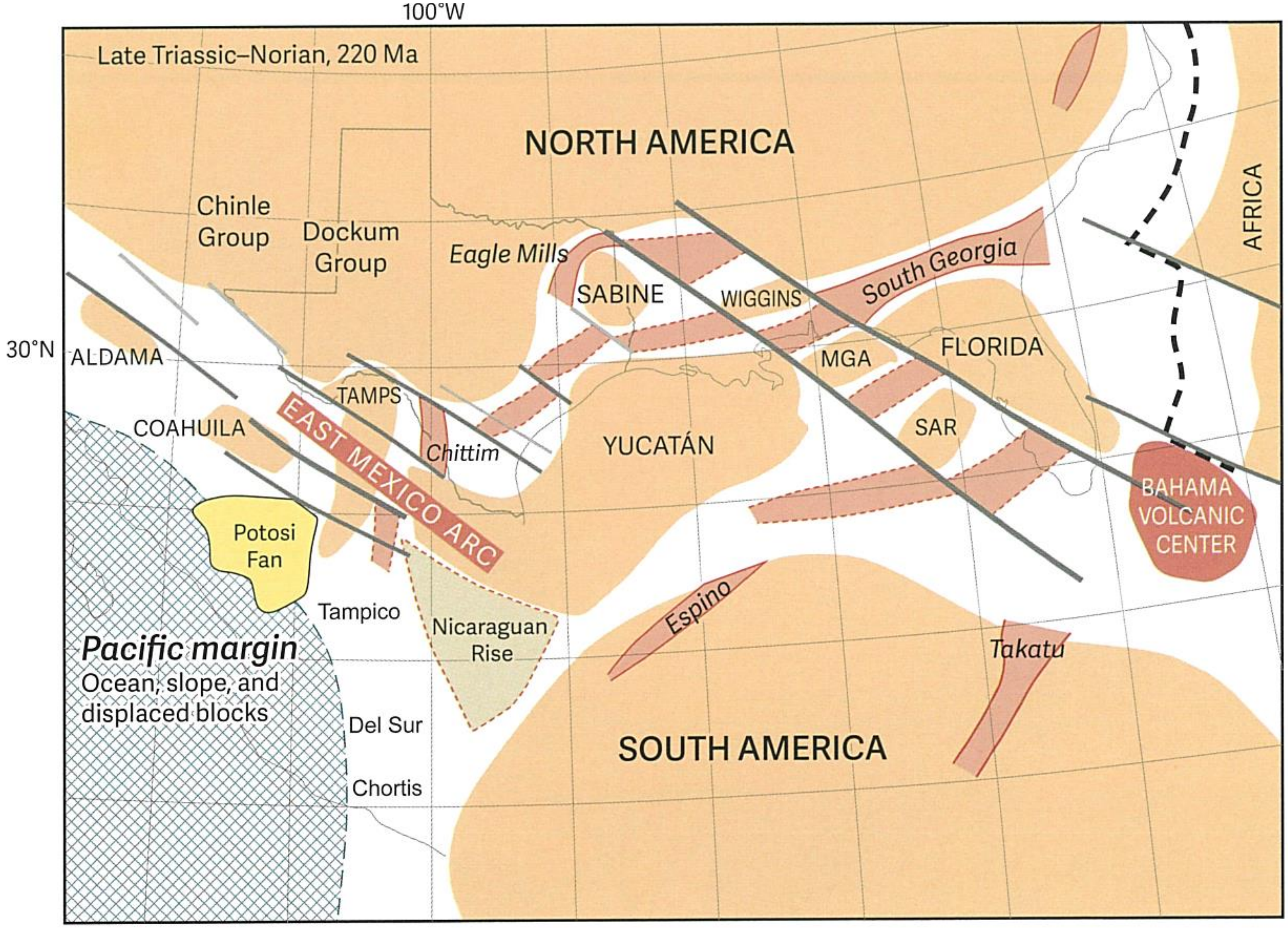

Figure 2.2-3. **Chittim rift is shown against the rifts and blocks associated with the opening of the Gulf of Mexico. TAMPS = Tamaulipas Peninsula. MGA = middle ground arch block. SAR = Sarasota high block. The dashed black line is the location of the initial ocean crust in the Central Atlantic (Ewing, 2016, after Pindell and Kennan, 2009).**

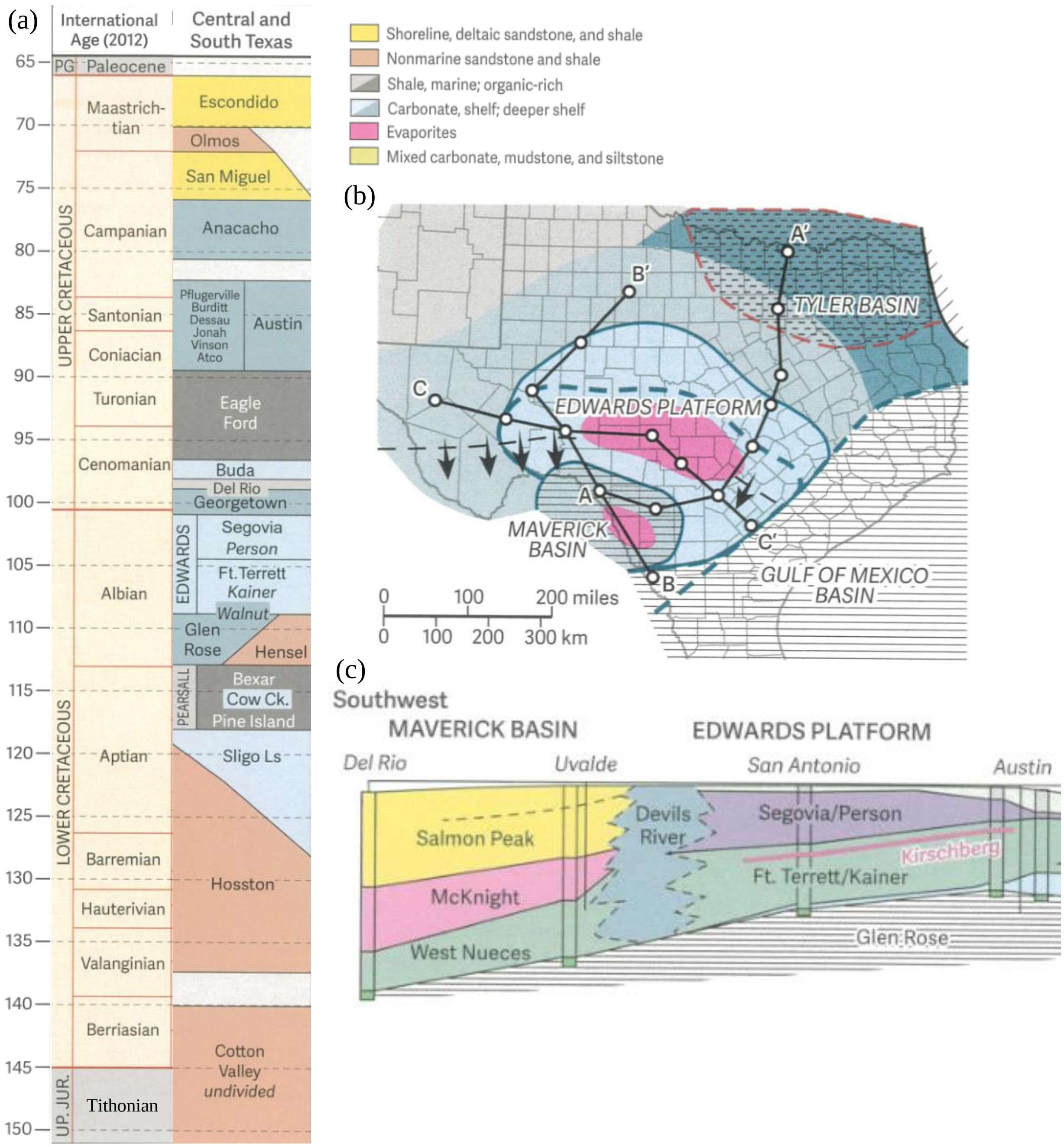

Figure 2.2-4. **(a) Stratigraphic Column for the Cretaceous in Central Texas. (b) Basemap for Cross Section A-A' in c. (c) stratigraphic section depicting Edwards Group stratigraphy in the Maverick Basin versus the rest of the Edwards Platform. (Ewing, 2016)**

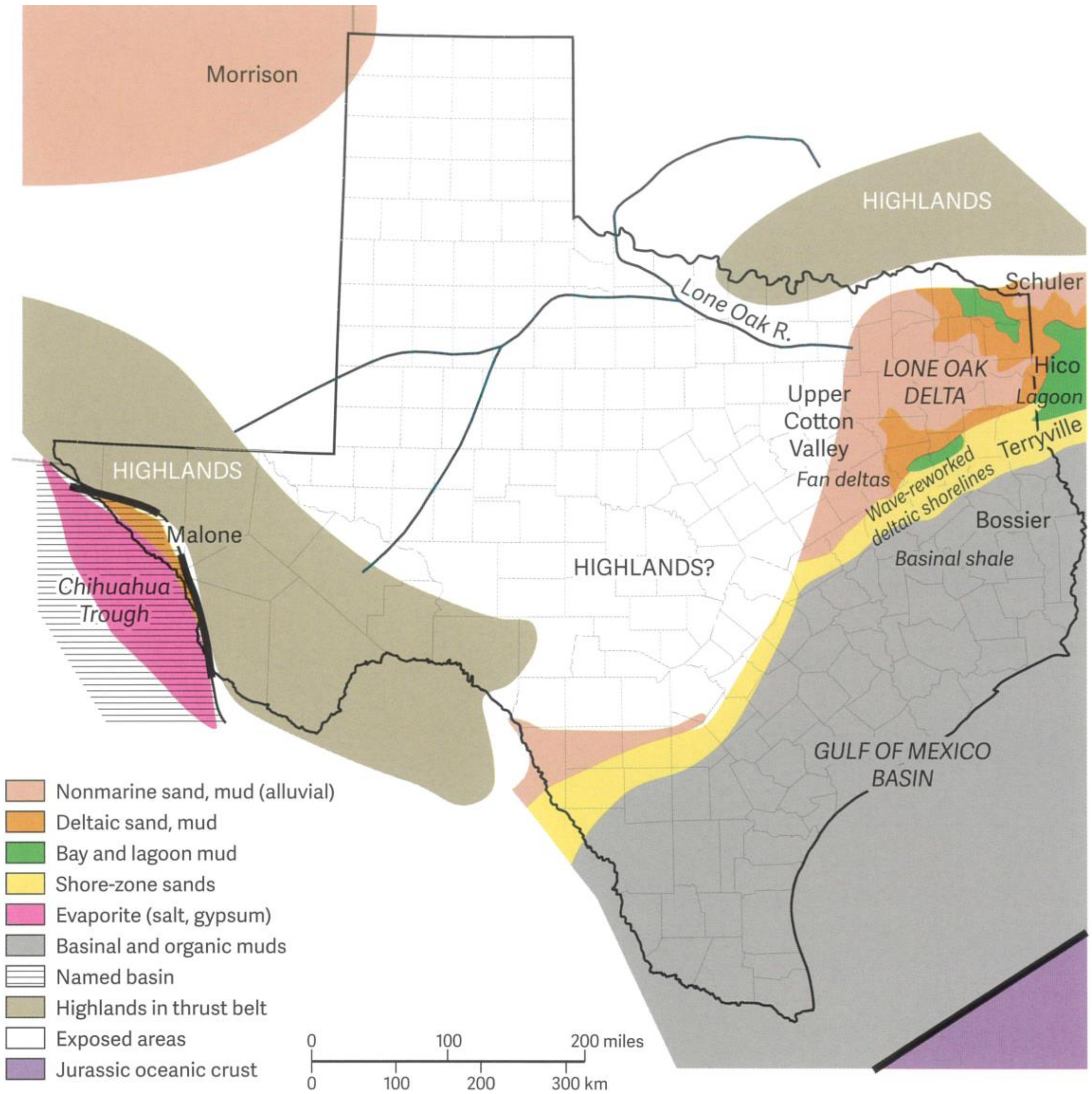

Figure 2.2-5. **Tithonian Stage (Late Jurassic) environments and rocks; Cotton Valley Group and equivalents (Ewing, 2016).**

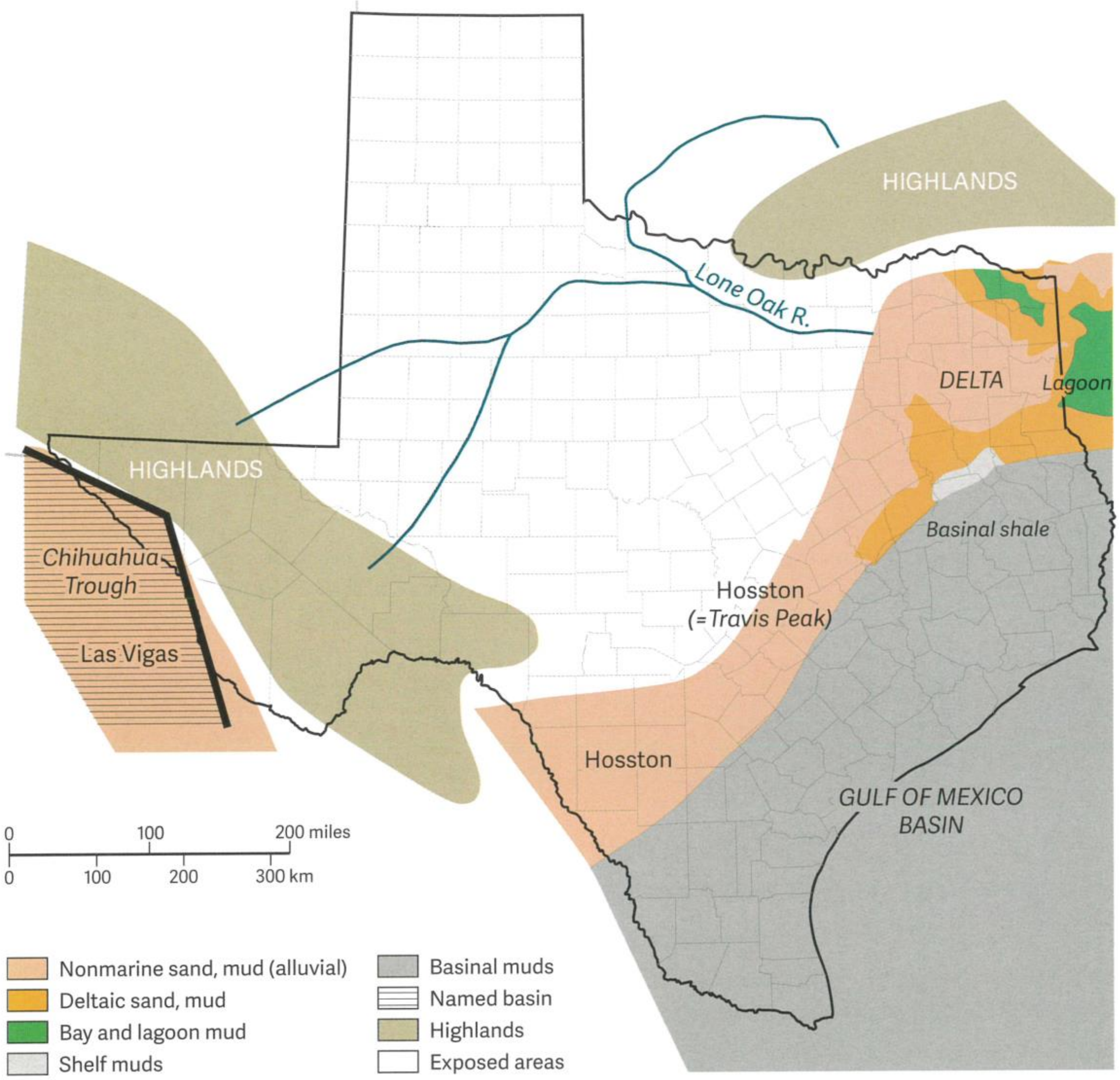

Figure 2.2-6. Barremian (Early Cretaceous-Coahulian Stage) environments and rocks; Hosston Formation and equivalents (Ewing, 2016).

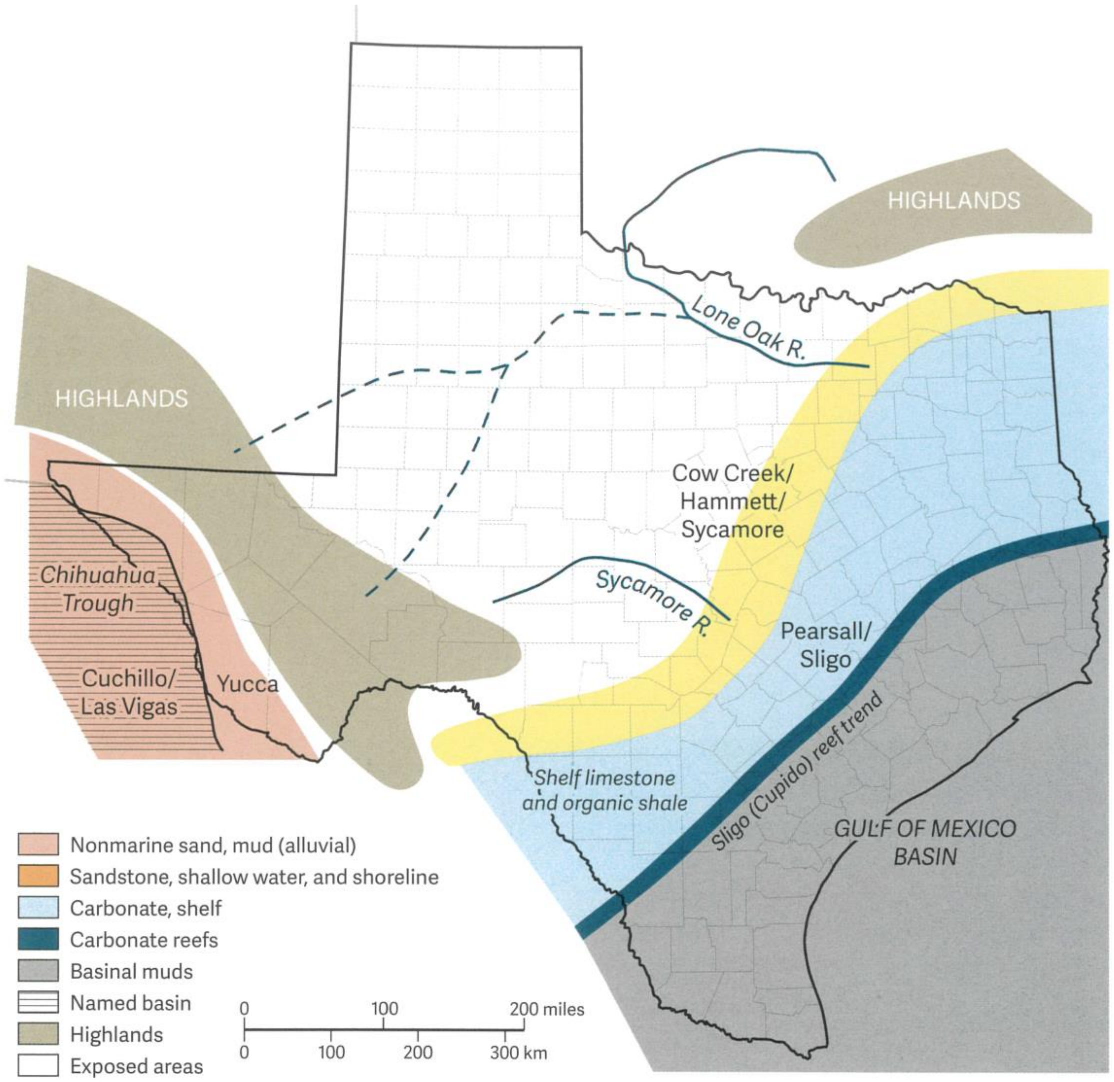

Figure 2.2-7. Aptian Stage environments and rocks; Sligo Formation and equivalents (Ewing, 2016).

Deposition of the Sligo Formation preceded a sea-level fall, then a sea-level rise accompanied by an ocean anoxic event, which allowed for the deposition of an organic-rich group called the Pearsall Formation. There are three organic shale-dominated members, the Pearsall Shale, the Cow Creek Limestone, and the Bexar Shale. Environmental changes shifted the depositional scheme back to carbonate and subsequently resulted in the deposition of the Glen Rose Formation. Carbonate deposition dominated with a full reef margin in the Edwards Group during the Albian Stage (Phelps, 2011).

The Glen Rose Formation represents a fresh to slightly saline groundwater reservoir in Maverick County (Railroad Commission of Texas, 2021a). Within the study area, the Glen Rose Formation consists of shelf carbonates with occurrences of patch reefs from Maverick County into central Texas (Scott, 2004). At the time of Glen Rose Formation deposition, there was only minor relief within the Maverick Basin (Figure 2.2-8) (Scott, 2004).

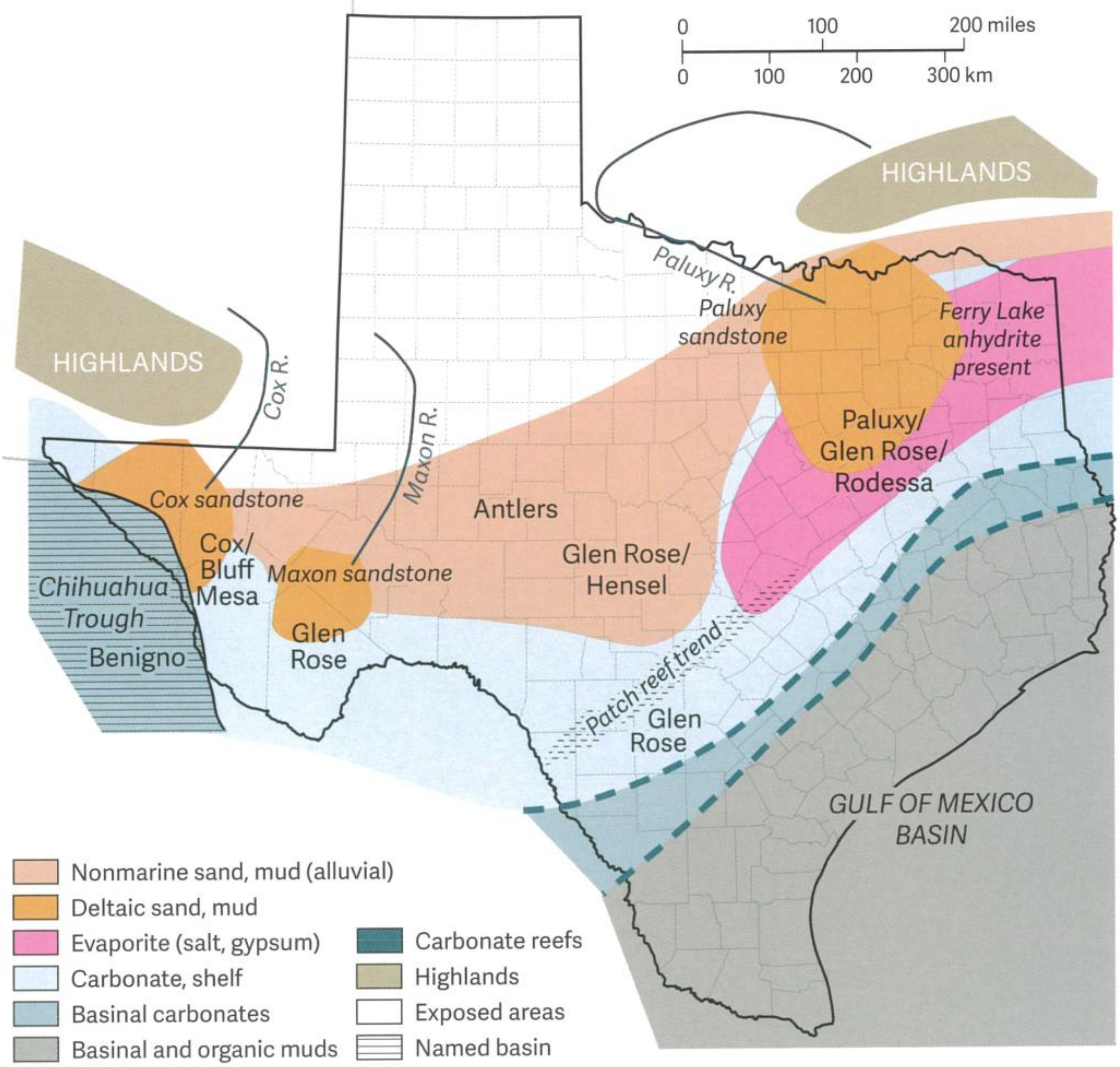

Figure 2.2-8. Early Albian Stage environments and rocks (Ewing, 2016).

Syn-Maverick Basin

This grouping includes the Edwards Group to the Escondido Formation. The Edwards Group comprises the upper Edwards-Trinity (Plateau) Aquifer (Figure 2.2-4) (George and others, 2011). These units have not been found to contain fresh water at depth in the Maverick Basin and are only used in this study to inform on structural trends.

Following Glen Rose Formation deposition, the lower Edwards Group was widely deposited throughout Texas. In the Maverick Basin, the West Nueces and the McKnight Evaporite are equivalent to the Edwards (Figure 2.2-4) (Ewing, 2016). The McKnight is a distinctive evaporite unit found only in the Maverick Basin. These units are the first deposits above the Glen Rose Formation, however there is no evidence that they are targets for groundwater development.

As the McKnight period progressed, there was greater subsidence in the basin, causing the geologic units to thicken. Simultaneously, the San Marcos Arch uplifted as a forebulge in response to the rapid subsidence of the Maverick Basin (Ewing, 2016; Phelps, 2011).

2.2.3 Late Cretaceous - Cenozoic

Post-Maverick Basin

This grouping includes the Paleogene Midway Formation, the Paleocene to Eocene Wilcox Group, the middle-Eocene Carrizo Sand through the most recent Eocene sedimentary units in the Maverick Basin (George and others, 2011) (see Figure 2.2-4).

During this period, the Laramide Orogeny was the most influential structural event, inducing compression directed from the west-southwest into the study area. As a result, the Chittim Anticline, Zavala Syncline, and other related folds were formed, which are visible in outcrop and impact units as young as late Eocene (Figure 2.2-9).

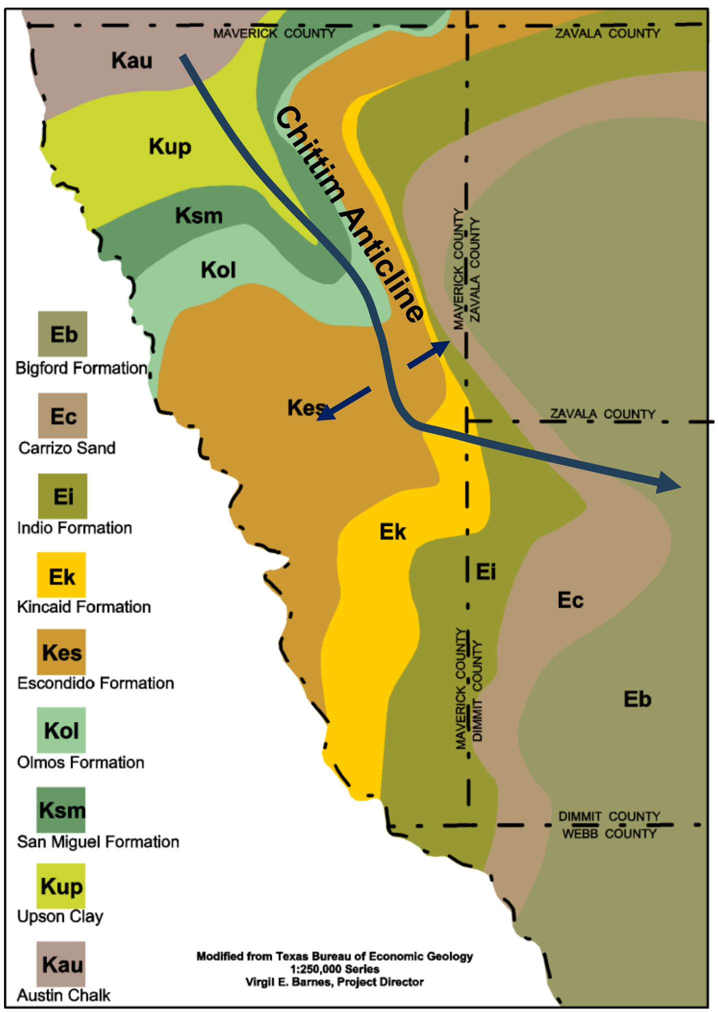

Figure 2.2-9. Surface geology of the Chittim Anticline. Modified (Scott, 2004).

2.3 Reservoir Characteristics

2.3.1 Seismic Expression

The Maverick Basin aquifer has been seismically imaged, with some of these images being made publicly available. The best examples are from Scott (2004) and Smith (2013), shown in Figures 2.3-1 through 2.3-5. Since the seismic data was based on a 3D volume, both cross section views and time slices (map views) are provided. This data is excellent for examining the nature and distribution of the porosity networks that influence groundwater production trends.

Figure 2.3-1 shows line 1612 from Smith (2013). Annotations show the locations of seismic anomalies within the Glen Rose Formation that were targeted for oil exploration. One anomaly, outlined in white and intersected by a vertical line, indicates the location of seismic line A-A' from Scott (2004), shown in Figure 2.3-2.

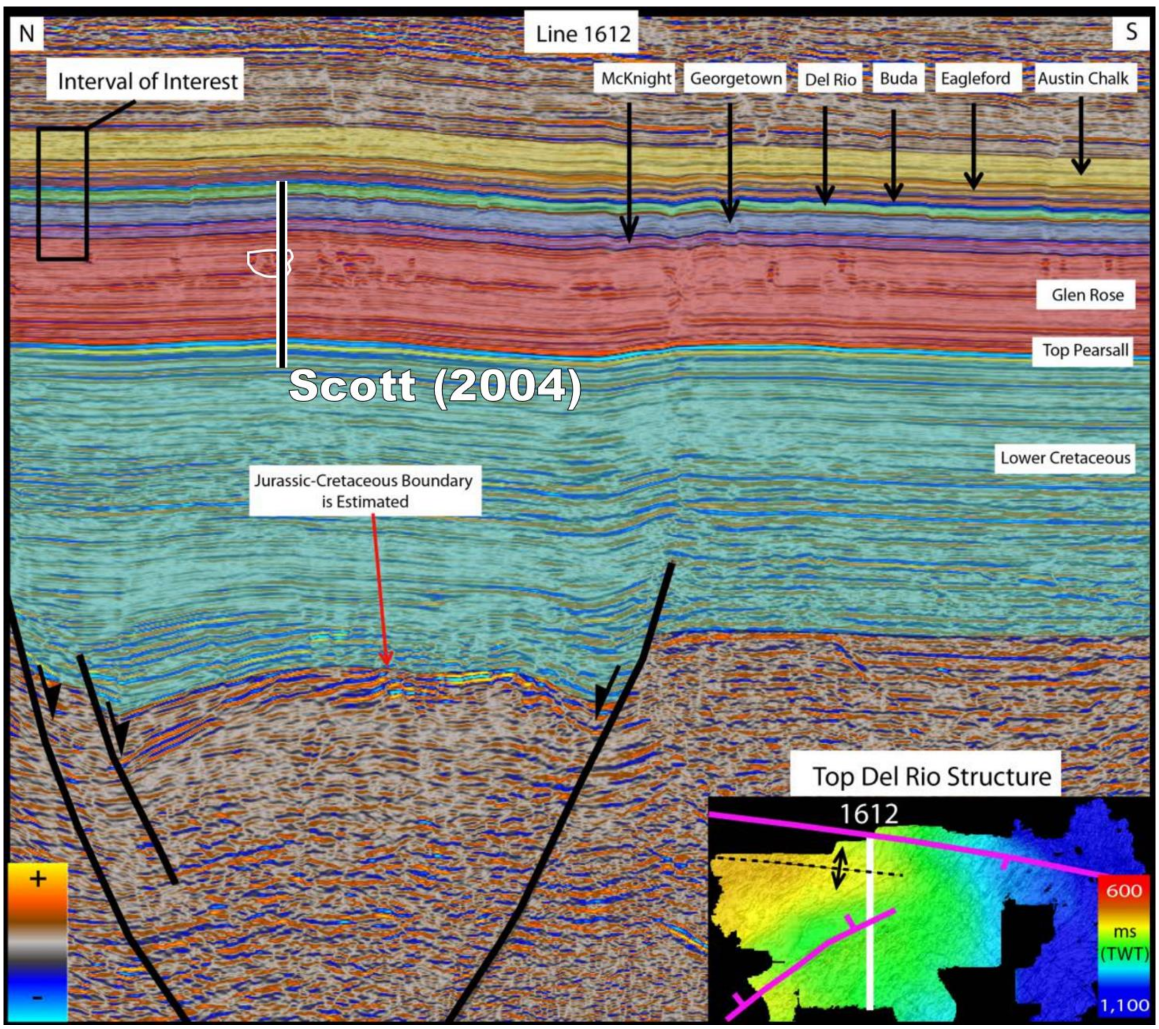

Figure 2.3-1. Line 1612 from Smith (2013). White outline shows the seismic anomaly imaged on Section A-A' from Scott (2004) shown in Figure 2.3-2.

The seismic anomalies detailed in Figure 2.3-2 occur as deviations from the background characteristics of the Glen Rose Formation reflectors and are common in a zone in the upper Glen Rose Formation. Typically, there are bright, continuous reflectors in the bottom and middle of the Glen Rose Formation, with mostly transparent reflectors (indicating homogeneity) comprising the rest of the seismic volume. The deviations from this background character manifest as small clusters of bright reflectors against the transparent background, or transparent reflectors against the middle bright, continuous reflectors, indicating differences in the character of the rock.

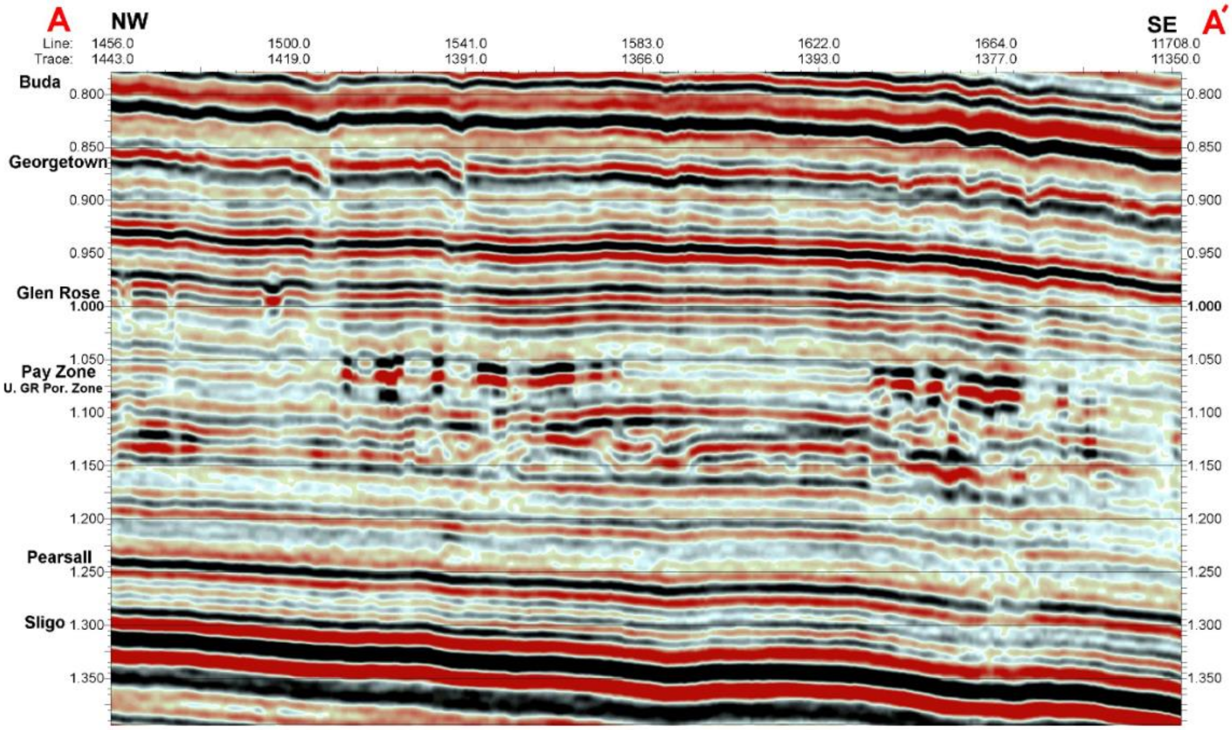

Figure 2.3-2. Seismic section A-A'. X-axis is line and trace. Y-axis is in time. The porosity anomaly manifests as mounded and bright reflectors against a series of transparent and otherwise non-mounded reflectors. Geologic formations are named on the left of the section (Scott, 2004).

Figure 2.3-3 shows a basemap with the location of seismic section 1612, along with an azimuth attribute extraction slice on top of the Del Rio Formation (after Smith, 2013). The northern oblique-normal fault shown in the georeferenced Smith (2013) figure was reactivated during the Laramide Orogeny. The reactivation of the faults resulted in the deformation of the overlying units (at least through the upper Cretaceous), including fracturing of the more competent rock. The intensity of deformation highlighted at the top of the Del Rio seismic slice (Figure 2.3-3) serves as a good proxy to identify locations that may have more deformation across all units.

Figure 2.3-4 shows the locations of the N-S line 1612 from Smith (2013) (Figure 2.3-1) and the shorter NW-SE section from Scott (2004) (Figure 2.3-2).

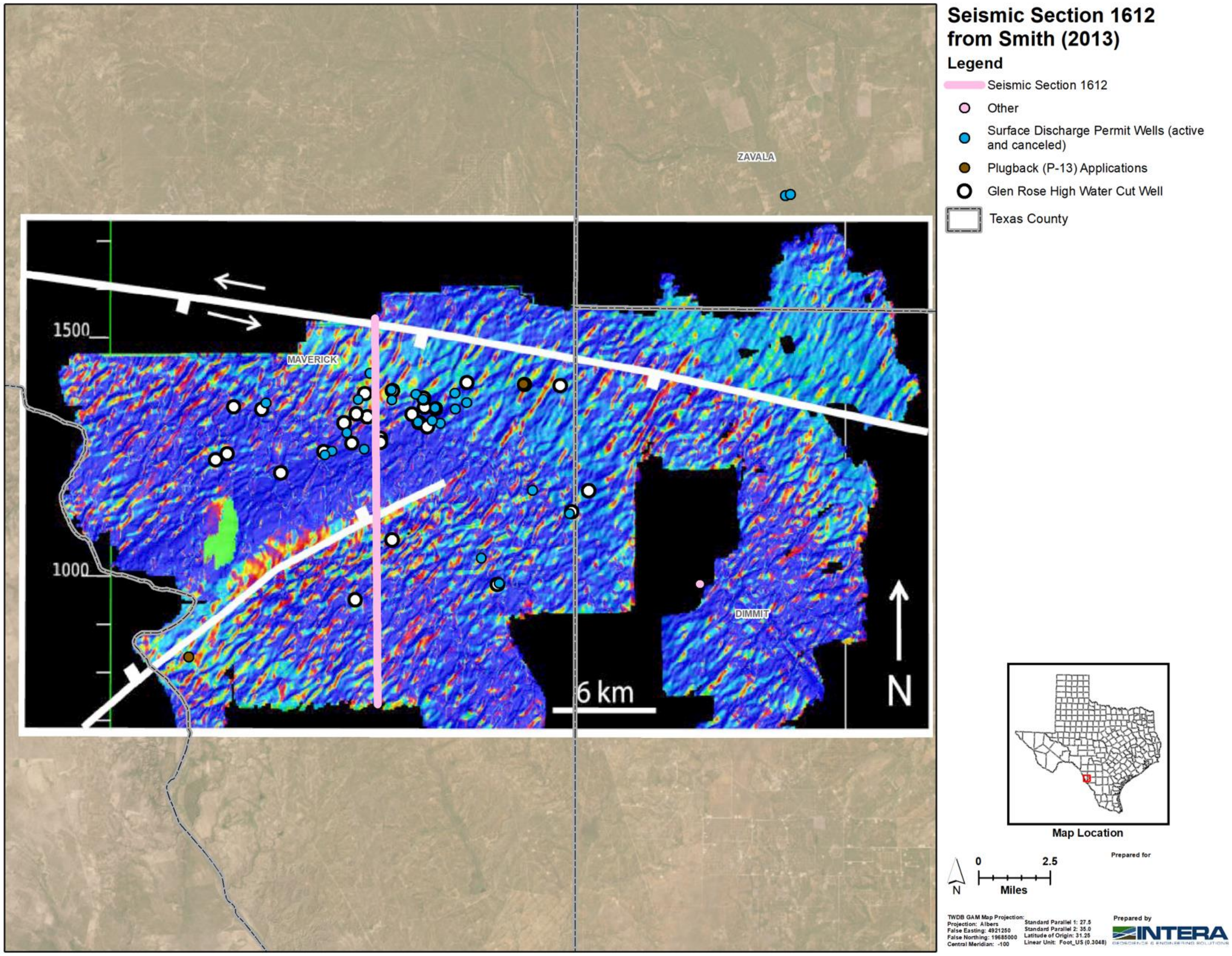

Figure 2.3-3. Stratal slice of the top Del Rio Formation with an azimuth attribute extraction overlain onto the basemap with relevant wells (Smith, 2013).

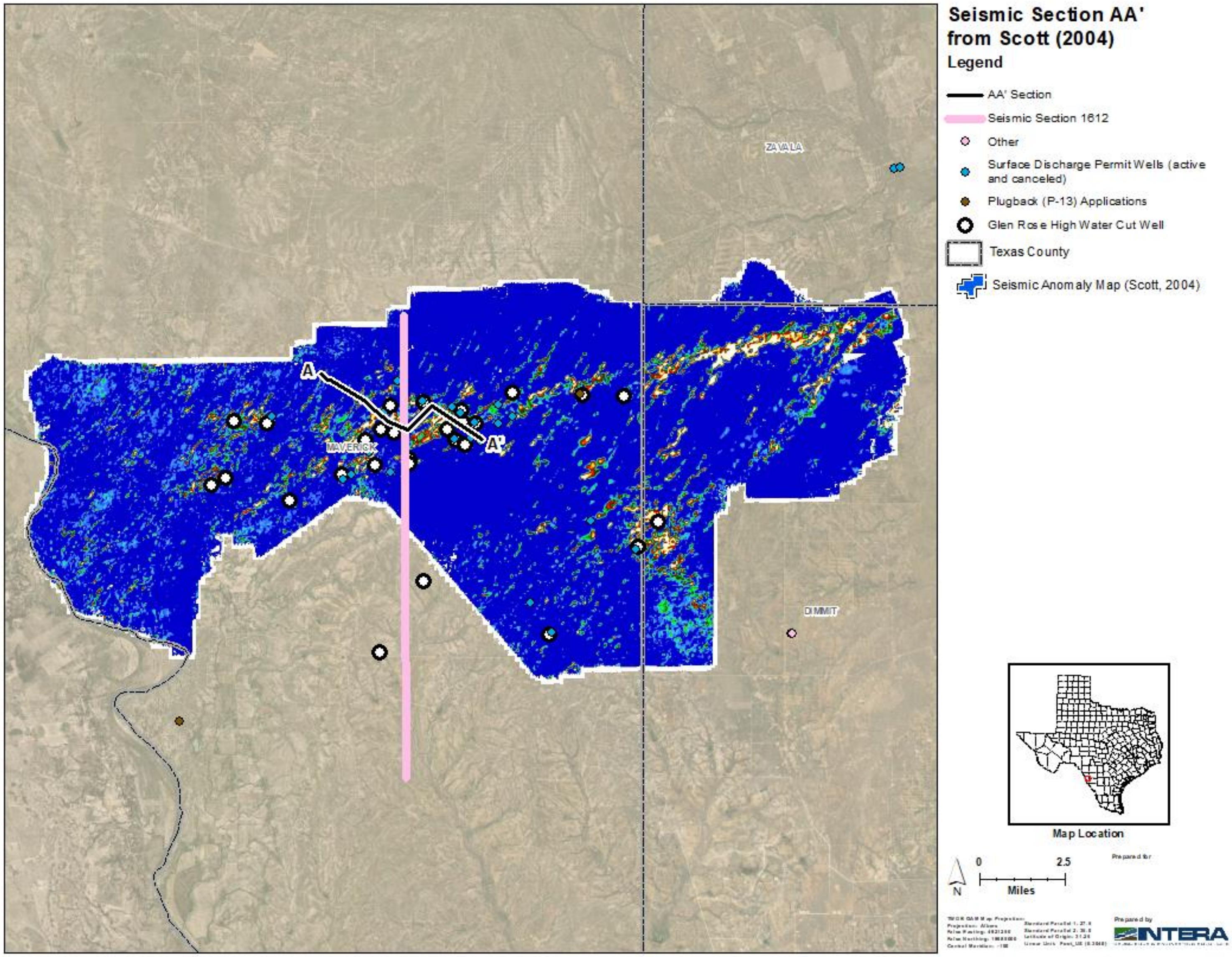

Figure 2.3-4. **The locations of lines 1612 from Smith (2013) and A-A' from Scott (2004), overlain on the seismic anomaly map from Scott (2004).**

Figure 2.3-4 is a seismic amplitude map of the upper Glen Rose Formation porosity zone utilizing Coherency processing with the porosity-induced amplitude anomalies shown in red (Scott, 2004). The Coherency processing emphasizes discontinuous events such as faults, and in Figure 2.3-4 it is apparent that the porosity anomalies occur mostly along faults that comprise a shear zone (Scott, 2004). These porosity anomalies are associated with hydrothermal dolomitization of the Glen Rose Formation. The shear zone created a system of passageways in the rock strata (Scott, 2004) where hot, mineral-rich acidic waters from depth flowed through these conduits and caused diagenetic changes that converted dense limestone into a high-porosity oil reservoir (Scott, 2004). Based on this system of faults and diagenetic changes, Scott (2004) categorizes the upper Glen Rose Formation porosity zone as a hydrothermal dolomite reservoir. The seismic map view shows a shear zone that mirrors some other major structural features in Maverick County and Kinney County (Zahm and Kerans, 2010). The east-west trend is similar to the Carta Valley fault zone north of Del Rio and, more importantly, the Wipff fault zone in northern Maverick County (Zahm and Kerans, 2010; Rose, 1984).

Figure 2.3-5 shows the seismic basemap used in Scott (2004) and the location of the NW-SE line in Figure 2.3-2. This map is annotated with the main shear and companion faults. Both Smith (2013) and Scott (2004) highlight the orientation of a large shear feature with a series of companion faults oriented at N50E. It is apparent from Figure 2.3-5 that not all wells intersect the colored porosity anomalies. This could be because the time slice provided is not sufficient to highlight the porosity zones through the entire upper Glen Rose Formation.

2.3.2 Development History

In 2001, operators initiated 3-D seismic acquisition on Comanche Ranch (Scott, 2004). During the acquisition, they discovered mounded reflectors located at approximately 6,500 feet depth within the Glen Rose Formation. As the reflectors appeared similar to the patch reefs that had previously yielded gas on the Chittim anticline to the northwest, geologists interpreted them as patch reefs (Figure 2.3-2). A significant discovery of oil in the early 2000s drew more attention to the prospect (Scott, 2004). The discovery well, and subsequent wells, experienced drilling problems including mud loss, reduced cuttings recovery, and poor core recovery, lending further evidence to the presence of high porosity zones within the Glen Rose Formation. Density porosity readings from geophysical logs run on the discovery well were over 45 percent (Scott, 2004). From core data, the dominant rock is a micritic, mixed skeletal–peloidal wackestone to packstone with molluscs, echinoids, and scattered planktic microfossils (Scott, 2004). While this rock type is not typical of a reservoir with high porosity and permeability, petrographic studies found evidence of advanced diagenetic changes due to the presence of authigenic quartz, iron sulfides, saddle dolomite, and replacive dolomite in thin sections (Scott, 2004). Porosities in the 30 percent range, which were frequently filled with bitumen and pyrobitumen, were not uncommon (Scott, 2004). The mineral assemblage, hydrocarbon types, and porosity are all products of diagenesis, frequently associated with the dissolution of the host limestone by mineral-rich, high-temperature acidic fluids (Scott, 2004).

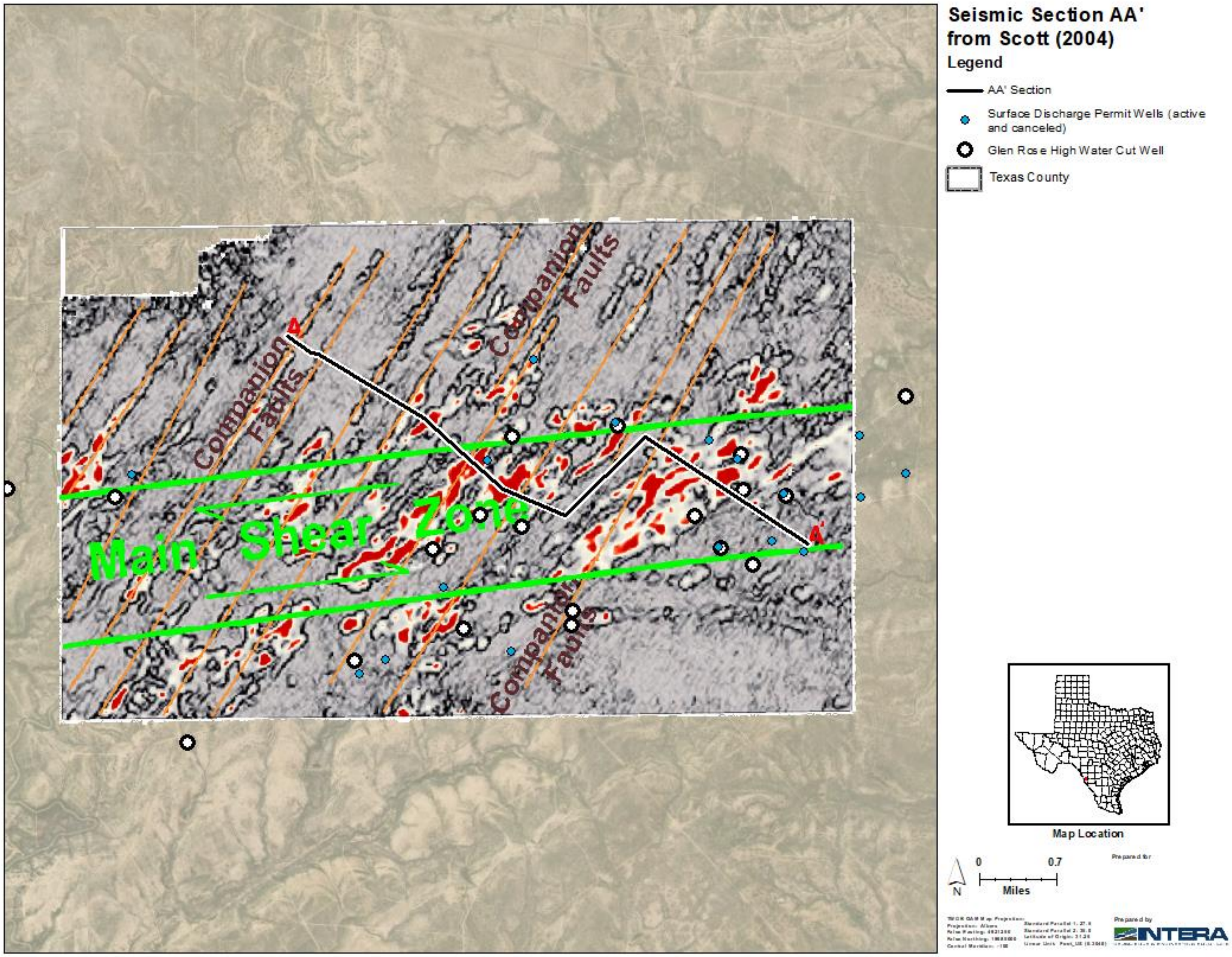

Figure 2.3-5. **Section A-A' is shown with the black and white line. Green annotation shows the left lateral strike slip zone and orange annotation shows the companion faults oriented 50˚ from the main shear. Red and yellow highlights on the section indicate porosity anomalies (Scott, 2004).**

Geologists originally hypothesized that a significant water drive would be needed to produce oil from the reservoir (Scott, 2004). Seismic reflectors are interrupted by numerous vertical features prominent throughout the seismic data (Scott, 2004). Figure 2.3-6 shows a representation of these features or “chimneys” from Smith (2013). These chimneys are believed to be the passageways initiated by the shear zone through which the diagenetic fluids subsequently moved (Scott, 2004). Geologists interpreted that the water drive for the oil zone originates beneath the Glen Rose Formation and flows upwards through the chimney structures to drive the oil (Scott, 2004). This interpretation was substantiated by the production of fresh water in a deeper test well within the fault zone (Scott, 2004). The source of the fresh water is unknown.

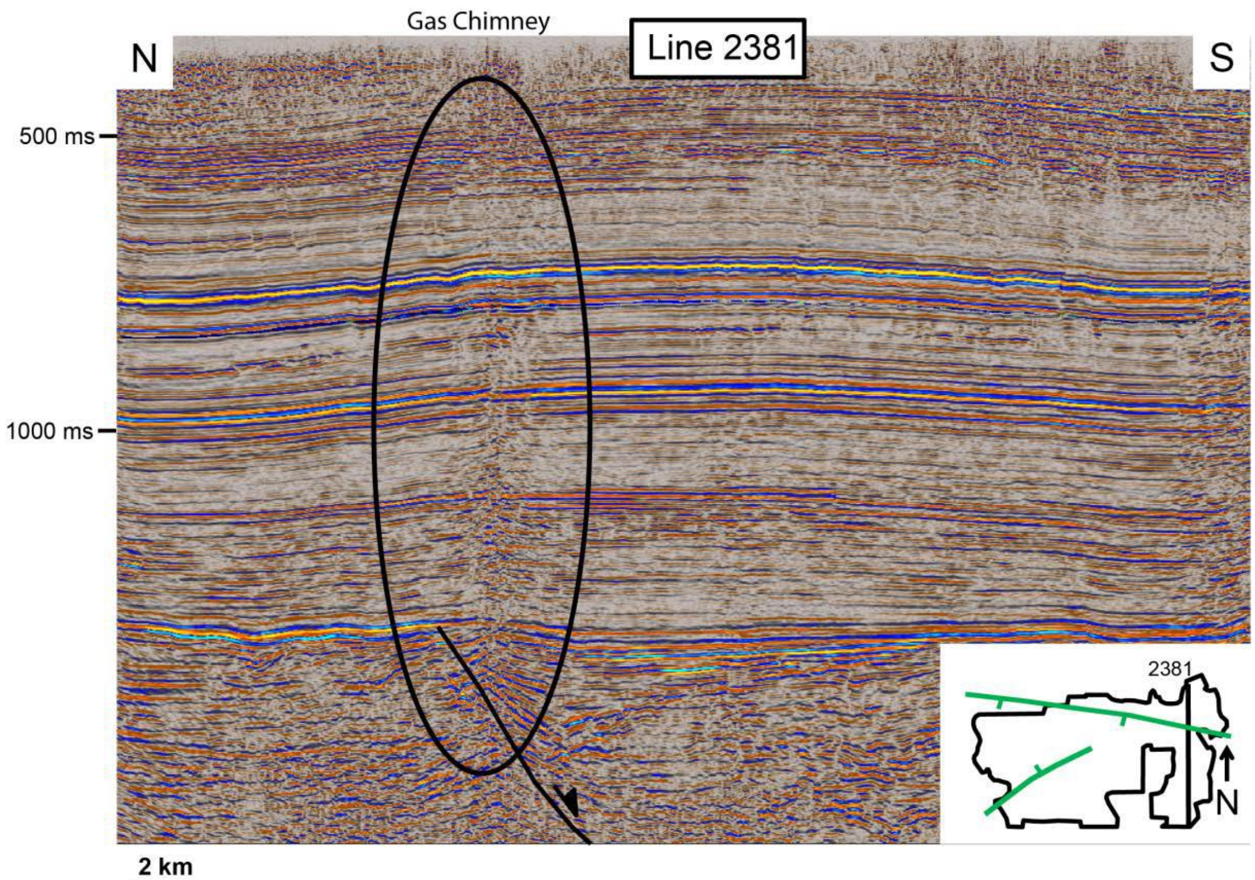

Figure 2.3-6. Cross section of seismic data showing an example of a chimney structure initiating from a basal fault, which are hypothesized in Scott (2004) to serve as conduits for water transport. (Smith, 2013)

Figure 2.3-4 also shows the wells with surface discharge applications versus the porosity map, which was georeferenced with the help of Smith (2013). The coincidence of the surface discharge applications with the porosity anomalies lends credence to Scott's (2004) interpretation.

2.3.3 Hydrothermal Dolomite

There is minimal information in the literature regarding hydrothermal dolomitization in the Maverick Basin (Scott, 2004). Hydrothermal dolomitization has been postulated to affect Members of the Ellenburger Group and the Wristen Formation, two Early Paleozoic Period carbonate units. However, the issue has been the subject of debate.

Figure 2.3-7 is a summary diagram from Davies and Smith (2006) showing the mechanisms for emplacement of hydrothermal dolomite. Similarities between the Maverick Basin hydrogeologic system and the system show in Figure 2.3-7 exist, including a basal aquifer, a shear zone creating faults which serve as fluid conduits, limestone overlying the basal aquifer, and a top seal.

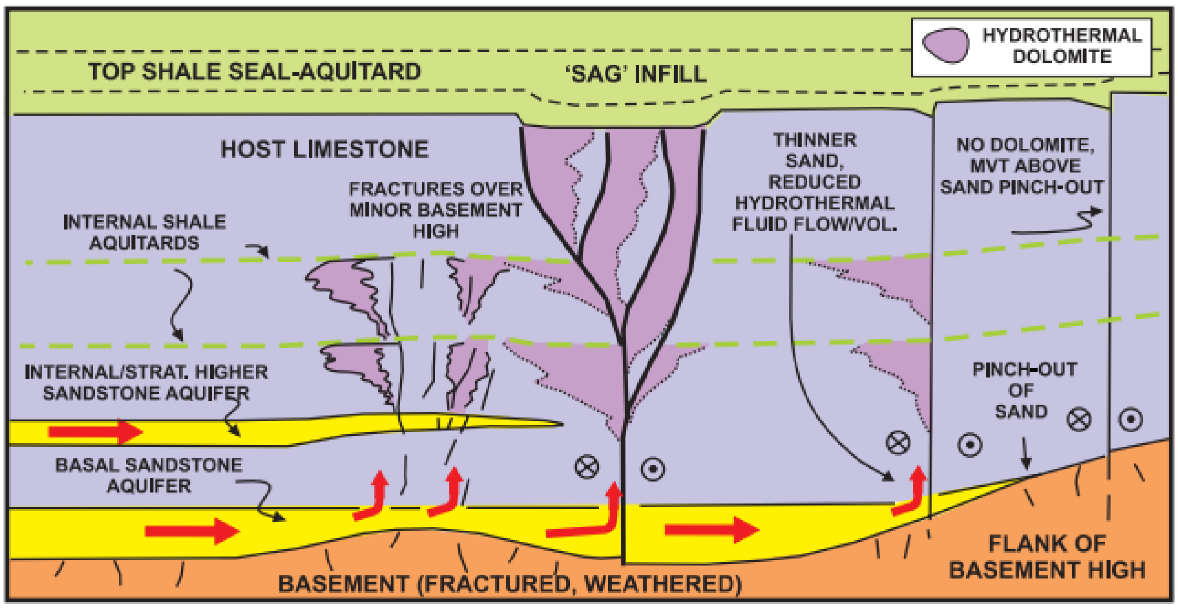

Figure 2.3-7. Mechanisms of emplacement of hydrothermal dolomite (Davies and Smith, 2006).

There are several candidates in the Maverick Basin hydrogeologic system for an underlying basal aquifer that is providing the fresh water to the Glen Rose Formation. The Pearsall Formation is dismissed as a possible source due to lack of porosity and permeability. The Cotton Valley/Hosston Formations are possibilities (Figure 2.2-4) because they are traditionally clastic units made up of permeable sediments and underly all other units of the Trinity Group. However, it would be expected that the Sligo and Cow Creek Formations would also be hydrothermally altered. Since similar seismic anomalies or similar water-rich oil wells have not been found, it is assumed they have not been altered by fluids migrating from the Cotton Valley/Hosston Formation. Insufficient evidence exists as to why the Glen Rose Formation is diagenetically altered.

2.3.4 Recharge Area

When creating a comprehensive hydrogeological conceptual model, the recharge mechanism for the aquifer must be considered. Three origins of aquifer recharge: clay conversion, juvenile (or magmatic), or recent precipitation will be discussed.

The first theorized origin is the result of smectite-illite clay conversion. However, the lithologies in the basin do not support the possibility of clay conversion since no such clays have been found in the limestones. A magmatic origin to the recharging groundwater is refuted by oxygen isotope data obtained from water samples from wells completed into the Glen Rose Formation. The isotope data lends itself to a meteoric origin for the recharge. However, the nearest recharge zone is over 50 miles away. Typically, an aquifer system will have less mineralized water quality closer to the recharge zone, and as the fluid migrates down-gradient in the aquifer, it picks up additional ionic constituents and the water becomes more saline. However, water quality samples from the Maverick Basin aquifer are fresh to slightly saline at depths of 6,000 feet. This is unexpected and is the reason that recharge mechanisms other than clay conversion or magmatism were evaluated.

Traditional recharge mechanisms include gravity driven flow of the water through transmissive conduits within the host rocks. These conduits could be interconnected primary porosity or secondary porosity features such as fractures, faults, or karst. The significant depth of the aquifer and the seemingly mildly fractured limestone rocks at surface do not lend themselves to a direct infiltration of precipitation model for the recharge to the Maverick Basin aquifer. Lateral flow is a potential mechanism however, it is unknown which water bearing unit in connection with the Glen Rose Formation would transmit the water. The Glen Rose Formation, where unaltered, is considered to have low porosity throughout the basin (Rose, 1984). Scott (2004) hypothesized that water drives the oil upward through gas chimneys, instead of stratigraphically updip, resulting in the absence of an oil-water contact, as is usually the case. Therefore, if the water driving the oil up the gas chimneys originates from beneath the Glen Rose Formation, recharge must be in other, more permeable, underlying units such as the Sligo Limestone, Hosston Sandstone, or a deeper Jurassic unit. Given the very limited well control, little is known about these deeper units. Further, if the water drive is from a deeper unit, the lower salinities would be even more anomalous (salinities/water quality will be discussed in Section 3).

Aquifers that lie beneath oil and gas deposits exist in Texas as well as throughout the world. For example, the McCullough and Ford Ranch wellfield in McCullough County produces from the Hickory Aquifer beneath overlying oil and gas bearing units (Reed and others, 1972). The Hickory Aquifer is recharged to the east of the wellfield where the unit outcrops around the Llano Uplift. The infiltrating groundwater is transmitted via gravity driven flow both vertically and horizontally to the west where it is intersected by wells in the McCullough wellfield.

Outcrops of the Glen Rose Formation exist to the northeast of the Maverick Basin in Texas and to the west in Mexico. Researchers at the Railroad Commission of Texas (2022a) hypothesized that recharging groundwater making it to depth within the Maverick Basin could come from the Serrania del Burro Mountains to the west in Coahuila (Figure 2.3-8). The Serrania del Burro Mountains are the nearest exposure of

Lower Cretaceous rocks that could likely source this water. The Glen Rose Formation outcrops in Texas at a slightly further distance to the northeast, however, given the structural complexity and low water cuts within the Texas Cretaceous strata, recharge from the Texas outcrops appears somewhat less likely.

There is substantial hydraulic head in the flowing wells on and near the Comanche Ranch. The shut-in hydraulic head of the aquifer in the Saxet well is at elevation 1,580 feet, almost 800 feet above ground surface. The head in the Saxet well was presumably derived by recharge at a relatively high elevation, assuming a gravity-driven flow system. The elevation in the Serrania del Burro Mountains in Mexico is a maximum of approximately 4,700 feet, while the elevation of the outcrop area in Texas is a maximum of approximately 2,300 feet, about 2,400 feet lower. The head evidenced by the shut in pressure in the Saxet well would be most reasonably ascribed to a relatively high elevation recharge, such as the Serranias del Burro, although the surface elevation of the Texas Glen Rose outcrops offers a possible, if less likely due to lower elevation, alternative.

Scott (2004) suggests that the Maverick Basin aquifer water comes from a unit below, so relevant outcrops might also include the Hosston through the Glen Rose Formations. The United States Geological Society's Geologic Map of North America (Reed and others, 2005) shows the Serrania del Burro Mountains include exposures of both the Glen Rose and Hosston Formations (Figure 2.3-8).

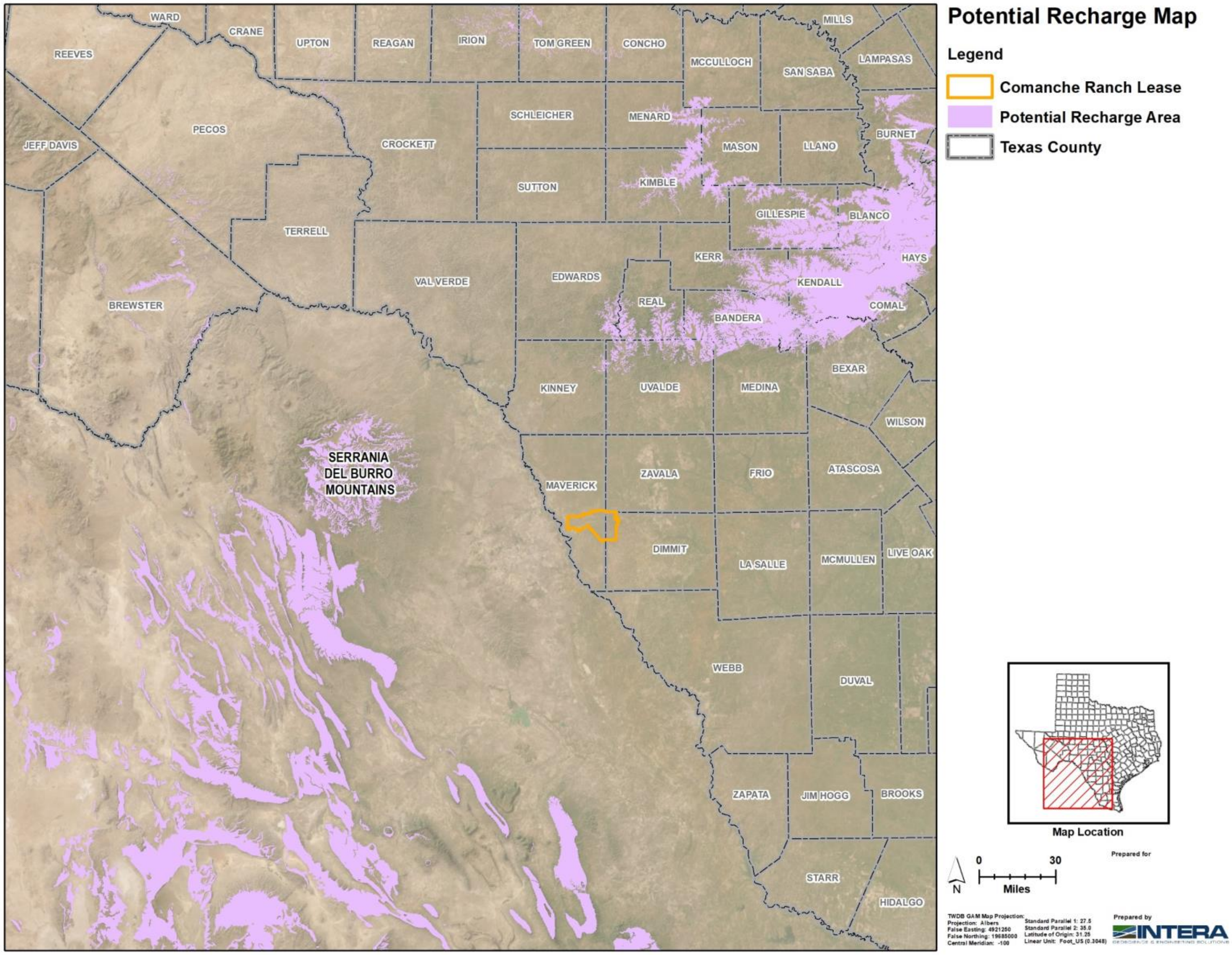

Figure 2.3-8. **Serrania del Burro Mountains location relative to the Comanche Ranch Lease. Lower Cretaceous and Trinity Group Outcrop (Servicio Geológico Mexicano, 2023).**

3 Data

This section provides available and relevant data for wells intersecting the deep Glen Rose Formation in the Maverick Basin. Well data of interest include the locations of Railroad Commission of Texas P-13 applications for fresh to slightly saline water production from abandoned oil/gas wells, surface discharge wells, water cuts, water quality analyses, and production rates. This section also presents a cross section showing where the Glen Rose Formation wells are producing fresh to slightly saline water and the structural and stratigraphic relationship of the zones with high water content.

3.1 Basemap

Figure 3.1-1 is a basemap of the Comanche Ranch Lease and surrounding areas, displaying Maverick, Zavala, and Dimmit counties in South Texas. Subsequent maps use this basemap as the backdrop, with county lines serving as reference points.

3.2 Petroleum Wells by Depth

Figure 3.2-1 is a map of the petroleum wells available from the S&P Global database (S&P Global, 2024) colored and sized by total depth. The abundant wells with only shallow penetrations are displayed as black and grey circles. Colored circles represent wells that penetrate below 5,000 feet, which is considered a reasonable ceiling for this study. The map also shows major field names in the area. Many of the Maverick basin aquifer wells are in the Comanche-Halsell (6,500) field.

3.3 Available Geophysical Logs

Figure 3.3-1 is a map of the geophysical well logs available in the S&P Global dataset (S&P Global, 2024), colored by whether the log is a digital log, or a scanned paper log (raster). This dataset is fairly comprehensive and has sufficient density in the study area for a high-level overview of the Maverick Basin aquifer. For publicly available logs in the area, contact the Texas Water Development Board Brackish Resources Aquifer Characterization System (BRACS) department.

3.4 Glen Rose Formation Structure

Glen Rose Formation structure was interpreted in S&P Global's PETRA (S&P Global, 2024) based on geophysical well logs in the study area. The measured depth values for top and bottom of the Glen Rose Formation were interpolated to generate top and bottom surfaces for the geologic unit. Calculated thickness values at each data point were used to interpolate a thickness map of the Glen Rose Formation.

3.4.1 Glen Rose Formation Top

Figure 3.4-1 is a map of the depth to the top of the Glen Rose Formation. Control points are marked on the map as small black dots. The control points are geophysical logs from wells that have penetrated to the top of the Glen Rose Formation.

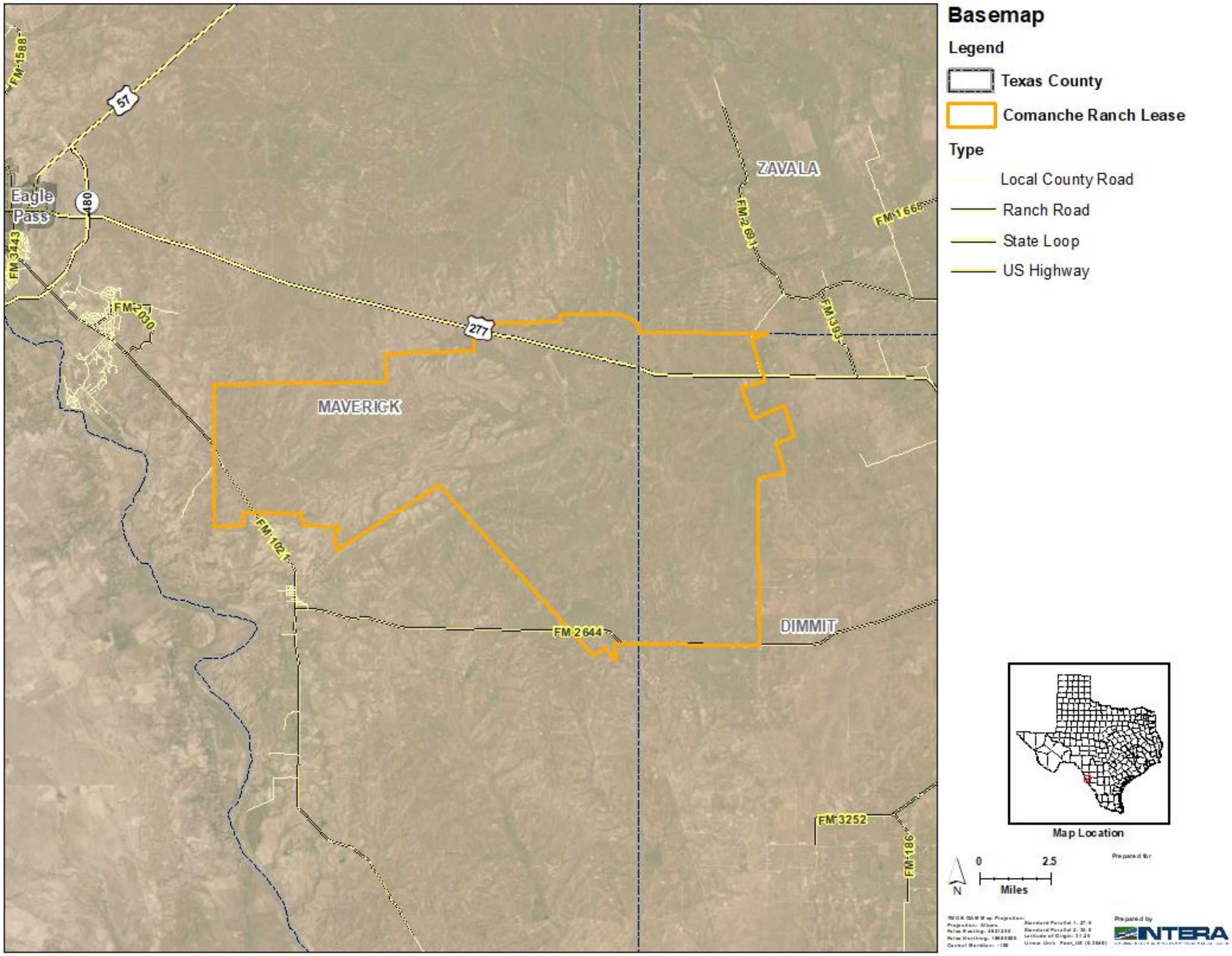

Figure 3.1-1. Location basemap for the Comanche Ranch Lease and surrounding area.

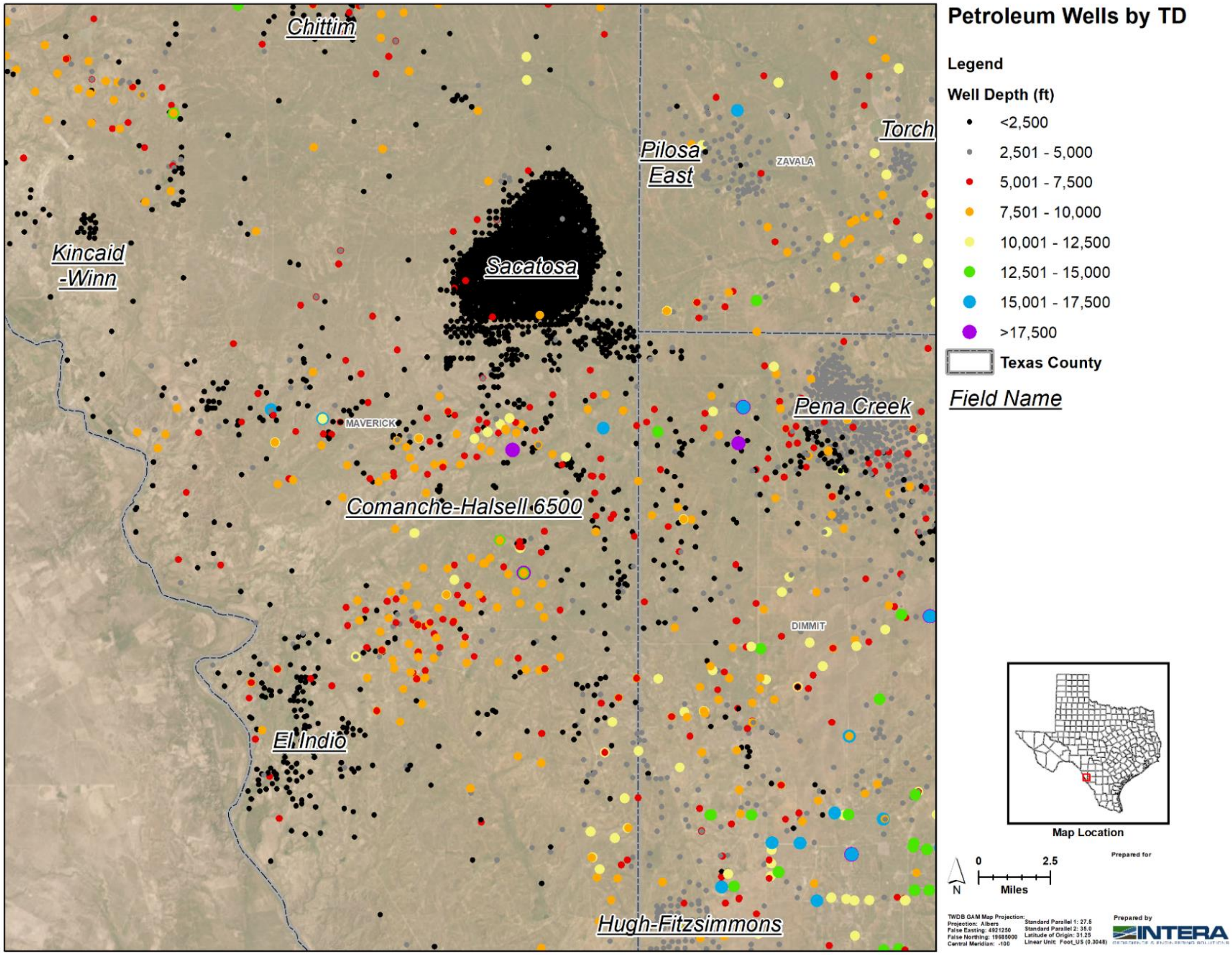

Figure 3.2-1. **Petroleum Wells by Total Depth(TD = Total Depth) (S&P Global, 2024).**

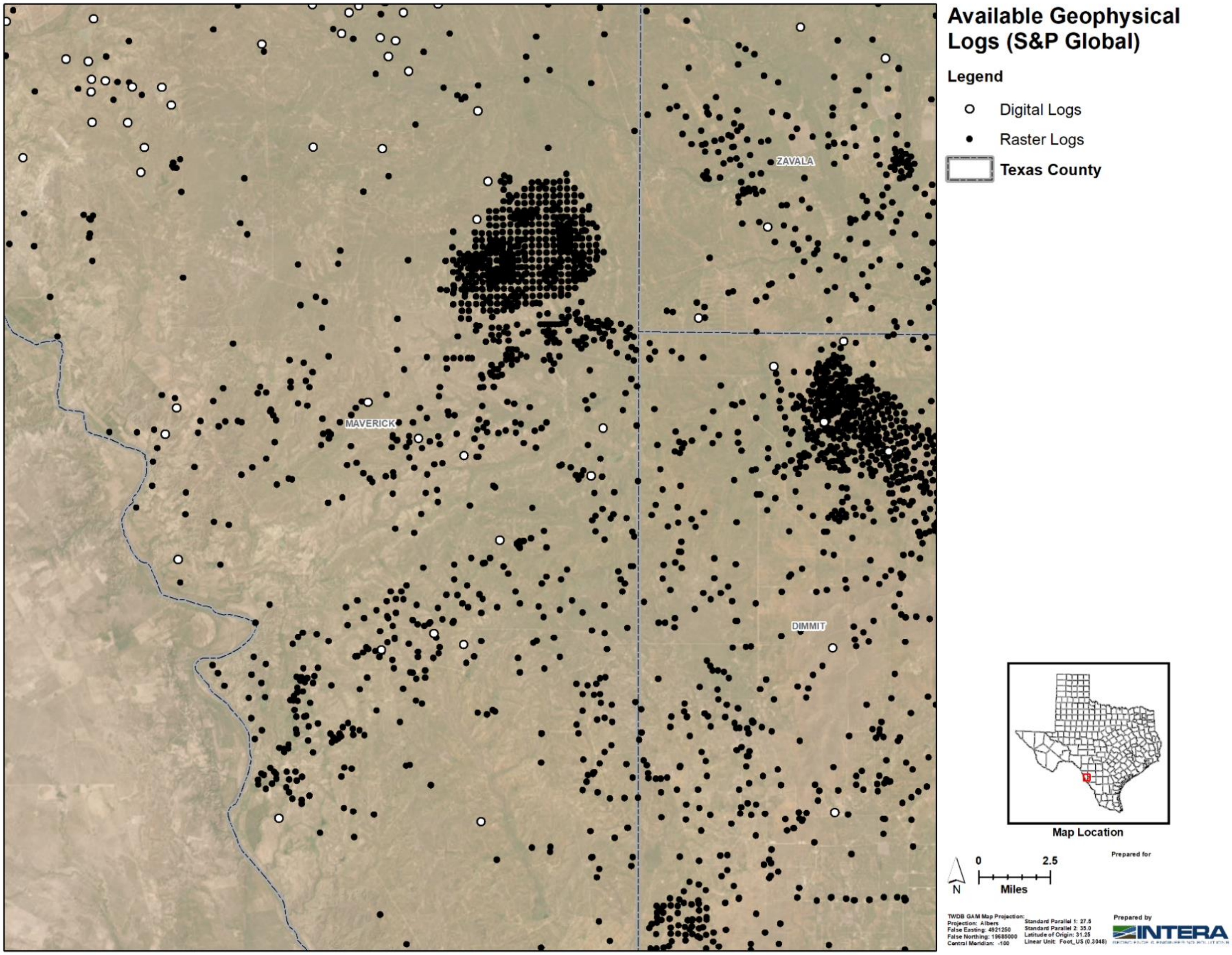

Figure 3.3-1. Available geophysical well logs (S&P Global, 2024).

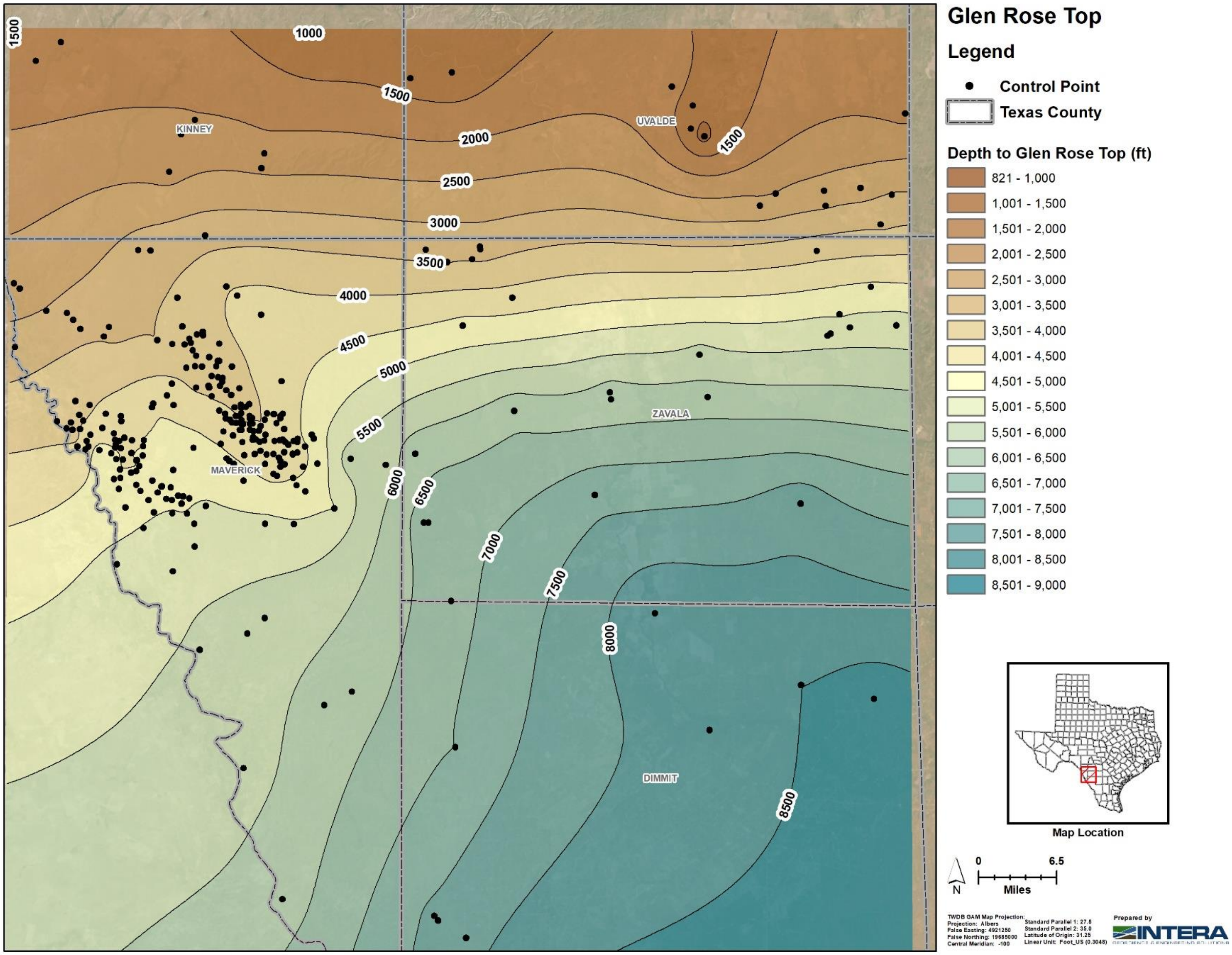

Figure 3.4-1. Depth to top of Glen Rose Formation.

The depth to the top of the Glen Rose Formation ranges from 1,000 feet north of the study area to 9,000 feet in the southeastern corner of the study area. The Chittim Anticline can be seen in the southeast-pointing contours in northern Maverick County. Contours deepen toward the center of the Maverick Basin to the southeast.

3.4.2 Glen Rose Formation Base (Rodessa)

Figure 3.4-2 is a map of depth to the base of the Glen Rose Formation, which is the top of the Rodessa Formation. Control points are marked on the map as small black dots. The control points are geophysical logs from the few wells that have penetrated the top of the Rodessa Formation. There is less well control on this surface, although the Chittum anticline remains reasonably well defined. Most wells penetrating the Glen Rose Formation produce from the Glen Rose Formation, so few wells are completed past the base of the Glen Rose exist.

3.4.3 Glen Rose Formation Thickness

Figure 3.4-3 is a map of the thickness of the Glen Rose Formation. Control points are marked on the map as small black dots. The control points are geophysical logs from wells that have penetrated to the top of the Glen Rose and Rodessa Formations. The vertical distances between these tops are interpolated between wells to produce the contours in the map. The formation thickens to the southeast and south-southwest and it appears that there is a zone of increased thickness coincident with the Chittim Anticline to the southeast, but there are relatively few wells bounding the anticline to validate the interpolation artifact.

3.5 Glen Rose Formation Production Wells with Water Cut over 90%

Figure 3.5-1 is a map of the petroleum wells assigned with Glen Rose Formation production that have water cuts above 90%. This helps to highlight where the Maverick Basin aquifer is producing water in high volumes. Figure 3.5-1 shows that the main production trends east-northeast to west-southwest, with some minor production to the south of that trend.

Figure 3.5-2 shows the coincidence of this trend with a seismic anomaly described by Scott (2004) in a seismic amplitude map generated on an upper Glen Rose Formation porosity pay zone. Some production to the south can also be correlated with this seismic anomaly. According to Scott (2004), the numerous bright colored features (non-blue colors) are low velocity amplitude anomalies, hypothesized to represent high porosity trends. The dominant linear feature appears to be a shear zone (Scott, 2004), and the smaller linear features (also brightly colored) intersecting the main lineament at approximately 50 degrees appear to be companion faults (Scott, 2004).

There are some high water cut wells not on this main arc; two to the southeast in a known seismic anomaly, and three directly to the south outside of known seismic anomalies. It is possible that the two wells outside of Scott's (2004) seismic anomaly map are completed in a lower interval that was not the target of the analysis.

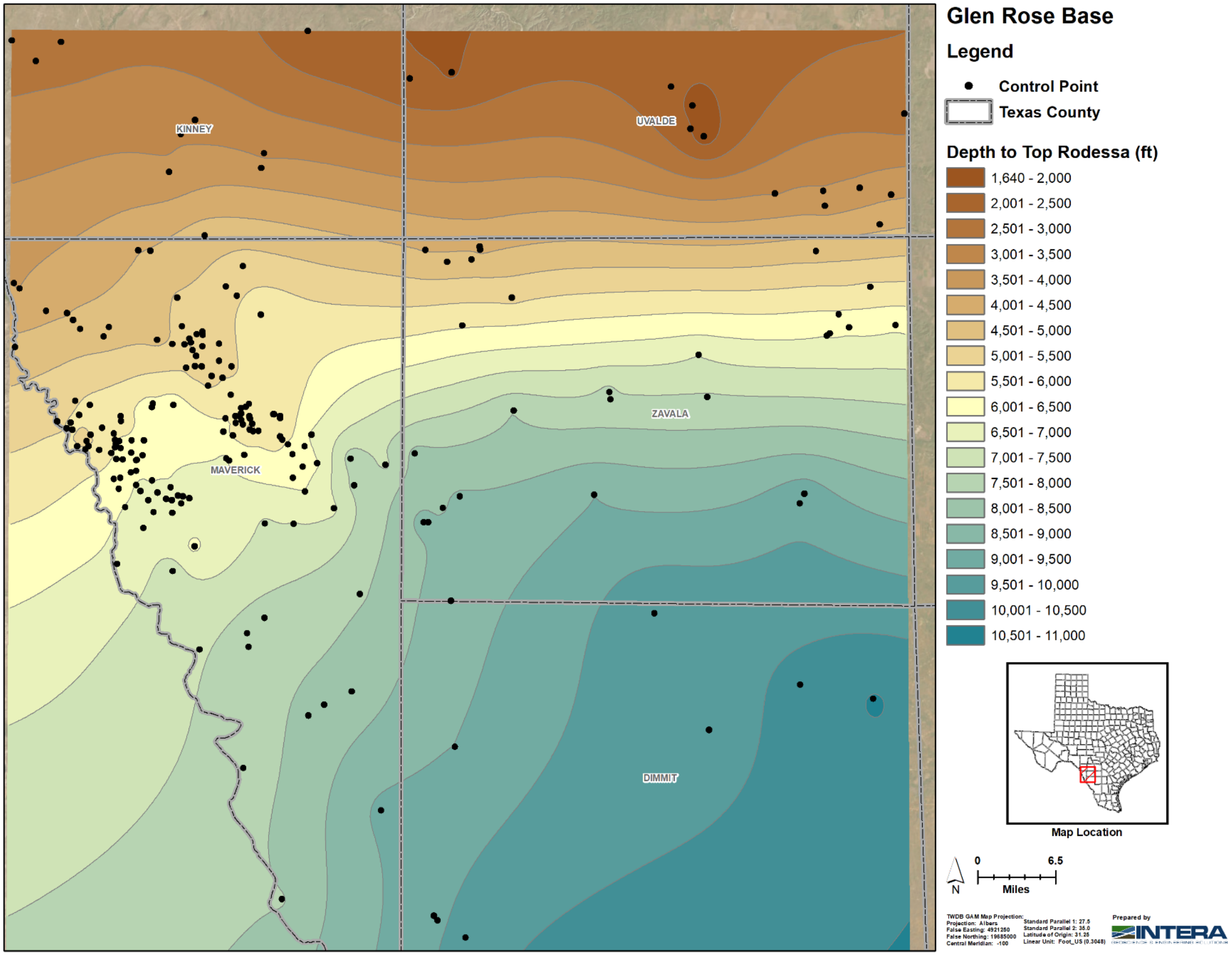

Figure 3.4-2. **Depth to base of Glen Rose Formation (top of Rodessa Formation).**

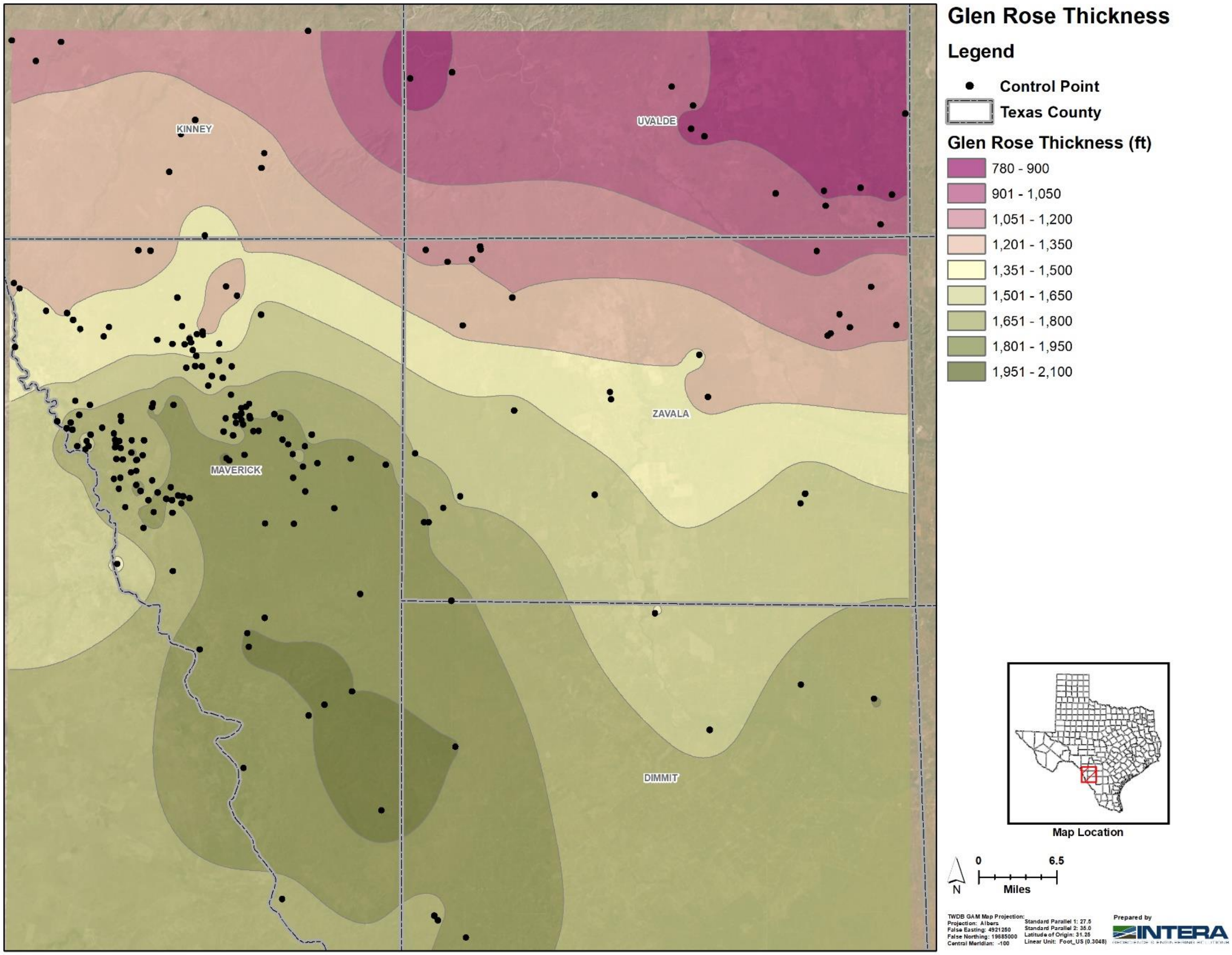

Figure 3.4-3. Thickness of the Glen Rose Formation.

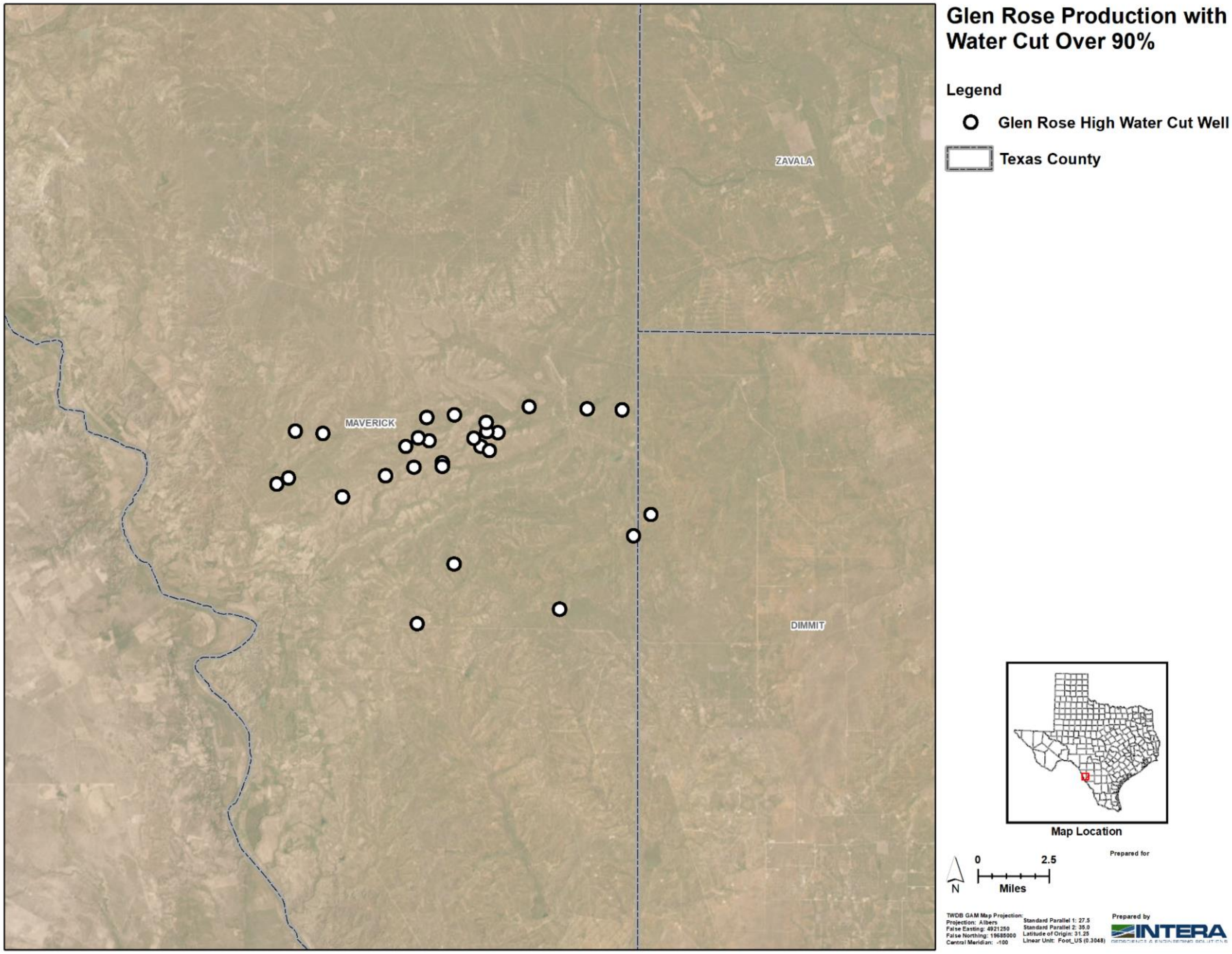

Figure 3.5-1. Petroleum wells in the Glen Rose Formation with water cuts over 90%.

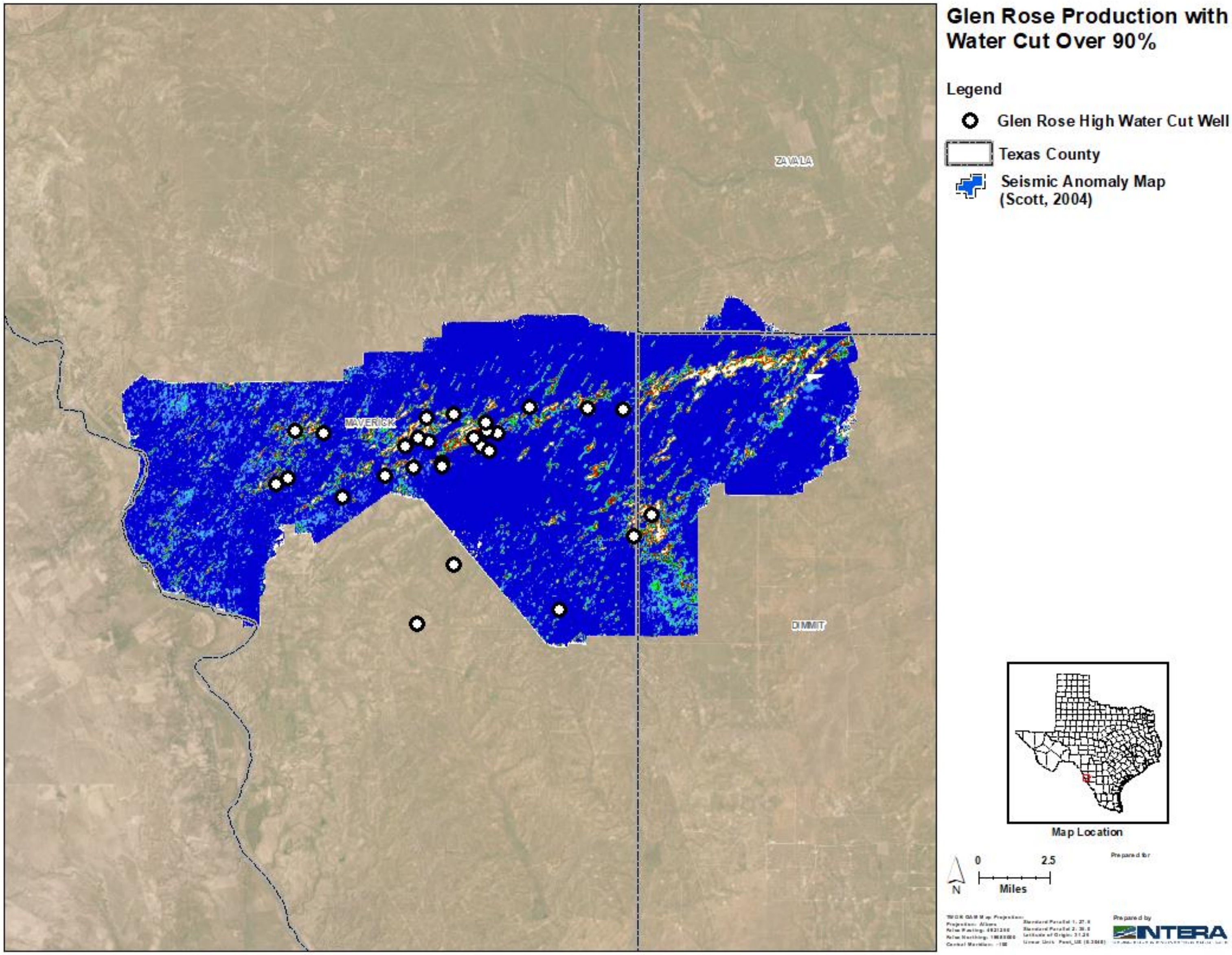

Figure 3.5-2. Seismic anomaly map and petroleum wells in the Glen Rose Formation with water cuts over 90% (Scott, 2004).

3.6 Isotope Data

Figure 3.6-1 is a map of the groundwater stable isotope data collected from Glen Rose Formation outcrop (streams and springs) and producing wells. The stream and spring data in Mexico was collected by Rosario Sanchez with the Texas Water Resources Institute (Texas A&M University), and James Harcourt and Royce Massey serving as volunteer private citizens. The well samples were collected by the Railroad Commission of Texas' San Antonio district office. Oxygen and hydrogen isotopes were analyzed by the Texas Bureau of Economic Geology. Isotopic data is presented in Appendix A (Table 6.1-1). Hydrogen is notated as δD and oxygen as $\delta^{18}O$.

The isotope data in Maverick County represents samples taken from produced water in actively producing P-13 and R-2 wells. The data in the Serrania del Burro Mountains of Mexico, the most likely hypothesized recharge area for the Maverick Basin aquifer, are from springs and surface water streams. Both data sets show little variance, apart from two outliers from the Serranias del Burro group. Both outliers exhibited heavier values than meteoric water, likely due to evaporation. They were not included in the average values shown on Figure 3.6-1, as they are not likely to be representative of the water potentially infiltrating in the Serrania del Burro Mountains.

The oxygen isotopes from each group of samples are very similar with averages within one per parts per thousands. The hydrogen isotopes differ somewhat more, with a spread of 11.0 parts per thousand, with both averages being relatively light. Within the Maverick County group, the produced water isotopes are reasonably consistent, the entire range being within 0.5 parts per thousand. Hydrogen values for the produced water in the Maverick County group are within 1.1 parts per thousand. There is more variance within the Serrania del Burro Mountains group, with a spread in oxygen of 0.9 parts per thousand and 4.5 parts per thousand for hydrogen.

The Maverick County produced water averages are slightly lighter than the Serranias del Burro averages, however the averages of both data sets fall very close to the meteoric water line, $\delta D = 8.0 \times \delta^{18}O + 10$ parts per thousand. If it is assumed the recharge area for the groundwater in both groups is the Serrania del Burro Mountains, and the Maverick County group represents groundwater that has flowed downgradient from the Serranias del Burro recharge area, there may be some minor geochemical rock-water reactions that have influenced the hydrochemistry of the produced water, but the samples show little, if any, isotope fractionation.

3.7 Permitted water discharge wells

Figure 3.7-1 is a map of the petroleum wells that have a water production permit (R-2 or P-13) in addition to the wells with produced water samples. This includes canceled or non-active permits. Sampled wells are highlighted in red. In all cases of which the authors are aware, these wells produced to surface without a pump (artesian). These wells follow a similar east-northeast to west-southwest arc and are in the same location as the high water cut wells in Figure 3.5-1. There are however a few wells in Zavala County and one to the southeast in Dimmit County that deviate from the trend.

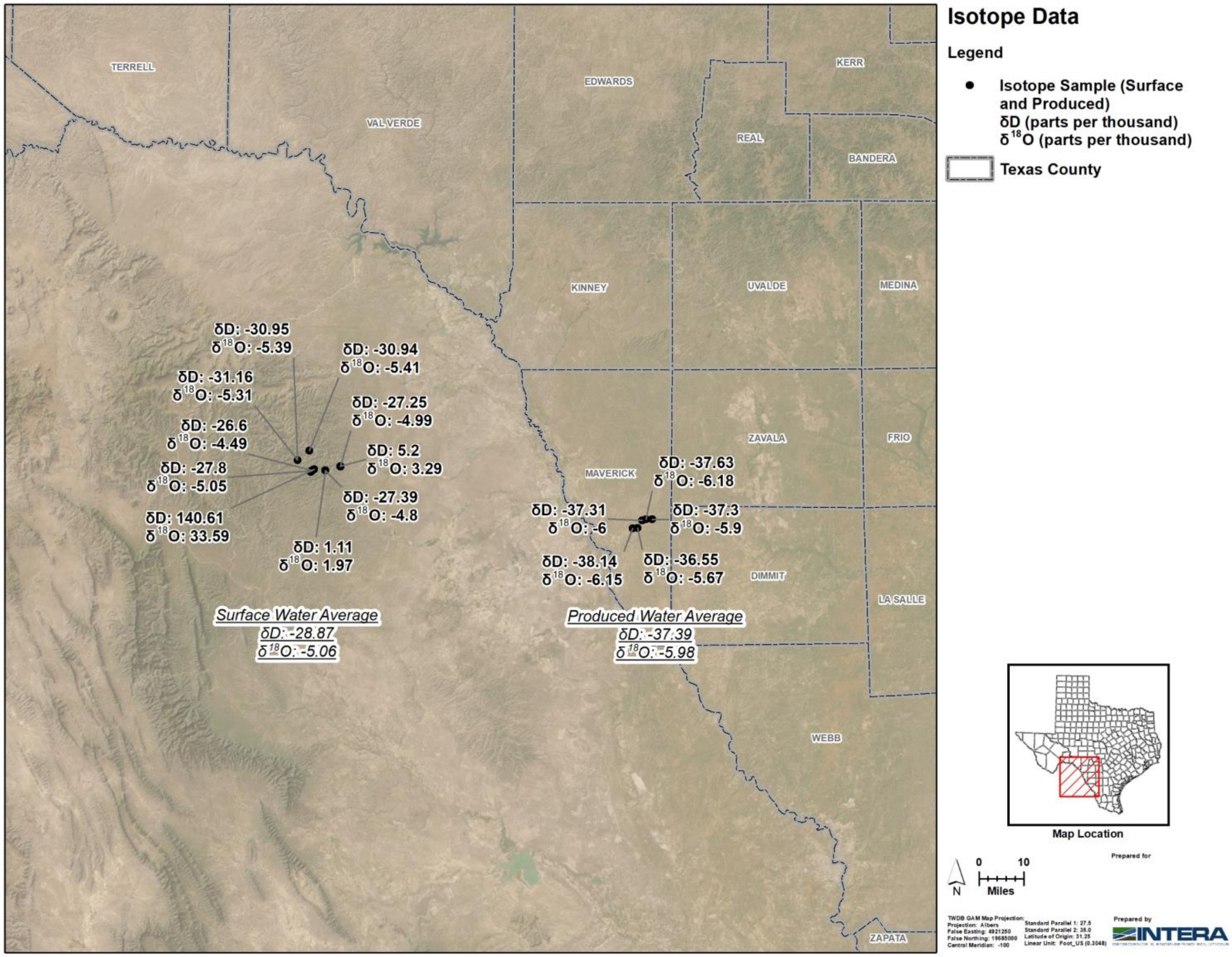

Figure 3.6-1. **Isotope data from produced water from the Glen Rose Formation in Maverick County, and surface water over outcrop of the Glen Rose Formation in Mexico. Pink polygons indicate outcrops of Cretaceous rocks equal in age or older than the Glen Rose Formation. Surface water averages eliminated outliers, which are the positive δ^{18}O values. (d = δ).**

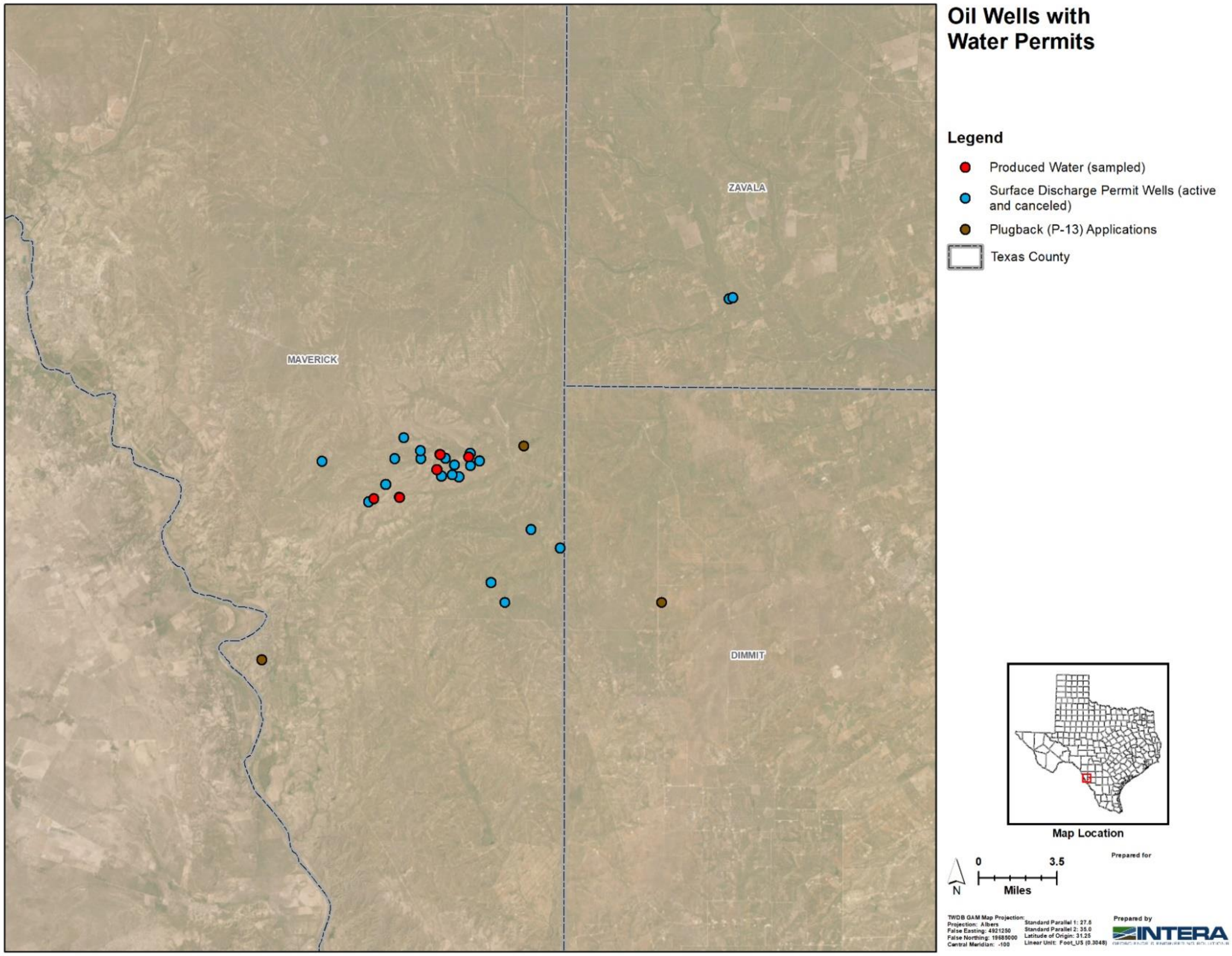

Figure 3.7-1. Permitted discharge wells, sampled produced water wells, and P-13 applications. A Surface discharge permit is an R-2 Permit.

Some of the wells in Figure 3.7-1 are included in Figure 3.5-1, but not all of them, since not all high water cut wells have discharge permits and not all wells with discharge permits necessarily meet the 90% water cut designation.

3.8 Glen Rose Formation Water Quality

Figure 3.8-1 is a map of the sampled wells in the area, with posted total dissolved solid and chloride concentrations in milligrams per liter. Data presented in Figure 3.8-1 comes from two sources, well completion reports archived by the Texas Water Development Board, and the sampling efforts and laboratory analysis by the Railroad Commission of Texas and the Bureau of Economic Geology, respectively. Water quality is relatively consistent across the area, with total dissolved solids concentrations between 800 to 2,200 milligrams per liter, and chloride concentrations between 50 to 600 milligrams per liter. Total dissolved solids and chloride values do not trend spatially. There is one point to the south that has total dissolved solids and chloride values within the range of the produced water from the east-northeast to west-southwest arc. There is also a drill stem test on a Hugh Fitzsimmons well that the Railroad Commission of Texas obtained indirectly from Balcones Energy Library. This Hugh Fitzsimons well is the southernmost well displayed in Dimmit County in Figure 3.8-1, and has an API number of 4212700636. All records for water quality and isotopes are provided in Appendix A (Table 6.1-1) with time series data for some surface discharge wells also provided in Appendix A (Table 6.1-2).

Organic constituents associated with petroleum production were noted as a concern in previous presentations by the Railroad Commission of Texas. These presentations showed data indicating there is some “Oil in Water”, generally below detection limits with occasional hydrocarbon detection (Railroad Commission of Texas, 2021b). These data are presented in Appendix A (Table 6.1-2).

3.9 Geologic cross section

Figure 3.9-1 is a map of the wells used in the geologic cross section presented in Figure 3.9-2. The cross-section line is annotated with the end labels used on the cross section (A-A’). This section contains 31 wells and is oriented from north-northwest to south-southeast. For clarity, the cross section has been broken into three shorter sections as shown in Figures 3.9-2b through 3.9-2d.

The purpose of the cross section is to show the well log response and completion style for the Glen Rose Formation in the area. The cross section shows geophysical well logs for each well overlain with formation tops/contacts, casing shoe locations, and perforated intervals. Casing shoes are symbolized as black triangles and perforated intervals are symbolized as pink rectangles. These wells are a good representation of the Glen Rose Formation wells. The geophysical logs on the cross section are almost all spontaneous potential and gamma ray on the left-hand side and resistivity on the right-hand side.

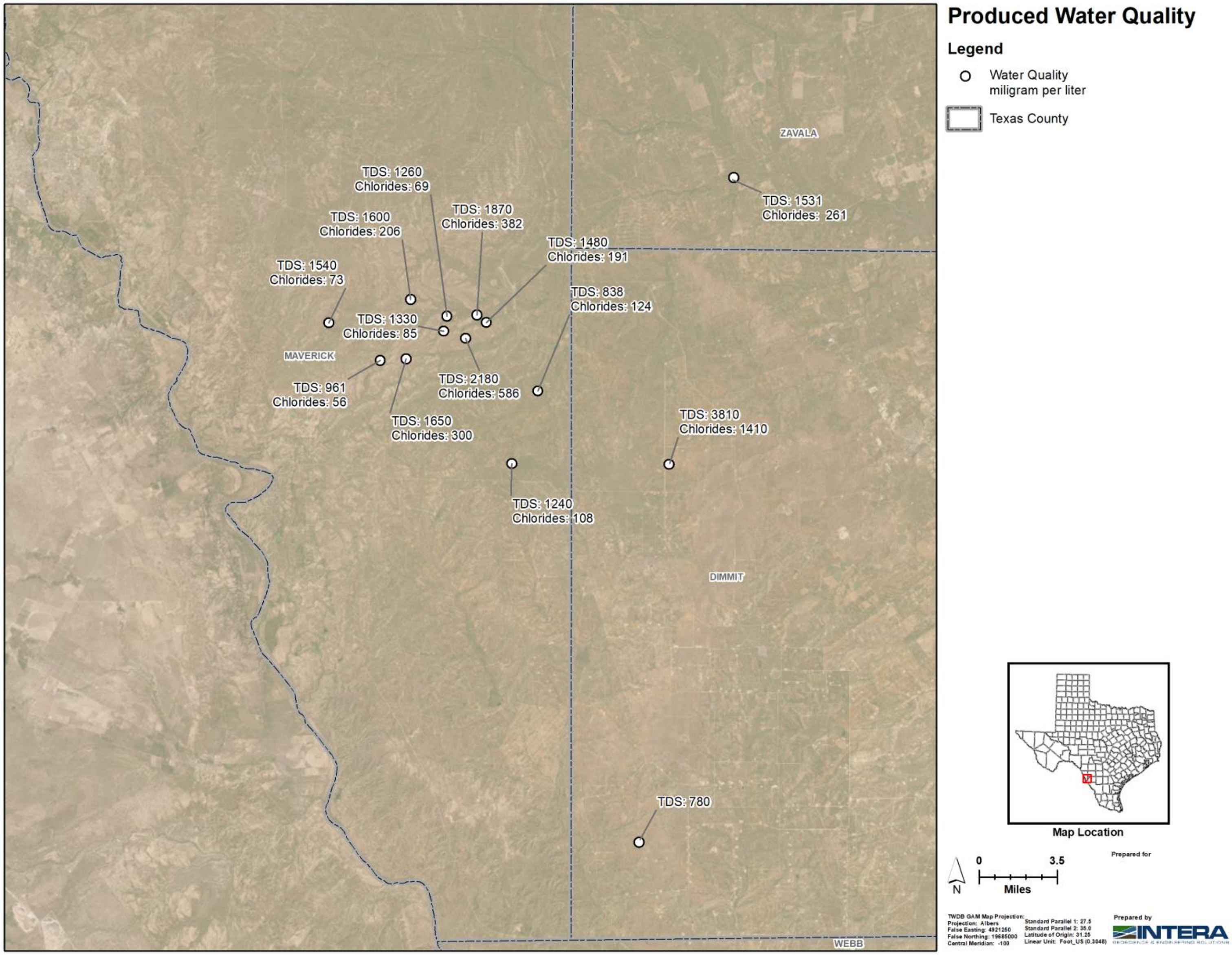

Figure 3.8-1. Produced water quality for sampled wells. (TDS – total dissolved solids)

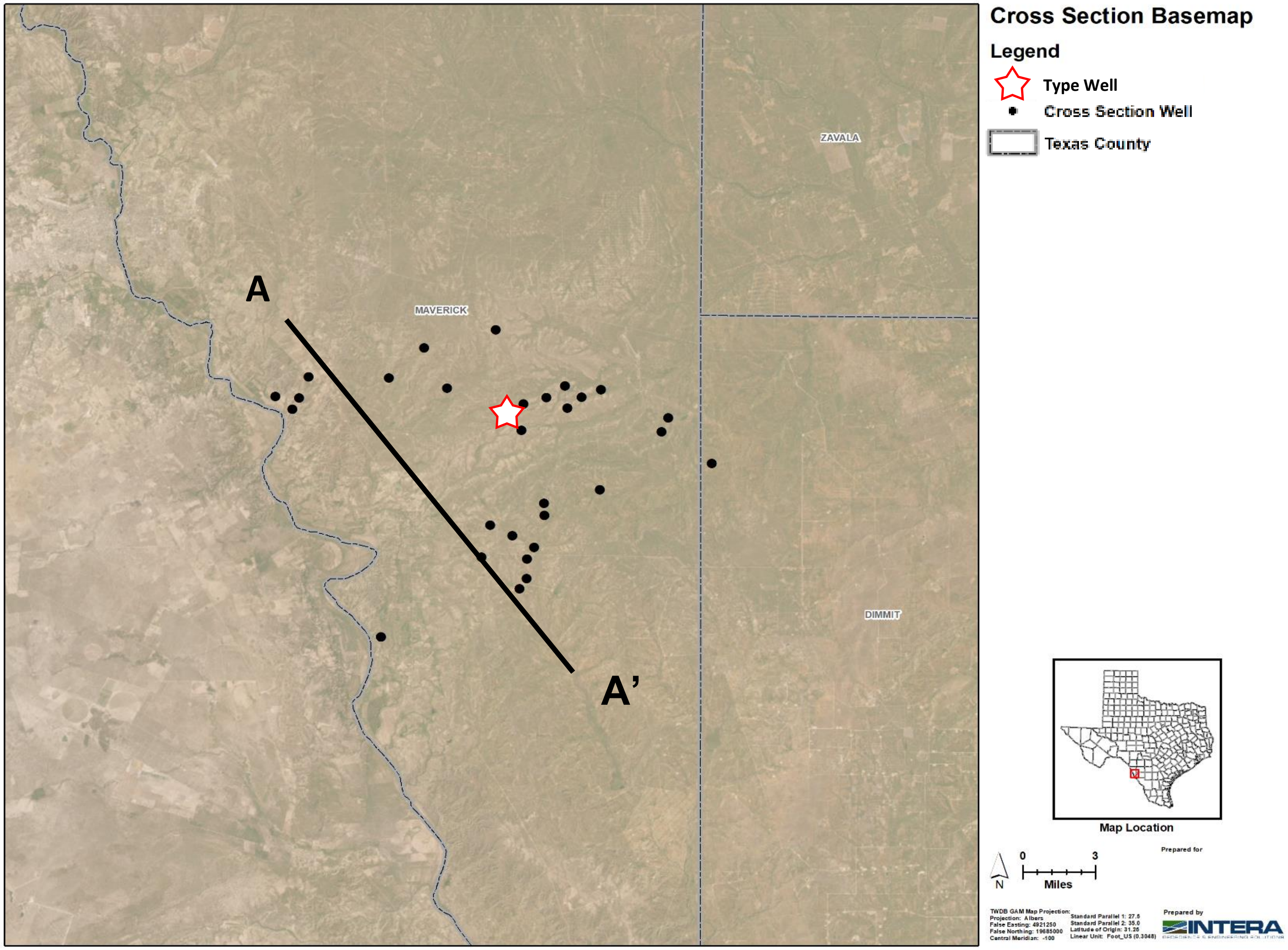

Figure 3.9-1. Cross section well locations.

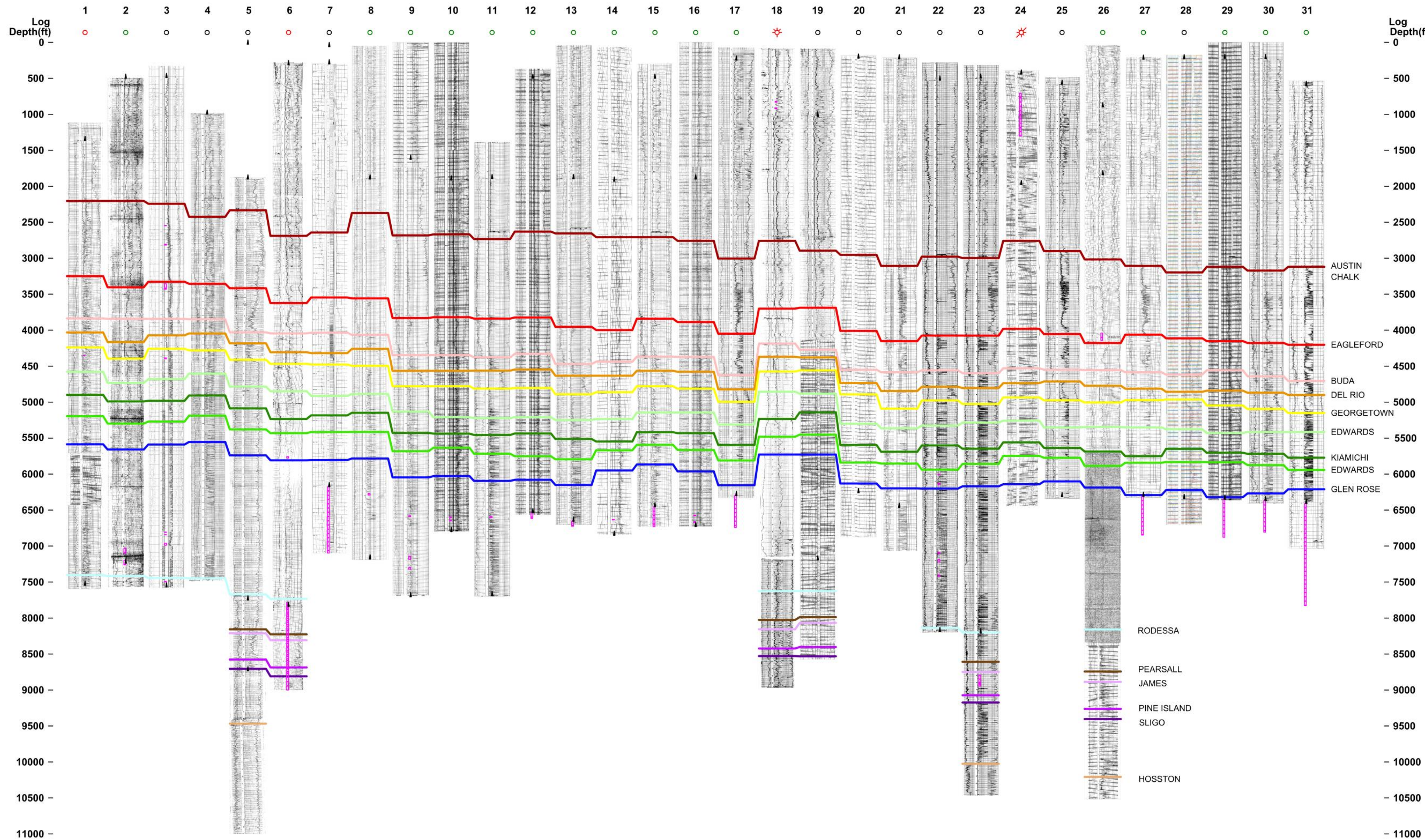

Figure 3.9-2a. Cross section A-A'.

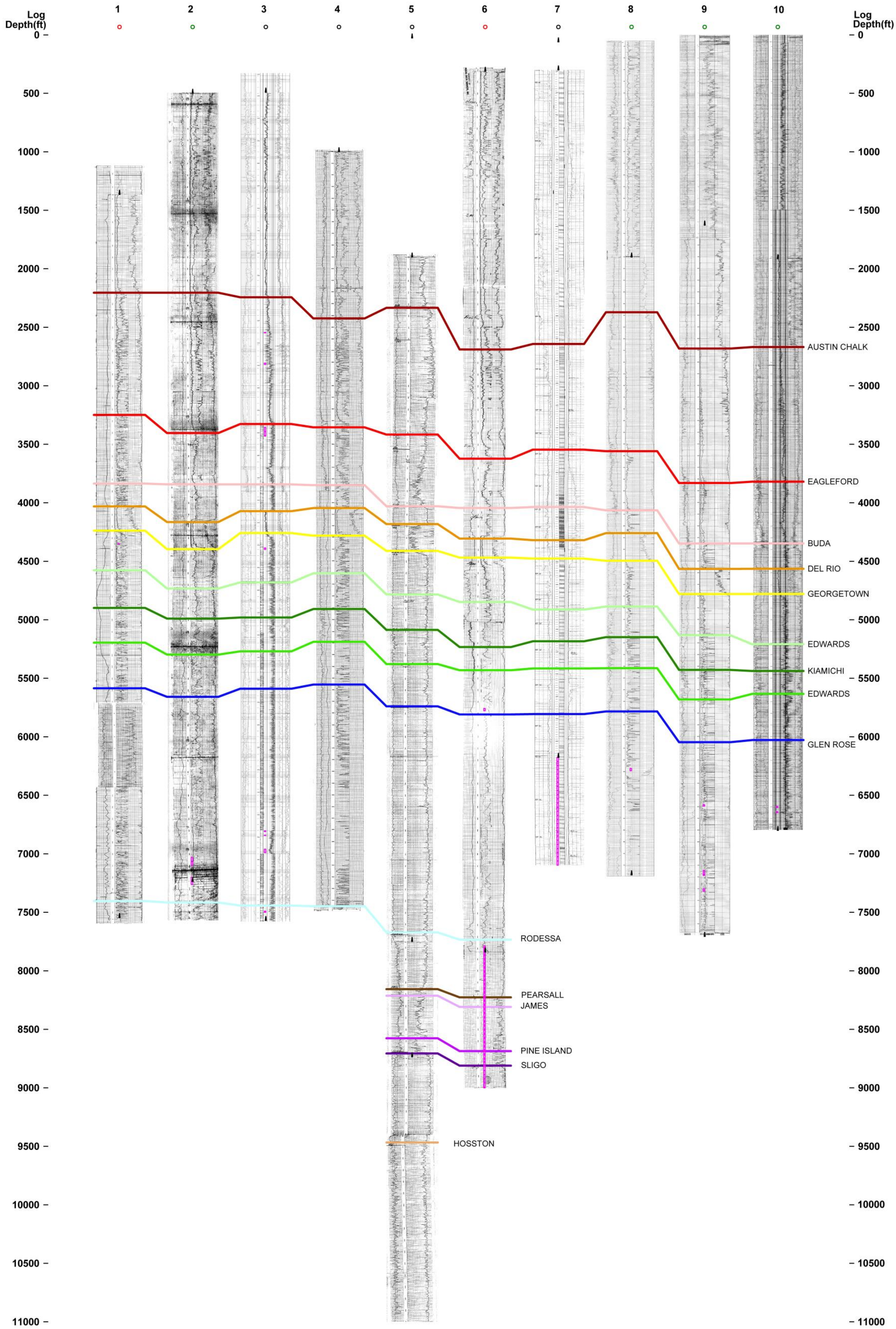

Figure 3.9-2b. Cross section A-A' (subset of logs 1 through 10).

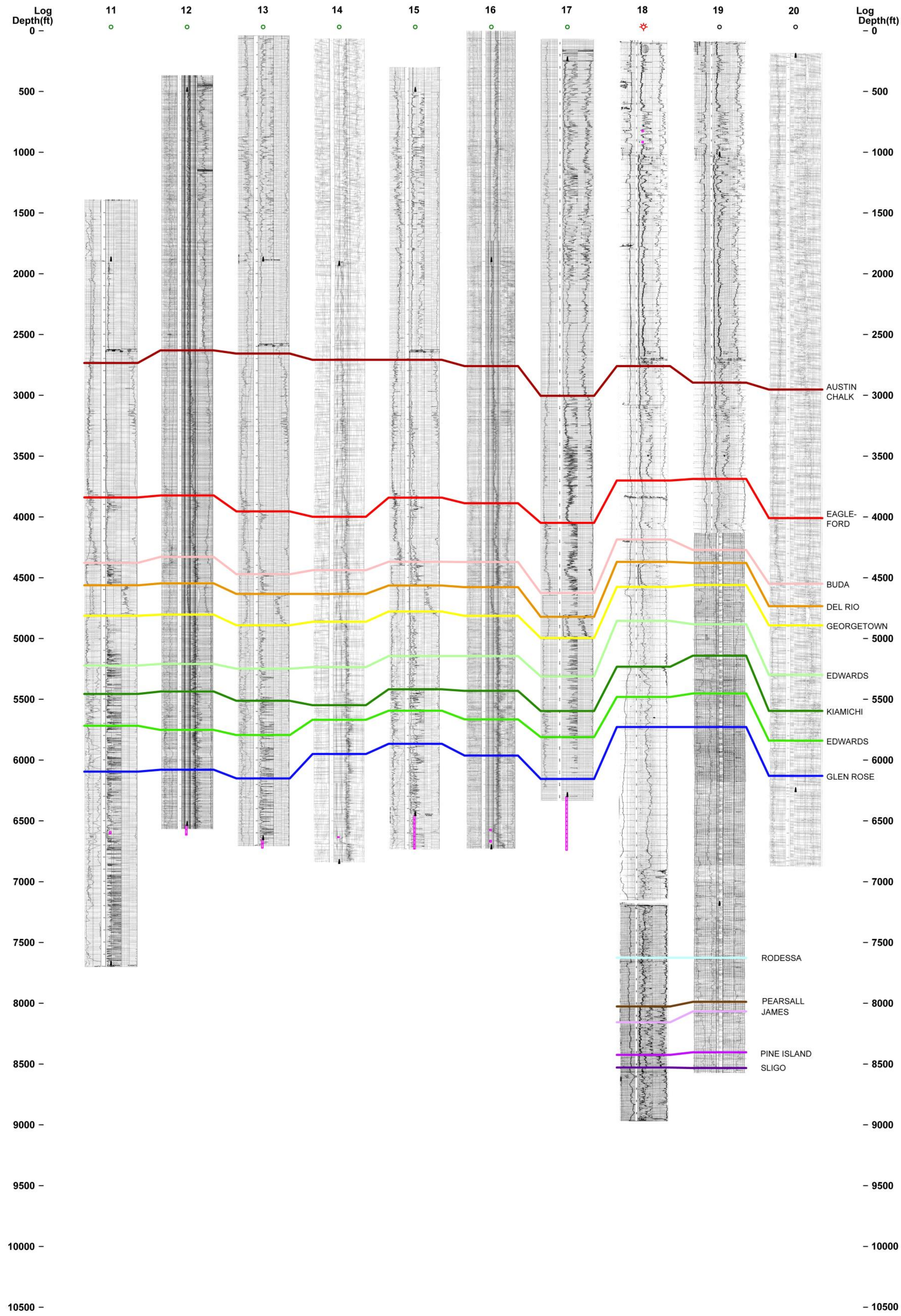

Figure 3.9-2c. Cross section A-A' (subset of logs 11 through 20).

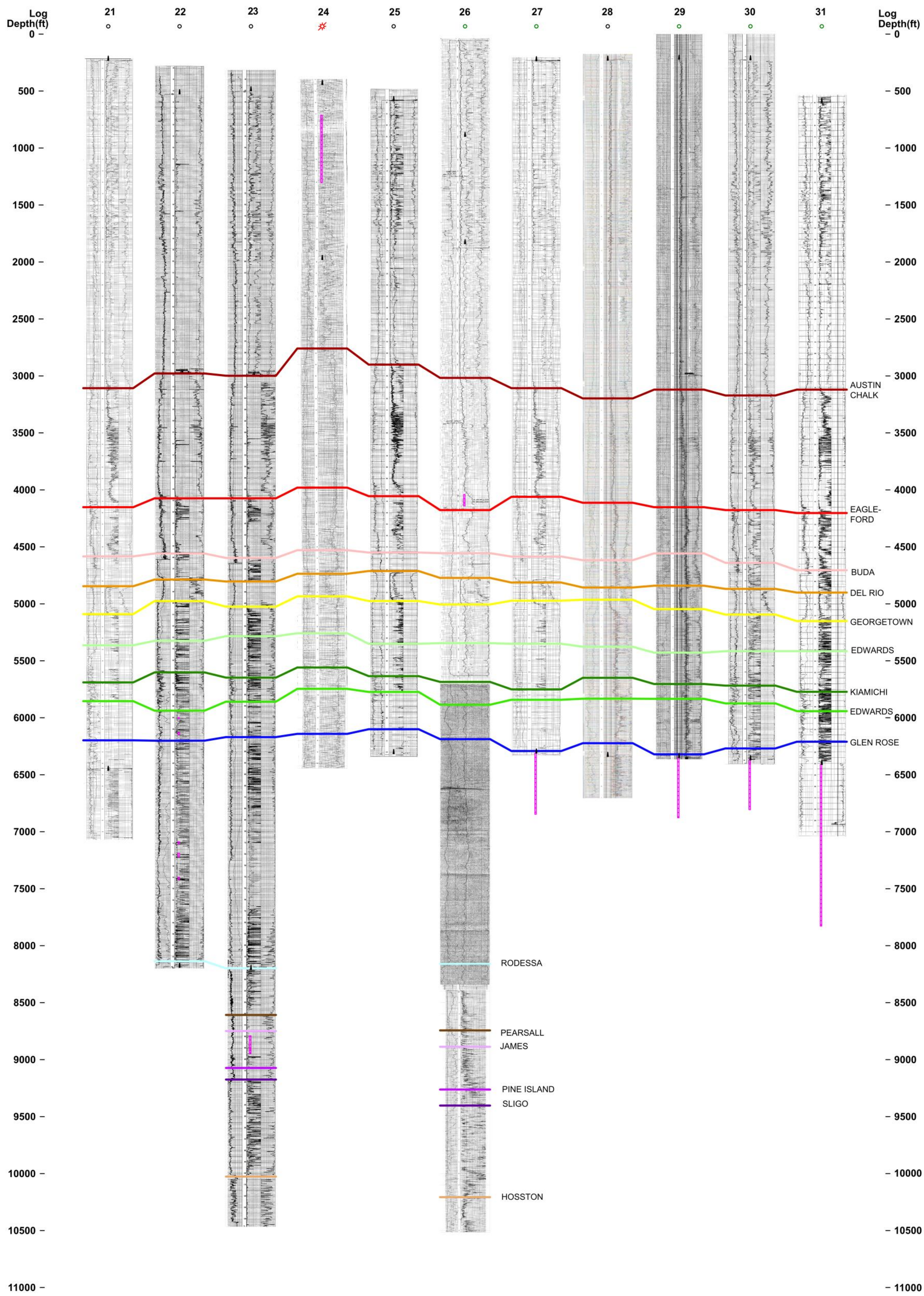

Figure 3.9-2d. Cross section A-A' (subset of logs 21 through 31).

From top to bottom, the geophysical markers at the top of the Austin Chalk through the Edwards are correlated. The Edwards-Glen Rose Formation contact is subtle but marked by a slight leftward deflection in spontaneous potential and gamma ray logs as well as a change in overall character, manifesting as less overall variability in the well log signature. The Glen Rose Formation is a uniformly low gamma ray and spontaneous potential formation, with fewer spikes or deflections. The Glen Rose Formation is also much thicker than the Edwards, so the pick is made by identifying where the log signature loses variability following a left deflection. The bottom of the Glen Rose Formation is often difficult to resolve by geophysical logs. On most logs, a positive deflection, or increase in value, of the spontaneous potential or an increase in the gamma ray log indicates the bottom of the Glen Rose Formation. The Sligo Formation top is defined relatively consistently as a sharp left deflection on the gamma ray logs, and a left deflection on the spontaneous potential log. Since the Sligo Formation has a known geophysical log character, it can be contrasted with the thick Glen Rose Formation to draw in contacts between the top of the Glen Rose Formation and the top of the Sligo Formation. The lowest marker in the cross section is the top of the Hosston Formation and is easily distinguished from the overlying Sligo Formation by an increase in the spontaneous potential and gamma ray signatures.

Perforations occur throughout the Glen Rose Formation, with some wells perforating the majority of the unit, and others only perforating a few tens of feet. From conversations with Mr. O'Brien at Saxet Petroleum, multiple horizons were being targeted within the Glen Rose Formation, and these can be observed in the section as clustered perforations around similar depths (Mr. O'Brien, Personal Communication, 2024). There are some wells that are perforated from the top of the Glen Rose Formation down several hundred feet, others are perforated from 500 to 700 feet into the formation, and others that target the lower portions of the Glen Rose Formation.

3.10 Type Log

Figure 3.10-1 is a type log from well 4232332617 located with a star in Figure 3.9-1. Data was obtained from the Railroad Commission of Texas and Comanche Ranch Energy. The geophysical logs are labeled with scales at the top of the figure and provide a complete set of geophysical readings from the Glen Rose Formation.

Logs presented here include caliper, gamma ray (GR), resistivity, neutron and density, photoelectric (PE), and sonic. The caliper logs measure the diameter of the borehole and are used to identify washouts or other anomalies in the borehole. Often washouts can affect geophysical signatures, so the caliper provides a check on interpretation. The neutron log measures the activity of the hydrogen atom, which is mainly found in fluids occupying pore space, and provides an estimate of porosity. The density log is a measure of how dense the lithology is relative to a standard. The photoelectric log measures the photoelectric response in the borehole, which is a rough indicator for lithology. A guide to interpreting the photoelectric log is given in Figure 3.10-2. The sonic log measures the sonic velocity of the formation and provides another estimate of density and, through analysis, porosity.

These logs show fairly low gamma ray values through the Glen Rose Formation, with some minor variations. Resistivity is relatively homogeneous throughout, and fairly similar to the overlying Edwards Formation. Neutron and density logs show minor variation however, it is likely attributed to washouts in the borehole, since much of the variation in the density log directly corresponds to variations in the caliper log. The photoelectric log, where not affected by the shape of the borehole, shows a mixture of carbonate/anhydrite and dolomite signatures, as expected. From literature (Scott, 2004; Railroad Commission of Texas, 2021b), the Maverick Basin aquifer is a hydrothermally altered carbonate unit with large porosity and water drive.

The well in Figure 3.10-1 (4232332617) produced 1.4 million barrels of water and 183 thousand barrels of oil, resulting in an oil-water ratio of 13%. Initial production test on the well produced 438 barrels of oil and 174 barrels of water from the uppermost perforation. Like other Maverick Basin aquifer wells, the oil production eventually diminished as water production increased.

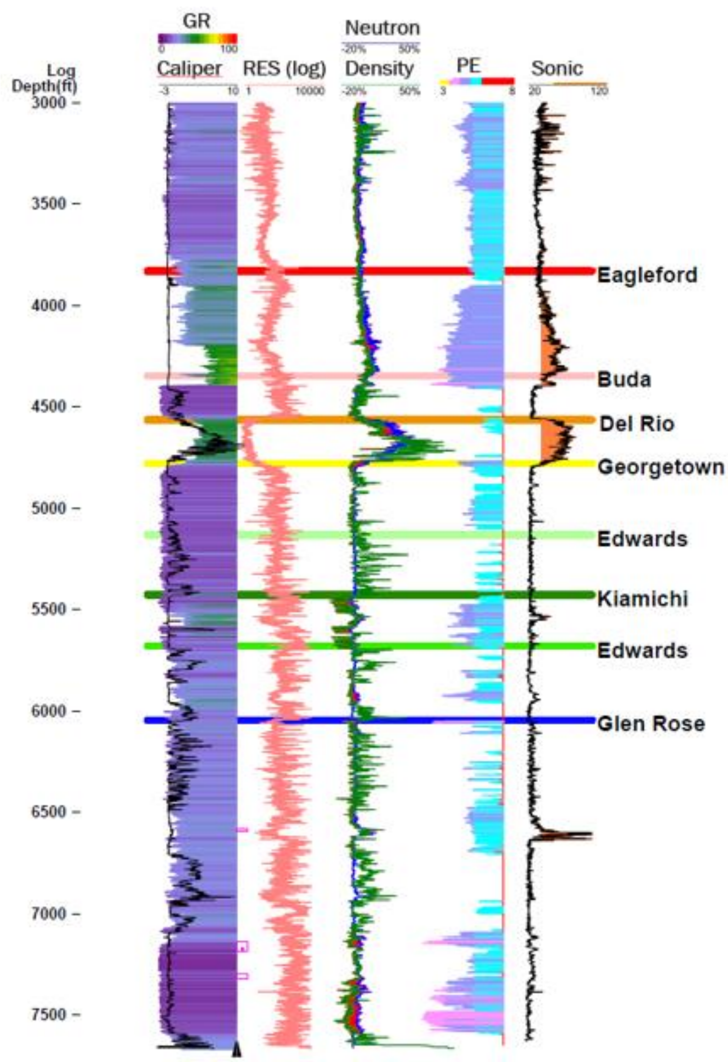

Figure 3.10-1. Type log from well 4232332617.

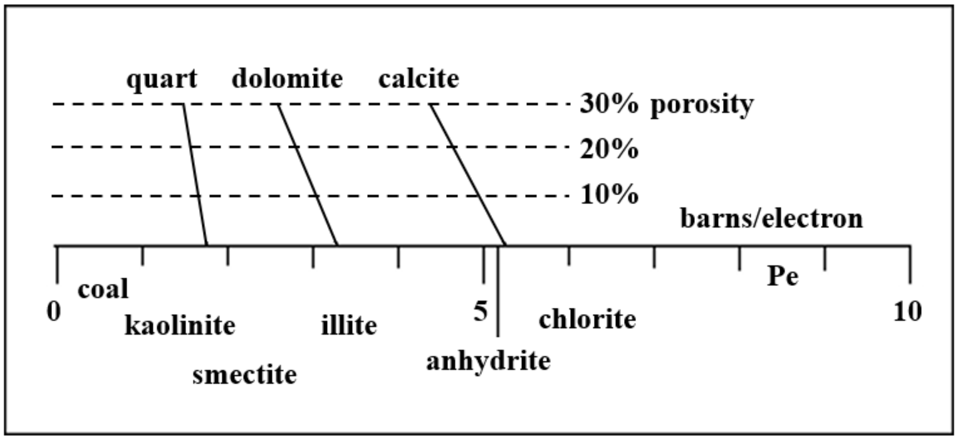

Figure 3.10-2. Photoelectric log values and interpretation with changing porosity. (Kansas Geological Survey, 2003)

There are three small (tens of feet) perforations in the Glen Rose Formation at this well. The first at 6,580 to 6,592 is inferred to target the anomalous increase in the porosity over that interval. The second perforation is at 7,142 to 7,185 and the third is at 7,298 to 7,320. It is not as obvious why these perforated intervals were selected.

3.11 Glen Rose Formation Well Production Curves

Figures 3.11-1 is a figure that shows oil and water production for five wells in the Glen Rose Formation, as provided by Comanche Ranch Energy. The x-axis is the time since the wells were brought online, and the y-axis is the volume in barrels. Oil production falls off substantially in the first few months after the well comes online. The graph is consistent with takeaways from Scott (2004) in that Maverick Basin aquifer wells appear to consistently decrease in oil production and increase in water production over time.

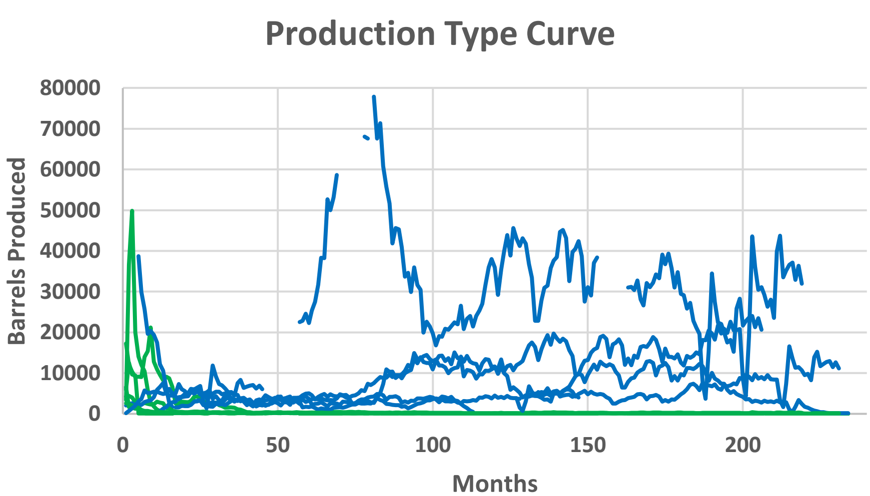

Figure 3.11-1. Production type curve for five different CMR Energy surface discharge permitted wells. Blue lines are water production and green are oil production. Gas is mostly negligible in this part of the basin.

3.12 Seismic data

Figure 3.12-1 is the available seismic data for the region from Draper and others (2021). This coverage represents all data advertised from SEI, Seitel, and other major seismic vendors, and is not exhaustive of all seismic data in the study area. The Scott (2004) seismic anomaly map presented in Figure 3.5-2 was constructed with a 3D volume sufficiently large enough to cover the entire area, which does not appear on the seismic map. It is likely that Scott's (2004) data is proprietary and has not been put out for lease.

3.13 Anecdotal information

Robert O'Brien, President of Saxet Petroleum, provided some anecdotal information from experience working on this reservoir. Below are his comments regarding Cinco Ranch Glen Rose Formation test wells:

"There are several wells drilled on or near the Cinco Ranch, but the only wells mentioned here are wells that penetrated the Glen Rose Formation.

In 1969, the Tiger Oil and Gas - #1 Lula B. Evans well, 42-323-30002, located on the Cinco, per the scout ticket, the well encountered a "kick", or contained blow-out situation, in the lower Glen Rose Formation reef section, reported testing gas and "hot fresh water" with an estimated flow potential of 3,000-4,000 barrels of water per day and they also tested a deeper water zone at 2,000 barrels of water per day lower in the Glen Rose Formation. No mention was made of the chloride content of the produced water, although the results of the testing displayed a highly porous and permeable reservoir. These reservoir zones are locally known as the Glen Rose Formation Reef or Rodessa Reef.

In the years following, this well was offset by two wells to the southwest, the North American Royalties – W.H. George 18 #1 well, 42-323-30167, and the Canus Petroleum – George #1 well, 42-323-31579. As observed from the e-log both wells were drilled through the Glen Rose Formation reef interval but there is no mention of testing the Glen Rose Formation reefs.

In 2001, Saxet Energy drilled the Cinco Ranch B-1 well, 42-323-32591, to test a seismic anomaly, and tested two freshwater zones within the same Glen Rose Formation reef formation previously tested by the Tiger–Evans well. The zones flowed water at rates of 300–348 barrels of water per day with chlorides measured at 440-800 parts per million. This well was subsequently plugged and abandoned.

In 2008, Red Arrow drilled the Cinco Ranch 1-10H well, 42-323-33218, and the Cinco Ranch 1-4H well, 42-323-33222. The 1-10H well encountered gas and formation water shows while drilling the horizontal hole and eventually lost drilling tools in the hole. No records of testing were made, and the well was junked and plugged two years later.

The Cinco Ranch 1-4H well was drilled to test the Glen Rose Formation 4 interval (near the top of the formation) and was kicked horizontally ~ 900' across a seismic anomaly.

The well produced water-free for a few days and then began making freshwater. The well produced over 12,000 barrels of oil and 357,000 barrels of water until being shut-in in 2013. Prior to plugging, the operator turned the well over to the surface owners (Cinco). The 1-4H continued as a stripper well from 2017 before being shut-in in 2018 producing another 670 barrels of oil and 105,000 barrels of water. Records show the chlorides of freshwater decreased over that year from 300 to 100 ppm.

The Cinco 1-4H well was converted to a P-13 status in the fall of 2022 and we began testing the well with various choke sizes to determine water volume rates. As the choke was opened, slugs of oil flowed with water with the oil cut remaining < 5%. In April of 2023, the chokes were pulled to see the results of the flow rate up the 2 7/8ths tubing and the well averaged 23 barrels of oil per day and 1,200 barrels of water per day. May averaged 12 barrels of oil per day and 1,193 barrels of water per day, June averaged 7 barrels of oil per day and 1,162 barrels of water per day, the well then stabilized for the months July, August, and September at approximately 4 barrels of oil per day and 1,239 barrels of water per day. Other notes: The oil cut continues to decrease. Chlorides are 59 ppm, wellhead temperature is ~ 170 degrees, FTP is < 5 psi, and the well is flowing and not on pump.

In conclusion, the Glen Rose Formation well tests on the Cinco have reported high volume freshwater tests from the Glen Rose Formation 4 to the Glen Rose Formation reef, approximately 1,800’ of column, indicating a large interval containing fresh water. We are encouraged by the data so far and are working on ideas for further development.”

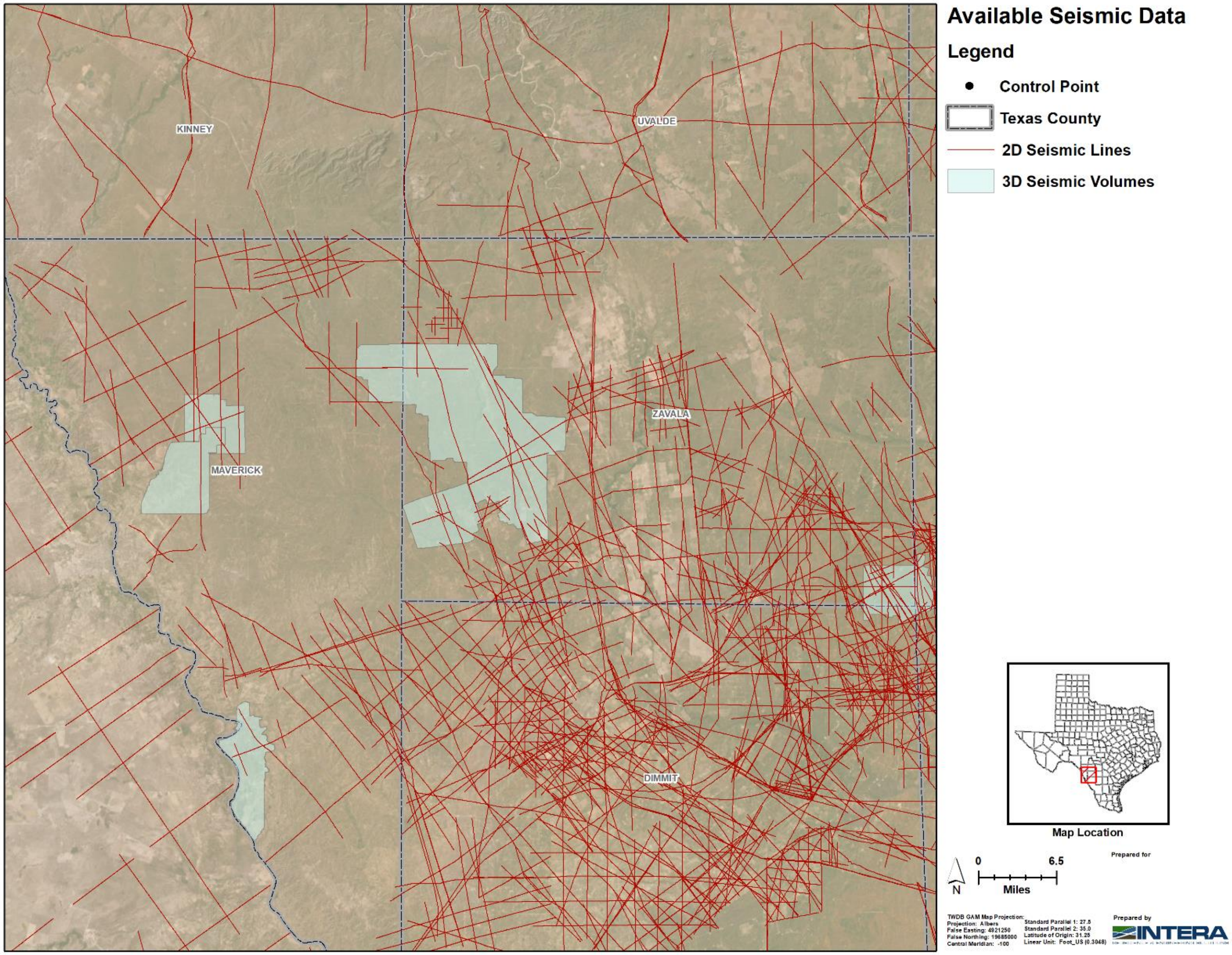

Figure 3.12-1. Seismic data coverage.

4 Discussion

4.1 Introduction

The recent publicity around the Maverick Basin aquifer has generated significant interest in its potential to serve as a new water resource in a water scarce region. However, there are substantial challenges that need to be addressed to develop this deep, complex aquifer into a viable long-term water supply. The first challenges relate to the lack of data. Additional challenges will need to address cross-border impacts of pumping in this aquifer and how the Railroad Commission of Texas and Texas Water Development Board will classify this potential resource.

This chapter explores the current state of understanding of the Maverick Basin aquifer system based on available research and outlines the critical challenges and future work needed to guide its development. Recommendations include basic data collection and aquifer testing.

4.2 Conceptualization

The current conceptual model of the Maverick Basin aquifer system is based on a small body of research focused on the unique hydrogeology of the Glen Rose Formation in this region. Key elements of this conceptual model, which are visualized in Figure 4.2-1, include:

- Recharge: The primary recharge zone for the aquifer is believed to be via the Glen Rose Formation outcrop in Mexico. Earlier hypotheses of recharge also occurring via outcrop zones in Texas appear unlikely based on very low water cuts observed in most Glen Rose Formation gas wells between the study area and the Glen Rose Formation outcrop north of the Anacacho mountains in Texas (Railroad Commission of Texas, 2021b).
- Transmission: In Maverick County, Glen Rose Formation groundwater flow is highly dependent on secondary porosity features associated with localized hydrothermal alteration and fracture networks, rather than matrix flow. This may be the case in Mexico, closer to the recharge zone.
- Discharge: Natural discharge from the aquifer is unknown, with the only exception being discharge from producing water and oil wells in Maverick County.

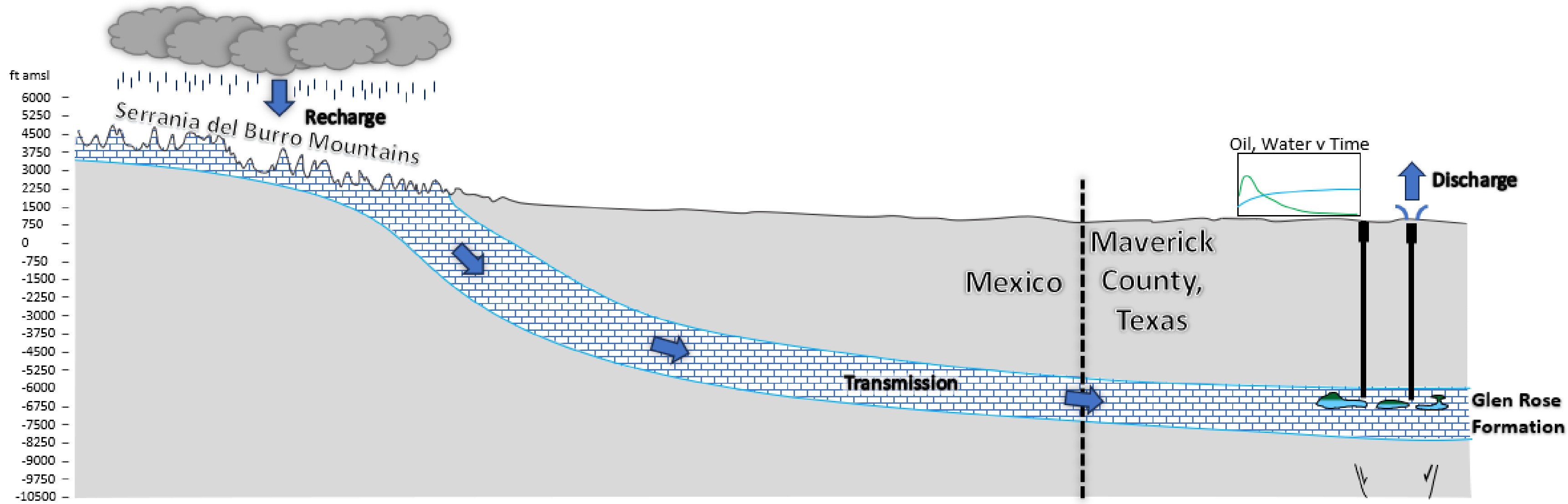

Figure 4.2-1. Simple conceptualization of the modern configuration of the Maverick Basin aquifer. It is hypothesized that recharge occurs in the Serrania del Burro Mountains in Mexico and is transmitted through the Glen Rose Formation where it eventually encounters zones of enhanced porosity in Maverick County. The only known discharge is through oil and water wells.

4.3 Preliminary Proposed Boundary for the Maverick Basin aquifer

With only a handful of P-13 and R-2 permit applications filed to date, establishing a formal boundary for the Maverick Basin aquifer remains highly uncertain. As an initial approach, a 3-mile buffer zone was applied around wells with recorded low total dissolved solids and wells with a permit application, yielding the preliminary aquifer footprint shown in Figure 4.3-1. An envelope that encompasses all the 3-mile buffers is presented in Figure 4.3-2. This initial approach at defining the potential aquifer boundary is a rough approximation at best given the lack of data and understanding of the porosity trends.

A more hydrogeologically-based definition for the aquifer boundary may be to include all areas where the groundwater has a total dissolved solids less than 10,000 milligrams per liter and producing oil and gas wells with water cut over 90%. This would require more data on both water quality and well performance across a large area but offers a more meaningful approach to mapping the extent of the aquifer. Until such data are available, any proposed aquifer boundaries for the Maverick Basin aquifer should be considered tentative and subject to revision.

4.4 Challenges and Future Work

4.4.1 Aquifer Characterization

Insufficient data exists to properly characterize the aquifer with traditional hydraulic parameters like transmissivity, storage, or hydraulic conductivity. There are however some long-term water production records which provide minor insights into potential production trends from the aquifer.

As noted by Scott (2004), the high-permeability zones in the upper Glen Rose Formation appear to be associated with hydrothermal alteration and fracture networks rather than primary matrix porosity. This suggests that groundwater flow and storage may be highly localized and anisotropic, making it difficult to extrapolate aquifer matrix properties from individual well tests. Thus, even if there were more ideally completed water wells in the Glen Rose Formation, there would need to be a thorough series of aquifer tests performed to conceptualize how hydraulic conductivity and storage are allocated in the aquifer.

Another challenge in assessing aquifer properties via aquifer tests is the inconsistency in well design. While most wells in the Glen Rose Formation are completed as a short horizontal lateral with an open hole, some are vertical and produce through perforated casings. Figure 4.4-1 shows these variations in completion patterns. Both inefficient perforations and lateral open hole completion present complications when trying to derive hydraulic parameters from aquifer pumping tests. Further, to determine aquifer storage, a monitor well completed in the same interval as the pumping well would need to be used to determine drawdown at distance.

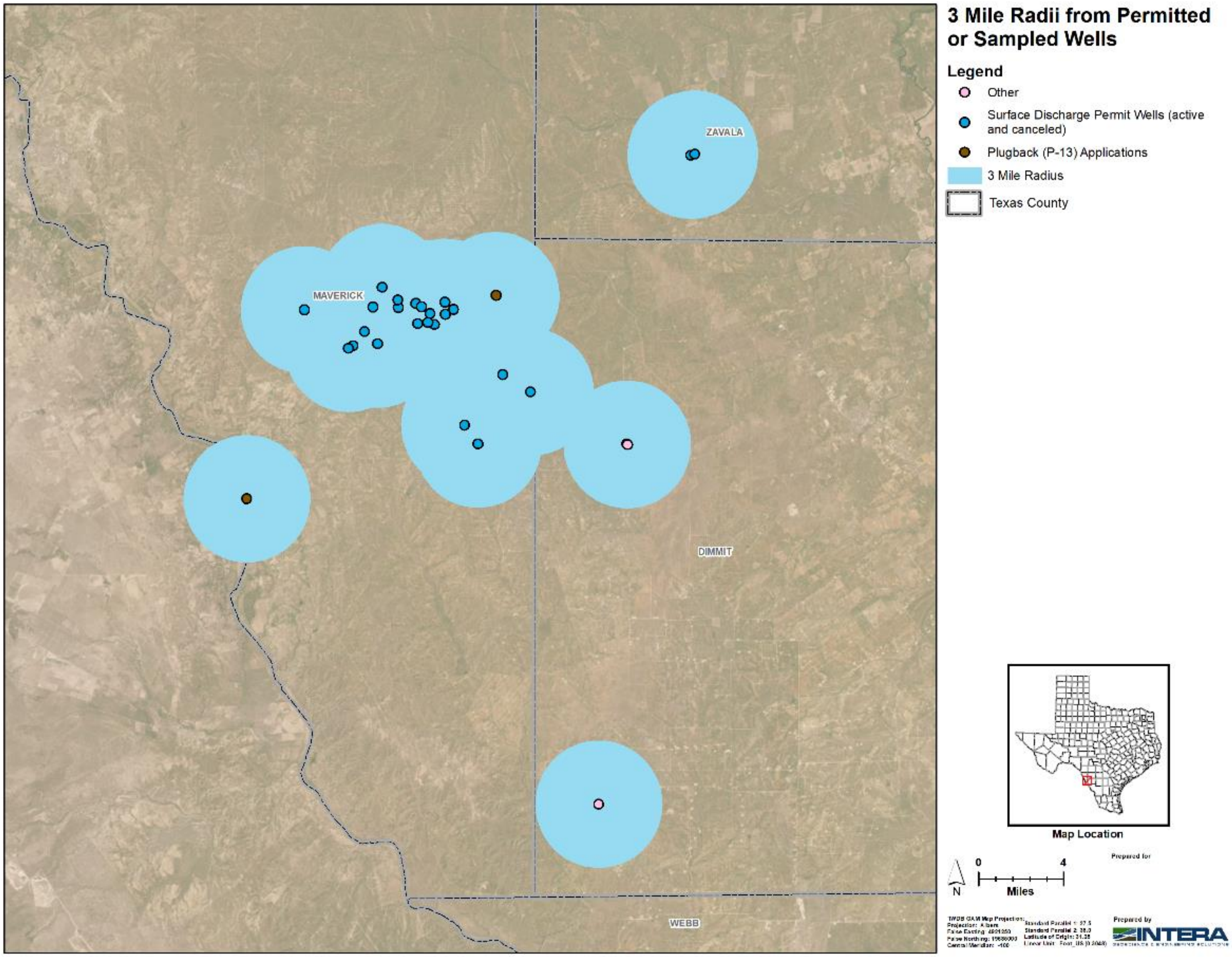

Figure 4.3-1. **Blue circles show all areas within 3-miles of a permit application for water discharge, P-13 application, or well indicating low total dissolved solids.**

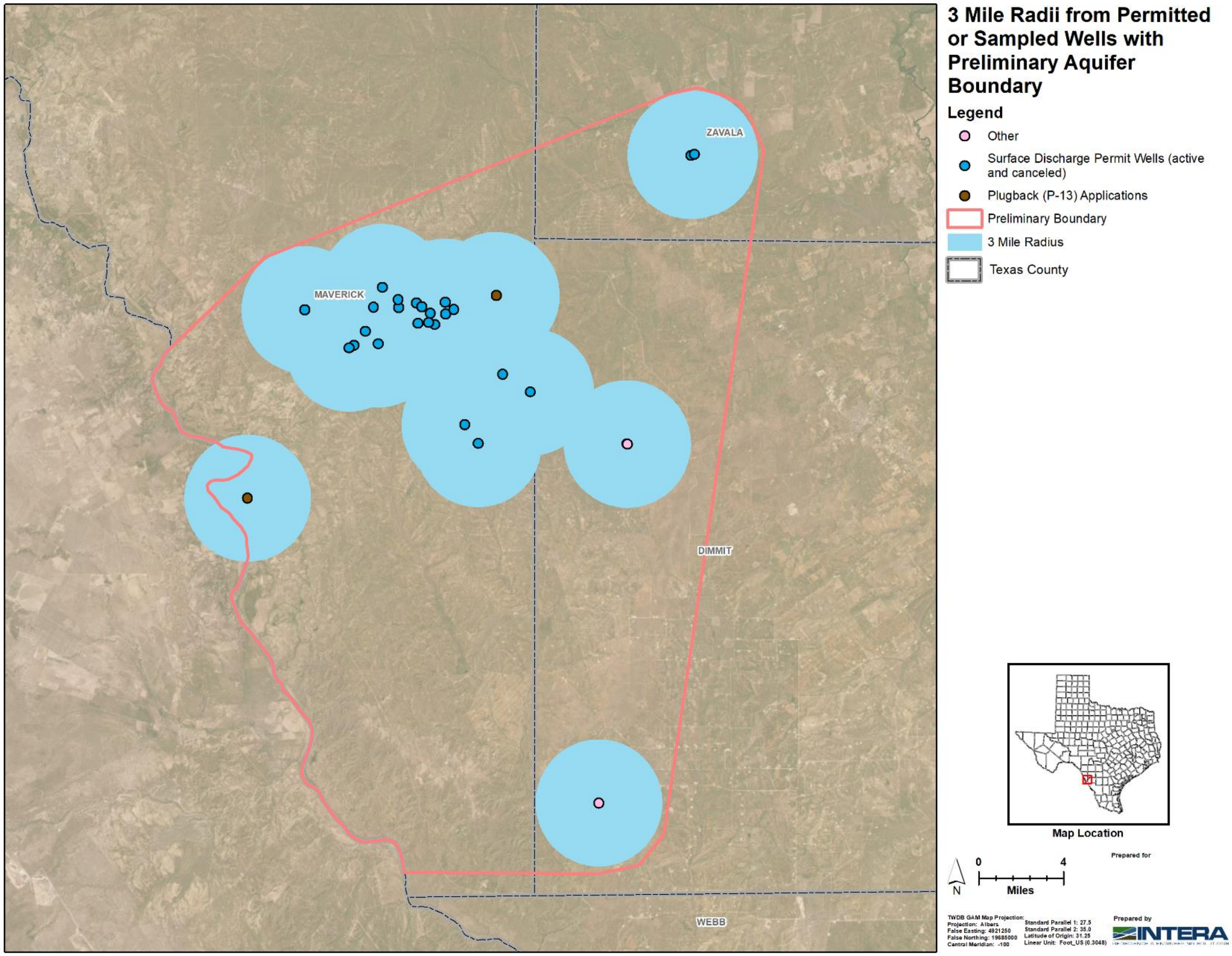

Figure 4.3-2. **Preliminary aquifer boundary that encircles all areas within 3-miles of a permit application for water discharge, P-13 application, or well indicating low total dissolved solids.**

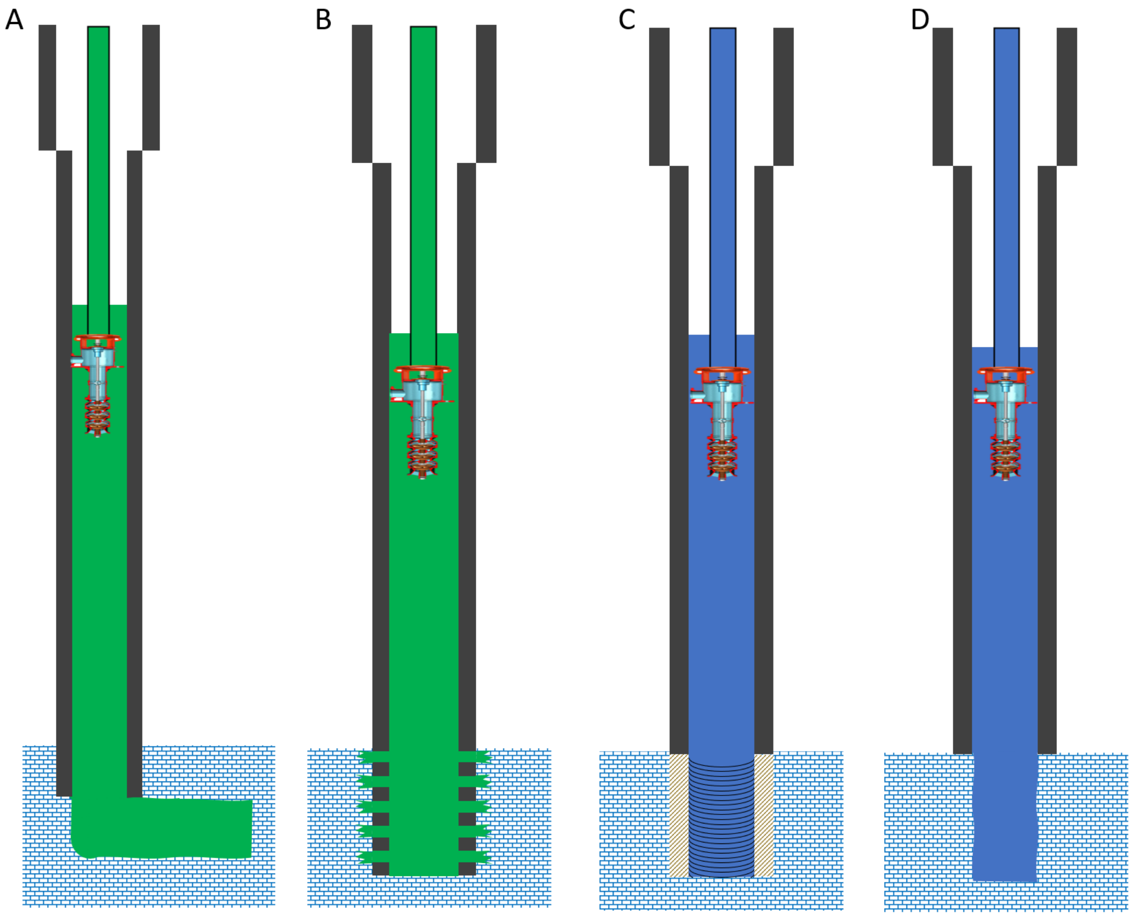

Figure 4.4-1. (A) is the typical Glen Rose Formation completion, (B) is a more standard oil and gas completion (some Glen Rose Formation wells are completed this way). (C) is a typical water well completion with a screened interval and filter pack between the screen and the formation. (D) is an open hole water well, a common water well completion in competent rock.

Despite the clear challenges, a comprehensive testing campaign is needed to better understand whether the Maverick Basin aquifer could be a viable water resource in the area. This should include the use of monitoring wells at key locations, as well as long-duration (72-hour to 30-day) multi-well aquifer tests specifically designed to evaluate the complex flow dynamics of the system. Single well tests could supplement the results obtained from the multi-well test. Similar to the approach presented by Scott (2004), 3D seismic surveys could also be employed to map the distribution of preferential flow paths and could help guide well completions. In addition, core data and borehole imaging could be used to better understand the aquifer.

The aquifer testing campaign should be comprised of two phases. Phase 1 is data collection, and Phase 2 is testing. Phase 1 aims to collect production and shut-in pressure values at open-hole Glen Rose Formation wells. Phase 2 aims to conduct aquifer tests on as many open-hole Glen Rose Formation wells as can be identified and accessed.

For Phase 1, selecting a subset of wells is necessary. Figure 4.4-2 contains open-hole Glen Rose Formation wells that have an R-2 or P-13 application. Example spacing from wells can be ascertained in Figure 4.4-3, which shows a cluster of these wells with tighter spacing. For each of the wells in Figure 4.4-2, water production records can be purchased from vendors such as S&P Global and ShaleXP or requested from the operator. Each of these wells should be shut-in to determine the shut-in pressure and then allowed to flow so that a flowing pressure could be acquired. Each pound per square inch of shut-in pressure equates to 2.3 feet of artesian head above the point of measurement. For example, a value of 15 pounds per square inch would equate to 34.5 feet of head above the measurement point. In combination with production data, a relationship between pressure and production can be developed. For example, if a well produces 36.1 gallons per minute with 34.5 feet of drawdown (hydraulic head determined by subtracting flowing pressure from shut in pressure), the specific capacity would be 1.04 gallons per minute/foot drawdown. Having measurements of production rate versus flowing and shut-in pressure could provide a rough estimated range of specific capacity. Phase 1 is necessary since the current well pressure data is either flowing tubing pressure or pressure from an initial production test, neither of which individually allow for the calculation of specific capacity. Phase 1 will also allow for the acquisition of well construction details and, potentially, which wells are adequately sized to get a small diameter slim line pump in for testing in Phase 2.

The first step of Phase 2 is determining the inner diameter of the production string of casing and what size submersible pump can be used to perform a drawdown test on the well. From available data, the typical completion is a surface casing of 8-5/8ths or 9-5/8ths inch to 500 to 600 feet below ground surface with a 5-5/8ths or 7-inch casing inside the surface casing to the top of the Glen Rose Formation, where the completion is open hole to total depth. It is possible that a 4-inch or a 6-inch submersible pump could be utilized for a drawdown test. Generally speaking, at a depth of 400 feet below ground surface, a 4-inch pump could produce up to 100 gallons per minute and a 6-inch pump in excess of 100 gallons per minute.

In an ideal situation, one Glen Rose well could be treated as the pumping well and a single or multiple proximal shut in Glen Rose wells could be treated as monitor wells. Both the pumping and monitoring wells would have pressure transducers installed. A step-drawdown test would be performed on the pumping well whereby the well would be pumped at four separate and increasing rates all while monitoring corresponding drawdown. Results from the step drawdown test would be used to determine the most ideal rate for a constant rate aquifer test. Drawdown at the test well and at the nearest monitoring wells would be recorded and analyzed for hydraulic properties.

At the end of each test, a full suite of water quality samples should be taken. This should also include a complete suite of analyses for hydrocarbon presence and associated organics. In addition, separate samples should be taken for isotopic analysis. Currently, only a lack of tritium constrains the timing of recharge to pre-1953. Carbon isotopes could help to better constraint the timing of recharge.

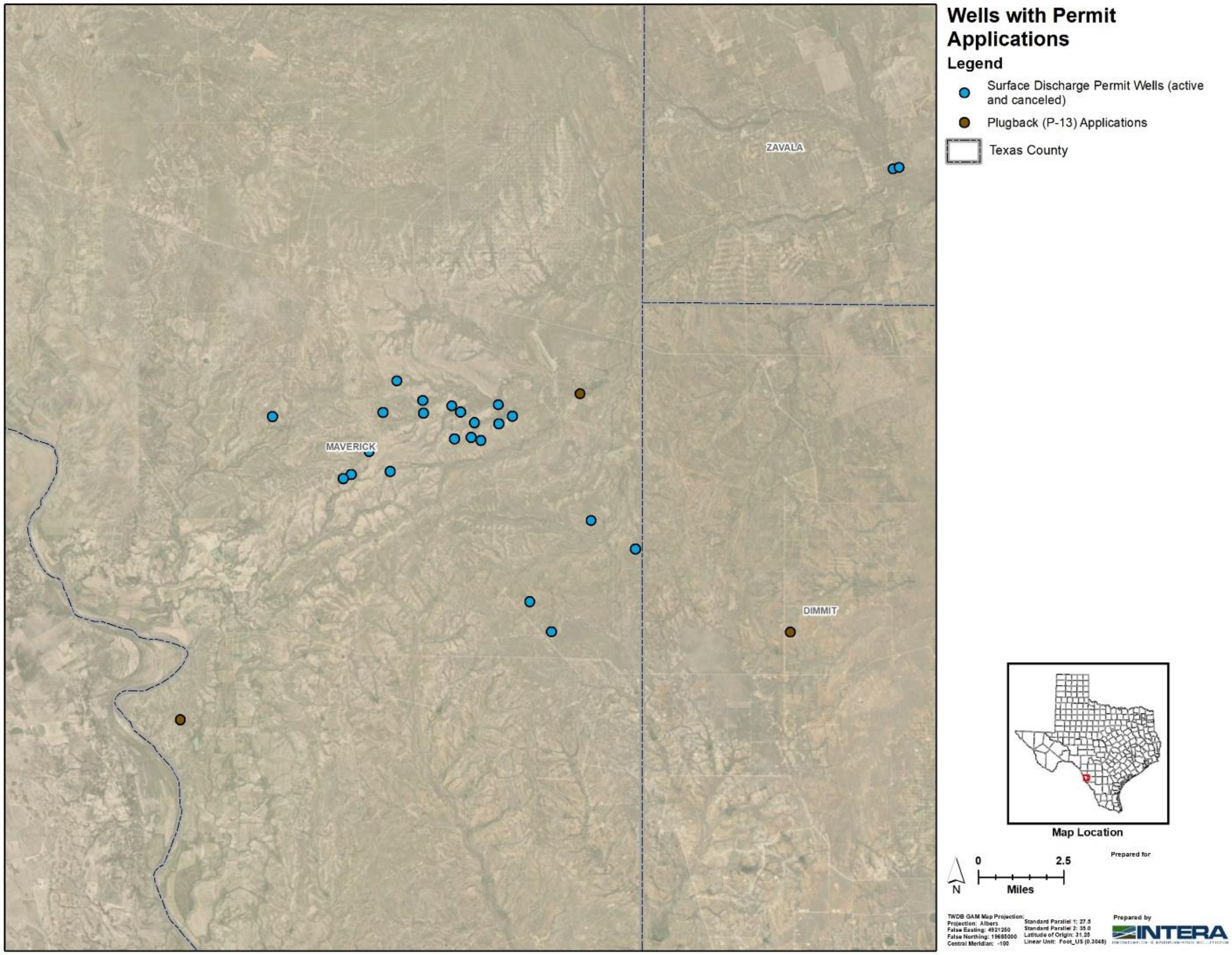

Figure 4.4-2. Wells with an open hole completion in the Glen Rose Formation.

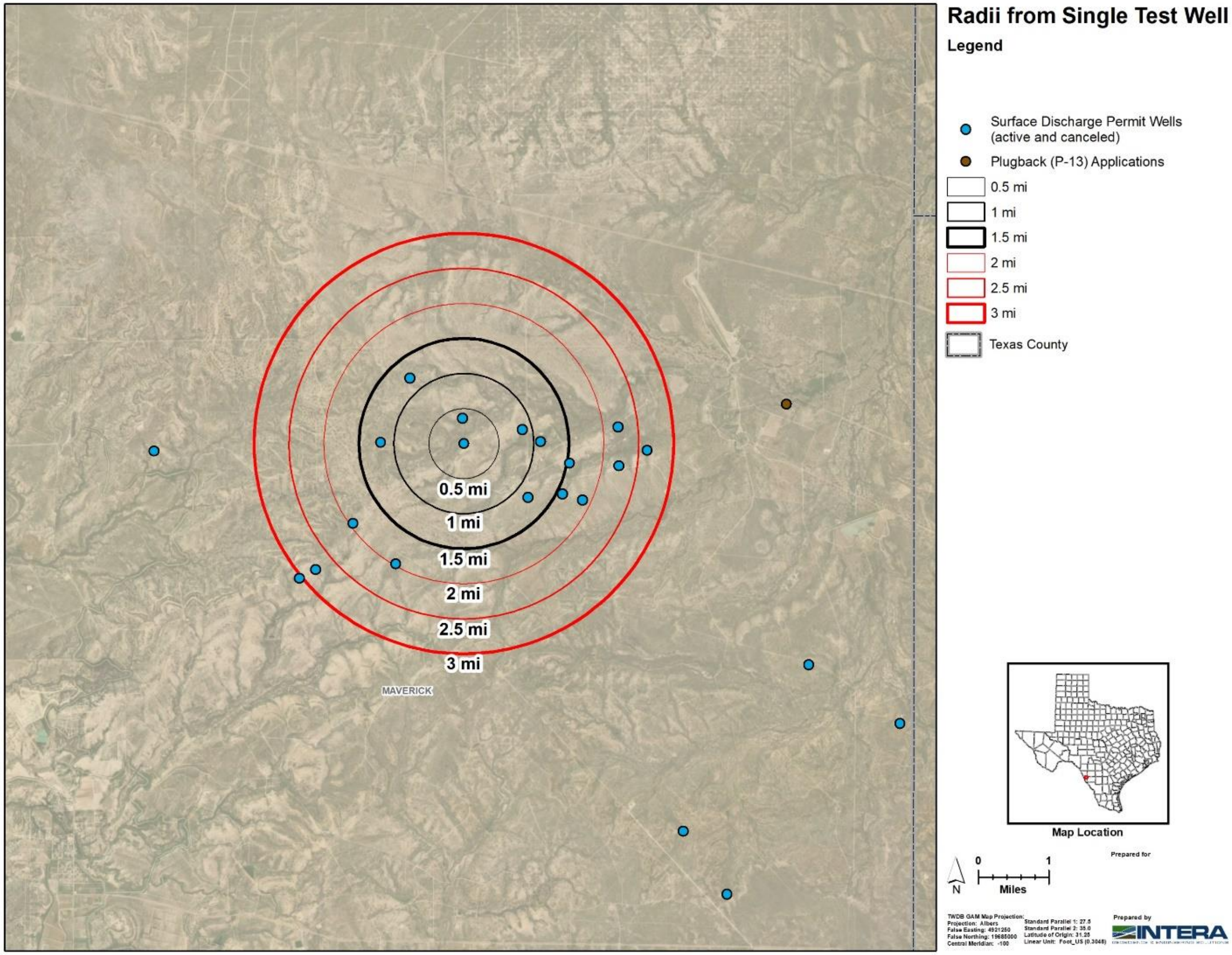

Figure 4.4-3. **Set of radii from a well to show distance from potential monitor wells. There are other wells not shown in this figure that may provide additional monitoring well opportunities.**

4.4.2 Hydrocarbon Removal

Another important consideration for the development of the Maverick Basin aquifer is the need to manage produced waters, which at many wells includes small but variable concentrations of liquid hydrocarbons. While available data suggests the oil concentrations are typically less than 5 parts per million, some level of treatment will be needed to remove these residual organics and make the water suitable for a beneficial use.

Fortunately, there are a variety of established treatment technologies that can be deployed, including physical separation (e.g., gravity separators, induced gas flotation) and filtration methods (e.g. multi-media filters, membrane separation) (Jimenez and others, 2018). The optimal treatment train will depend on site-specific factors like oil composition and concentrations, water volumes, and intended end-uses.

One unique challenge for treatment in the Maverick Basin aquifer is the potential for occasional hydrocarbon spikes during well operations. Opening well chokes can produce intermittent slugs of higher oil volumes that would require additional treatment to remove. Building in redundancies and additional surge capacity as part of the treatment design will be important to accommodate these potential fluctuations. Ongoing water quality monitoring before and after treatment will also be critical to ensure performance targets are being met.

4.4.3 Transboundary Issues

Currently, there are no active groundwater wells within the Glen Rose Formation of the Maverick Basin in Texas. There is also rule-of-capture operating in most of the area of the Maverick Basin aquifer as Maverick County is not under the jurisdiction of a groundwater conservation district (Figure 4.4-4). Even so, this aquifer is a transboundary aquifer, and as such is shared by the United States and Mexico (Sanchez and others, 2018). For any transboundary issues to be mitigated, there would need to be a Texas regulatory authority on the Texas side of the border.

It is currently unknown whether the same dissolution features and enhanced permeability exist on the Mexican side of the border. If so, groundwater development there may be less capital intensive due to shallower completion depths. This could result in increased pumping from the Mexican portion of the aquifer, which in turn could impact water availability for down-gradient users in Texas.

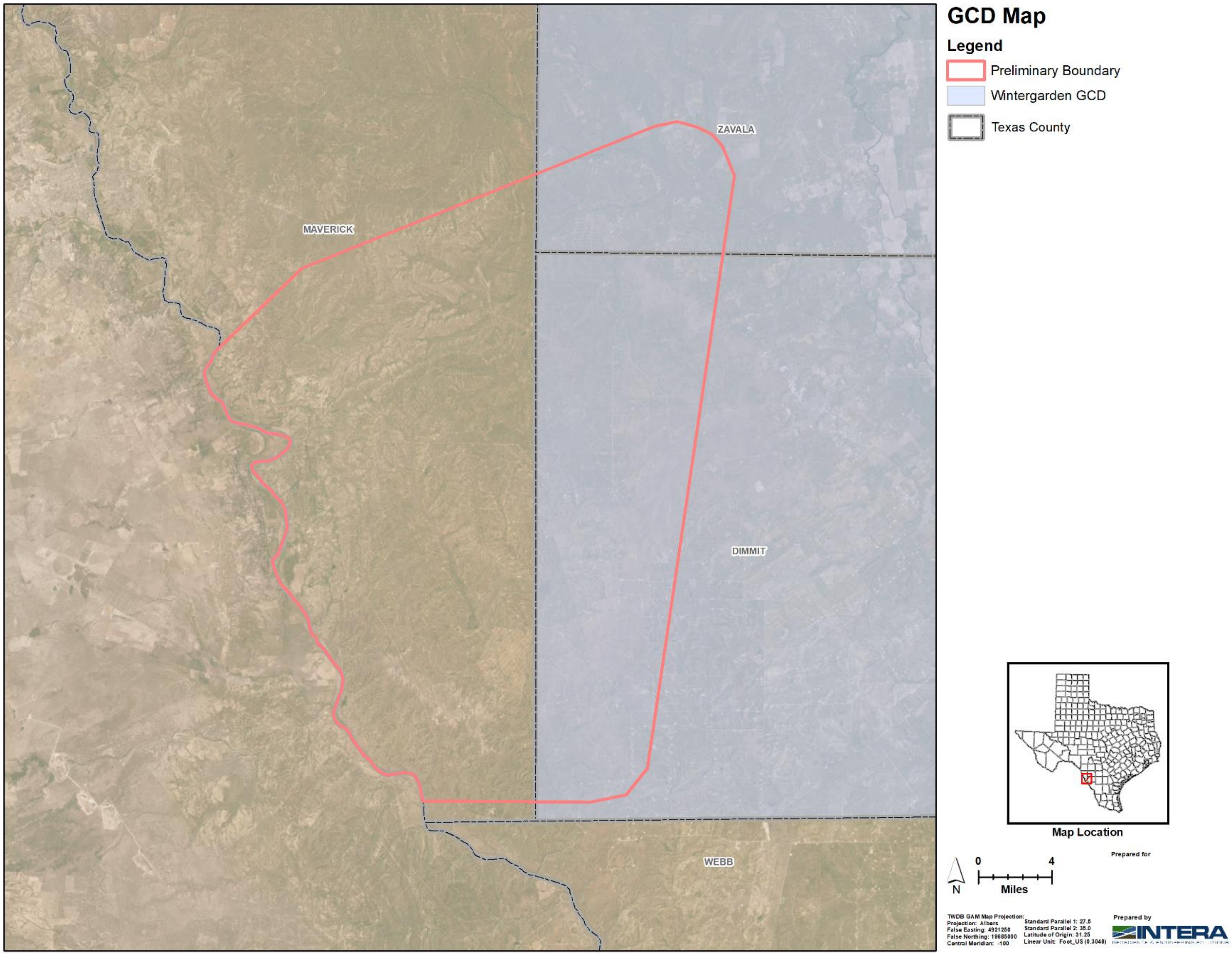

Figure 4.4-4. Groundwater conservation district map against the proposed boundary of the Maverick Basin aquifer.

4.4.4 Injection Wells

The presence of both active and inactive injection wells in the Glen Rose Formation (Figure 4.4-5) poses another challenge for the development of the Maverick Basin aquifer. In particular, the presence of an active saltwater disposal well near a newly submitted P-13 application raises concerns about the potential migration of lower-quality injectate into the aquifer over time. Depending on the future status of the Maverick Basin aquifer, the Railroad Commission of Texas may need to carefully evaluate the compatibility of proposed injection activities with the development of the Maverick Basin aquifer. Currently, there is only one active injection permit in the Glen Rose Formation within the preliminary aquifer boundary (Figure 4.4-5), with an injection permit for 15,000 barrels per day.

4.5 Regional Water Planning and Stakeholder Engagement

The Railroad Commission of Texas and other state agencies could work to clarify the regulatory status of produced water from the Glen Rose Formation and to develop guidelines for its management and reuse. This could include the development of specific rules or permits for the reinjection of produced water into the Glen Rose Formation for enhanced recovery or aquifer storage and recovery. The state of Texas has already started this process by funding the Texas Produced Water Consortium. The Maverick Basin aquifer presents an opportunity for the Texas Produced Water Consortium to develop a model consistent with its purpose of "*using produced water in a way that is economic and efficient and protects public health and the environment. The consortium will provide guidance for establishing produced water permitting and testing standards and will suggest changes to law and administrative rules to better enable the use of produced water.*" (https://www.depts.ttu.edu/research/tx-water-consortium/)

Another important area for future work is to integrate the Maverick Basin aquifer into regional water planning efforts and to engage stakeholders in the development of the resource. This could include:

1. Quantifying the potential contribution of the Maverick Basin aquifer to meeting water supply needs identified in the water plans for Region L South Central Texas and Region M Rio Grande (Figure 4.5-1).

2. Engaging with local water providers, such as the Eagle Pass Water Works or Laredo Water, to assess their interest in and capacity for developing the Maverick Basin aquifer.

3. Conducting outreach to local landowners and other stakeholders to understand their concerns and perspectives on aquifer development.

4. Collaborating with groundwater conservation districts and other local and regional water planning entities to develop policies and rules for the sustainable management of the Maverick Basin aquifer.

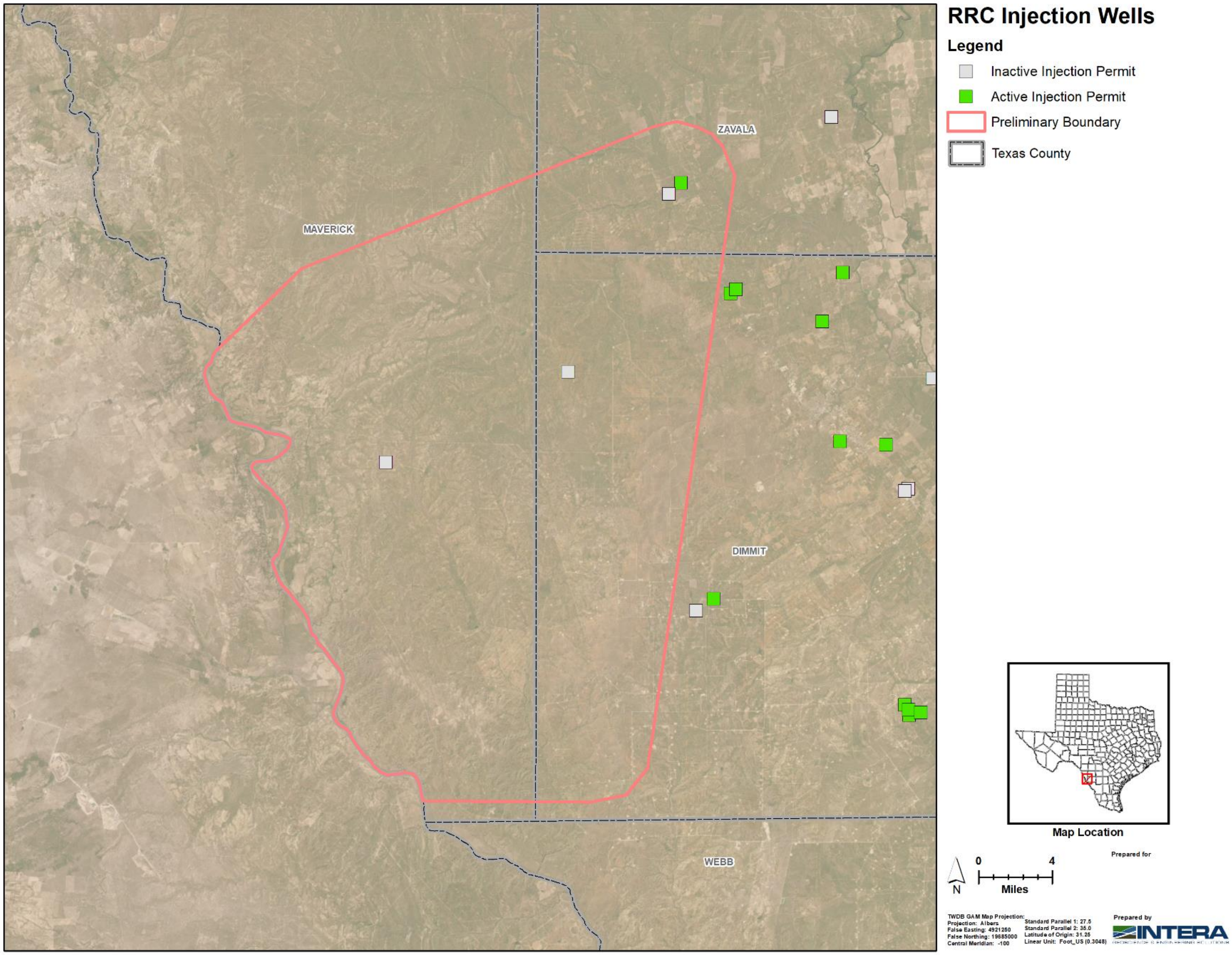

Figure 4.4-5. Railroad Commission of Texas injection wells, active and inactive, completed in the Glen Rose Formation.

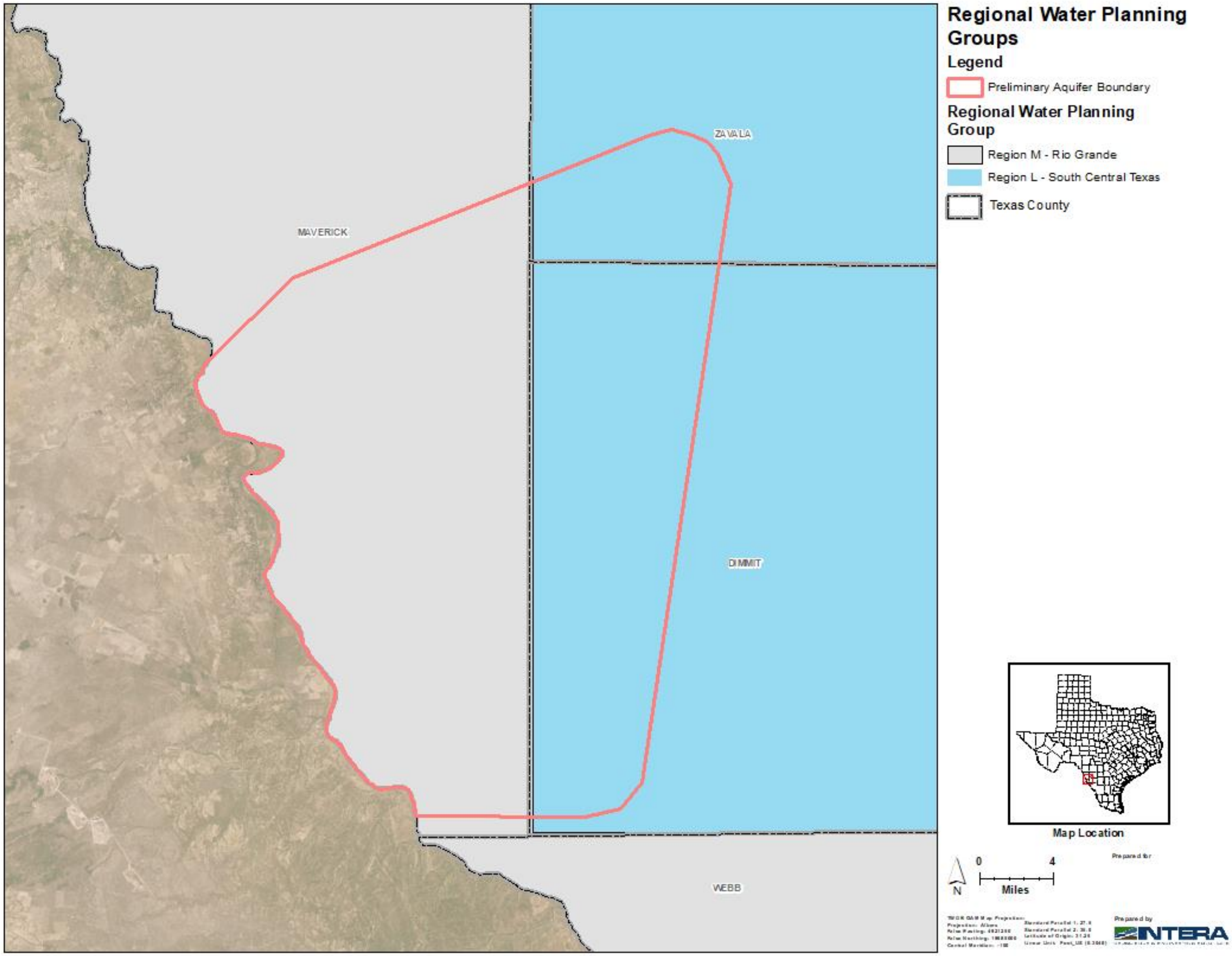

Figure 4.5-1. Regional water planning groups with the proposed boundary of the Maverick Basin aquifer.

By proactively engaging stakeholders and integrating the Maverick Basin aquifer into regional water planning, it may be possible to build support for the responsible development of the groundwater resource and to ensure that it is managed in a way that meets the long-term needs of the region.

4.6 Conclusions

The Maverick Basin aquifer system represents a potential new water resource for southwest Texas. However, significant knowledge gaps and challenges must be addressed to properly characterize and develop the aquifer. The current conceptual model, based on limited available data, suggests that groundwater flow in the aquifer is controlled by localized hydrothermal alteration and fracture networks rather than matrix porosity. This complex flow system requires a comprehensive aquifer characterization effort, including targeted data collection, multi-well aquifer tests, and advanced geophysical surveys.

In addition to the technical challenges of understanding the aquifer's hydrogeology, the development of the Maverick Basin aquifer must also navigate issues related to produced water management, transboundary coordination, and the presence of injection wells. Effective treatment strategies will be needed to remove residual hydrocarbons from produced waters, while the potential for cross-border impacts from future pumping in Mexico could exist. The compatibility of injection activities with aquifer development will also require coordination of regulatory agencies. To support the sustainable development of the Maverick Basin aquifer, it is recommended that the resource be integrated into regional water planning efforts and that stakeholders be actively engaged in the process.

Ultimately, the successful development of the Maverick Basin aquifer will require a concerted effort by researchers, regulators, water managers, and stakeholders to fill critical knowledge gaps, address key challenges, and develop a framework for sustainable management. With the right approach, this water resource could play a role in southwest Texas.

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6 Appendices

6.1 Appendix A. Tables

Table 6.1-1. Water data for springs and wells

API/ Spring ID	API	Well / Discharge Point	NPDES Permit No.	Outfall	Effective Date	Expiration Date	RRC Permit No.	Expiration Date
42-323-33103	4232333103	CMR 1025H	TX0134032				01081	
42-323-32599	4232332599	CMR 1111	TX0134034				01034	
42-323-32654	4232332654	CMR 3111H	TX0134062		07/06/2018	07/05/2023	01043	
42-323-32625 / 42-323-32960	4232332625 / 4232332960	CMR 1044 / 4014H	TX0134063		09/28/2018	09/27/2023	01051	09/27/2023
42-323-32627	4232332627	CR 2111	TX0134078	001	10/01/2019	09/30/2024	01033	01/09/2024
42-323-32686	4232332686	CR 2112H	TX0134078	003	10/01/2019	09/30/2024	01044	08/23/2023
42-323-33324	4232333324	CR 302H					01034	06/21/2023
42-323-33495	4232333495	CR 3044					01130	09/13/2023
42-323-32798	4232332798	CR 5111					01033	01/09/2024
42-323-32669	4232332669	CR 4111H	TX0134078	002	10/01/2019	09/30/2024	01041	09/06/2023
42-323-32812	4232332812	CR 3112D	TX0134078	004	10/01/2019	09/30/2024	01044	08/23/2023
42-323-32807	4232332807	CR 2113H					01044	08/23/2023
42-323-32969	4232332969	CR 1040H	TX0134078	005	10/01/2019	09/30/2024	01073	10/08/2023
42-323-32618	4232332618	CR 1039					01034	06/21/2023
42-323-32844	4232332844	CR 1108H					01131	12/13/2023
42-323-33032	4232333032	CR S106H ST3					01129	02/07/2024
42-323-32918	4232332918	CR 2117H					01031	09/23/2023
42-323-33474	4232333474	CR S103					01124	08/19/2023
42-323-32944	4232332944	CR 205H					01078	
42-323-32617 / 42-323-32891	4232332617 / 4232332891	CR 1013/ 4013H					01032	
42-323-32947	4232332947	CR 1013H					01072	
42-323-32731	4232332731	CR 2039H					01083	
42-323-32821	4232332821	STONE RANCH 1-58H						
42-127-33754	4212733754	HAMILTON FEE (JREDRANCH) 1G						
42-323-32666	4232332666	Comanche Ranch 1581H						
Spring 1 - Venados Spring								
Spring 2 - White Fish								
Spring 2A - White Fish								
Spring 4 - Goteras								
Spring 4A - Goteras								
Spring 5 - Nogalera Grande Spring								
Spring 6 - Ranch House Spring at Faucet								
Spring 6A - Ranch Spring								
Spring 7 - Teo Techo								
Spring 7A - Teo Techo 2								
42-127-00636 - Fitzimmons	4212700636	Hugh Fitzsimmons et al 1						
42-507-32727	4250732727	Felps Well No 1H						

API/ Spring ID	Completion Top (ft)	Completion Base (ft)	Comments	Application Type
42-323-33103			Not discharging; RRC Permit cancelled 11/7/18	R-2
42-323-32599			Not discharging; EPA Permit cancelled	R-2
42-323-32654			Not discharging; RRC Permit cancelled 1/29/19	R-2
42-323-32625 / 42-323-32960	6655	6723	used 1st API given	R-2
42-323-32627	6538	6616		R-2
42-323-32686	6025	6567		R-2
42-323-33324	6048	6606		R-2
42-323-33495	6095	6588		R-2
42-323-32798			Not discharging;	R-2
42-323-32669				R-2
42-323-32812				R-2
42-323-32807				R-2
42-323-32969				R-2
42-323-32618				R-2
42-323-32844				R-2
42-323-33032			middle of 5 horizontal drill lines	R-2
42-323-32918				R-2
42-323-33474				R-2
42-323-32944			Not discharging; Need to update Permit, southernmost of 2 horizontal drill lines	R-2
42-323-32617 / 42-323-32891			Not discharging; Cancelled 1/29/19; Possibly re-permit, used 1st API given	R-2
42-323-32947			Not discharging; Cancelled 11/7/18; P&A 6/7/21, used western middle of 4 horizontal drill lines	R-2
42-323-32731			Not discharging; Cancelled 1/29/19; Possibly re-permit	R-2
42-323-32821				P-13
42-127-33754				P-13
42-323-32666				P-13
Spring 1 - Venados Spring				
Spring 2 - White Fish				
Spring 2A - White Fish				
Spring 4 - Goteras				
Spring 4A - Goteras				
Spring 5 - Nogalera Grande Spring				
Spring 6 - Ranch House Spring at Faucet				
Spring 6A - Ranch Spring				
Spring 7 - Teo Techo				
Spring 7A - Teo Techo 2				
42-127-00636- Fitzimmons				
42-507-32727			Injection well permitted by RRC into the Glen Rose that only injects water made from the Glen Rose, max 1000BPD,	

API/Spring ID	Latitude	Longitude	Operator	County	Total Depth (ft)	BRACS ID	Plug Back Depth (ft)
42-323-33103	28.543003	-100.117180	CMR Energy	Maverick			
42-323-32599	28.596750	-100.194999	CMR Energy	Maverick			
42-323-32654	28.596249	-100.183425	CMR Energy	Maverick			
42-323-32625 / 42-323-32960	28.575802	-100.235787	CMR Energy	Maverick	6723	101493	
42-323-32627	28.603754	-100.206138	CMR Energy	Maverick	6616	101532	
42-323-32686	28.600816	-100.219879	CMR Energy	Maverick	10738	101533	
42-323-33324	28.604357	-100.183574	CMR Energy	Maverick	7441	101534	
42-323-33495	28.574626	-100.254709	CMR Energy	Maverick	6588	101561	
42-323-32798	28.601222	-100.201891	CMR Energy	Maverick			
42-323-32669	28.589140	-100.191942	CMR Energy	Maverick			
42-323-32812	28.606069	-100.220216	CMR Energy	Maverick			
42-323-32807	28.600992	-100.239397	CMR Energy	Maverick			
42-323-32969	28.599459	-100.176726	CMR Energy	Maverick			
42-323-32618	28.589730	-100.204725	CMR Energy	Maverick			
42-323-32844	28.614393	-100.232623	CMR Energy	Maverick			
42-323-33032	28.507569	-100.157755	CMR Energy	Maverick			
42-323-32918	28.599066	-100.292838	CMR Energy	Maverick			
42-323-33474	28.555074	-100.138666	CMR Energy	Maverick			
42-323-32944	28.572805	-100.258540	CMR Energy	Maverick			
42-323-32617 / 42-323-32891	28.584216	-100.245910	CMR Energy	Maverick			
42-323-32947	28.520522	-100.168132	CMR Energy	Maverick			
42-323-32731	28.590440	-100.196692	CMR Energy	Maverick			
42-323-32821	28.469815	-100.336954	The Exploration Co.	Maverick	7534	101620	6701
42-127-33754	28.507550	-100.042220	HAMILTON, J. R.	Dimmit	8100	0	8225
42-323-32666	28.606995	100.142743	CMR Energy, L.P.	Maverick	0	101499	7590
Spring 1 - Venados Spring	28.756825	-101.422805		Mexico			
Spring 2 - White Fish	28.752692	-101.430366		Mexico			
Spring 2A - White Fish	28.753457	-101.430876		Mexico			
Spring 4 - Goteras	28.785721	-101.483467		Mexico			
Spring4A - Goteras	28.785721	-101.483467		Mexico			
Spring 5 - Nogalera Grande Spring	28.816609	-101.441066		Mexico			
Spring 6 - Ranch House Spring at Faucet	28.753566	-101.380117		Mexico			
Spring 6A - Ranch Spring	28.754021	-101.382348		Mexico			
Spring 7 - Teo Techo	28.767940	-101.326733		Mexico			
Spring 7A - Teo Techo 2	28.767413	-101.326923		Mexico			
42-127-00636- Fitzimmons	28.261473	-100.063794	Gulf Oil Corp	Dimmit			
42-507-32727	28.693900	-99.994170	Rio-Tex, Inc.	Zavala	8217		

API/ Spring ID	Date Sampled	Lithium (mg/L)	Sodium (mg/L)	Ammonium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Floride (mg/L)
42-323-33103								
42-323-32599								
42-323-32654								
42-323-32625 / 42-323-32960	03/17/2022	0.7500	431.7	1.970	17.72	32.58	258.6	4.920
42-323-32627	03/17/2022	0.1300	67.1	1.010	11.03	26.70	223.9	4.550
42-323-32686	03/17/2022	0.1400	68.3	0.990	11.22	26.62	214.5	4.400
42-323-33324	03/17/2022	0.4000	196.9	1.740	14.22	29.36	244.2	4.490
42-323-33495	03/17/2022	0.0900	49.3	0.750	10.12	27.28	231.6	4.230
42-323-32798								
42-323-32669								
42-323-32812								
42-323-32807								
42-323-32969								
42-323-32618								
42-323-32844								
42-323-33032								
42-323-32918								
42-323-33474								
42-323-32944								
42-323-32617 / 42-323-32891								
42-323-32947								
42-323-32731								
42-323-32821								
42-127-33754								
42-323-32666								
Spring 1 - Venados Spring	03/26/2022	0.0204	56.0	1.421	13.42	37.72	106.8	0.235
Spring 2 - White Fish	03/26/2022	0.0016	2.0	0.002	0.27	8.50	91.8	0.084
Spring 2A - White Fish	03/26/2022	0.0014	2.0	0.001	0.22	8.65	89.3	0.078
Spring 4 - Goteras	03/26/2022	0.0008	1.3		0.18	5.76	58.2	0.067
Spring 4A - Goteras	03/26/2022	0.0008	1.3		0.18	5.77	58.2	0.068
Spring 5 - Nogalera Grande Spring	03/26/2022	0.0012	1.7		0.36	6.79	83.7	0.098
Spring 6 - Ranch House Spring at Faucet	03/27/2022	0.0025	2.9	0.037	0.87	9.89	47.2	0.084
Spring 6A - Ranch Spring	03/27/2022	0.0012	2.0	0.009	0.23	7.92	81.1	0.080
Spring 7 - Teo Techo	03/27/2022	0.0014	4.3	0.022	0.27	9.23	58.2	0.094
Spring 7A - Teo Techo 2	03/27/2022	0.0007	2.1		0.05	5.16	75.0	0.082
42-127-00636- Fitzimmons								
42-507-32727	06/09/2009							

API/ Spring ID	Chloride (mg/L)	Nitrite (mg/L)	Bromine (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	Predicted HCO3 (mg/L)
42-323-33103							
42-323-32599	382.0						
42-323-32654							
42-323-32625 / 42-323-32960	653.8	0.000	3.740	0.000	0.000	645.6	173.5
42-323-32627	57.9	0.000	0.180	0.000	0.000	596.3	143.8
42-323-32686	58.0	0.000	0.200	0.000	0.000	530.5	202.1
42-323-33324	233.4	0.000	1.170	0.000	0.000	663.1	185.9
42-323-33495	40.5	0.000	0.180	0.000	0.000	599.5	147.2
42-323-32798	69.0						
42-323-32669	586.0						
42-323-32812	85.0						
42-323-32807							
42-323-32969	191.0						
42-323-32618							
42-323-32844	206.0						
42-323-33032	108.0						
42-323-32918	206.0						
42-323-33474	124.0						
42-323-32944	73.0						
42-323-32617 / 42-323-32891							
42-323-32947							
42-323-32731							
42-323-32821							
42-127-33754	1410.0						
42-323-32666							
Spring 1 - Venados Spring	95.8					268.9	181.9
Spring 2 - White Fish	2.7			4.952		19.1	293.8
Spring 2A - White Fish	2.8			4.701		19.7	286.2
Spring 4 - Goteras	2.1			7.759		7.4	189.0
Spring 4A - Goteras	2.0			7.746		7.4	189.3
Spring 5 - Nogalera Grande Spring	2.0			2.928		15.6	267.5
Spring 6 - Ranch House Spring at Faucet	3.9			1.472		24.3	163.5
Spring 6A - Ranch Spring	3.1			4.912		19.9	256.7
Spring 7 - Teo Techo	5.4					8.3	215.5
Spring 7A - Teo Techo 2	2.8			7.424		6.6	239.2
42-127-00636 - Fitzimmons	780.0						
42-507-32727	261.0					871	

API/ Spring ID	Total Dissolved Solids (TDS) (mg/L)	TDS with predicted HCO3 (mg/L)	Sum of Cations (mmol)	Sum of Anions (mmol)	Charge balance	Lithium (ppm)	Boron (ppm)	Sodium (ppm)	Magnesium (ppm)
42-323-33103									
42-323-32599	1870								
42-323-32654									
42-323-32625/ 42-323-32960	2051	2225				0.767	1.641	428.8	33.44
42-323-32627	989	1133				0.146	0.250	66.8	25.66
42-323-32686	915	1117				0.148	0.260	65.9	27.43
42-323-33324	1389	1575				0.428	1.107	194.4	28.13
42-323-33495	963	1111				0.097	0.166	48.0	27.19
42-323-32798	1260								
42-323-32669	2180								
42-323-32812	1330								
42-323-32807									
42-323-32969	1480								
42-323-32618									
42-323-32844	1600								
42-323-33032	1240								
42-323-32918	1600								
42-323-33474	838								
42-323-32944	1540								
42-323-32617/ 42-323-32891									
42-323-32947									
42-323-32731									
42-323-32821									
42-127-33754	3810								
42-323-32666									
Spring 1 – Venados Spring	580	762	11.29	8.312	15%	0.020	0.023	52.7	37.71
Spring 2 - White Fish	129	423	5.37	0.559	81%	0.002	0.013	2.0	8.74
Spring 2A - White Fish	127	414	5.26	0.570	80%	0.002	0.013	2.0	8.76
Spring 4 - Goteras	83	272	3.44	0.341	82%	0.001	0.010	1.3	5.83
Spring 4A - Goteras	83	272	3.44	0.339	82%	0.001	0.010	1.3	5.91
Spring 5 - Nogalera Grande Spring	113	381	4.82	0.436	83%	0.001	0.012	1.7	6.88
Spring 6 - Ranch House Spring at Faucet	91	254	3.32	0.644	68%	0.003	0.010	2.9	9.93
Spring 6A - Ranch Spring	119	376	4.79	0.587	78%	0.001	0.013	2.0	7.95
Spring 7 - Teo Techo	86	301	3.86	0.330	84%	0.002	0.021	4.2	9.38
Spring 7A - Teo Techo 2	99	338	4.26	0.341	85%	0.001	0.012	2.1	5.19
42-127-00636- Fitzimmons									
42-507-32727	1531							140	28.3

API/ Spring ID	Aluminum (ppm)	Silicon (ppm)	Phosphorus (ppm)	Potassium (ppm)	Calcium (ppm)	Titanium (ppm)
42-323-33103						
42-323-32599						
42-323-32654						
42-323-32625/ 42-323-32960	-0.01323	37.27	-0.00967	18.67	259.5	0.0057
42-323-32627	0.00400	33.57	-0.00933	11.30	223.2	0.0050
42-323-32686	-0.00102	30.81	-0.01073	11.94	206.4	0.0041
42-323-33324	-0.00531	30.50	-0.00848	14.58	242.3	0.0048
42-323-33495	-0.01064	29.53	-0.00986	10.71	220.5	0.0043
42-323-32798						
42-323-32669						
42-323-32812						
42-323-32807						
42-323-32969						
42-323-32618						
42-323-32844						
42-323-33032						
42-323-32918						
42-323-33474						
42-323-32944						
42-323-32617/ 42-323-32891						
42-323-32947						
42-323-32731						
42-323-32821						
42-127-33754						
42-323-32666						
Spring 1 – Venados Spring	0.00298	22.24	0.01018	13.69	101.1	0.0035
Spring 2 - White Fish	-0.00202	4.83	-0.00993	0.32	92.6	0.0007
Spring 2A - White Fish	-0.00040	5.11	-0.00967	0.27	85.8	0.0007
Spring 4 - Goteras	0.00014	4.32	-0.01029	0.22	57.2	0.0006
Spring 4A - Goteras	0.00109	4.35	-0.01029	0.22	57.8	0.0008
Spring 5 - Nogalera Grande Spring	-0.00098	4.40	-0.01029	0.41	80.9	0.0006
Spring 6 - Ranch House Spring at Faucet	0.00816	3.64	-0.00770	0.94	46.1	0.0005
Spring 6A - Ranch Spring	0.00104	4.74	-0.00924	0.26	80.0	0.0007
Spring 7 - Teo Techo	0.00817	5.88	-0.00443	0.30	56.6	0.0011
Spring 7A - Teo Techo 2	0.00383	4.87	-0.01045	0.08	72.4	0.0007
42-127-00636- Fitzimmons						
42-507-32727				26.7	434	

API/ Spring ID	Vanadium (ppm)	Chromium (ppm)	Manganese (ppm)	Iron (ppm)	Cobalt (ppm)	Nickel (ppm)	Copper (ppm)	Zinc (ppm)
42-323-33103								
42-323-32599								
42-323-32654								
42-323-32625/ 42-323-32960	0.0000	1.70E-04	1.47E-01	1.45E-03	6.39E-04	7.45E-02	6.27E-03	1.47E-02
42-323-32627	0.0000	2.93E-05	1.83E-03	3.87E-02	3.87E-04	3.06E-03	1.06E-03	2.18E-03
42-323-32686	0.0000	1.94E-04	4.37E-02	7.48E-01	4.33E-04	5.73E-02	1.06E-03	9.80E-03
42-323-33324	0.0000	9.26E-05	8.06E-02	3.06E-01	6.14E-04	4.32E-03	2.83E-03	9.02E-03
42-323-33495	0.0000	1.42E-04	7.66E-02	1.02E-02	5.81E-04	8.53E-03	9.10E-04	1.70E-02
42-323-32798								
42-323-32669								
42-323-32812								
42-323-32807								
42-323-32969								
42-323-32618								
42-323-32844								
42-323-33032								
42-323-32918								
42-323-33474								
42-323-32944								
42-323-32617/ 42-323-32891								
42-323-32947								
42-323-32731								
42-323-32821								
42-127-33754								
42-323-32666								
Spring 1 – Venados Spring	0.0027	1.03E-04	4.42E-03	2.14E-02	3.82E-04	2.11E-03	1.49E-03	5.54E-03
Spring 2 - White Fish	0.0013	4.81E-05	6.05E-05	4.06E-04	1.74E-04	1.19E-03	1.06E-04	1.59E-03
Spring 2A - White Fish	0.0014	4.41E-05	9.44E-05	4.50E-04	1.52E-04	1.09E-03	6.97E-04	4.56E-03
Spring 4 - Goteras	0.0025	6.42E-05	1.03E-05	2.83E-04	1.03E-04	6.90E-04	7.15E-05	1.33E-03
Spring 4A - Goteras	0.0025	4.94E-05	3.36E-05	9.21E-04	1.04E-04	6.84E-04	7.48E-05	1.17E-03
Spring 5 - Nogalera Grande Spring	0.0013	6.36E-05	5.37E-05	3.61E-04	1.46E-04	1.00E-03	9.35E-05	1.58E-03
Spring 6 - Ranch House Spring at Faucet	0.0015	7.27E-05	8.95E-04	7.54E-03	7.62E-04	9.64E-04	2.24E-01	1.05E-01
Spring 6A - Ranch Spring	0.0013	6.25E-05	2.88E-04	2.25E-03	1.43E-04	1.08E-03	1.74E-03	3.59E-03
Spring 7 - Teo Techo	0.0015	3.76E-05	8.19E-04	2.67E-02	1.48E-04	9.24E-04	4.17E-04	1.59E-03
Spring 7A - Teo Techo 2	0.0032	6.29E-05	6.14E-05	1.72E-03	1.28E-04	9.60E-04	1.22E-04	1.14E-03
42-127-00636- Fitzimmons								
42-507-32727			0.022	0.069				0.023

API/ Spring ID	Arsenic (ppm)	Selenium (ppm)	Rubidium (ppm)	Strontium (ppm)	Zirconium (ppm)	Molybdenum (ppm)
42-323-33103						
42-323-32599						
42-323-32654						
42-323-32625/ 42-323-32960	-1.22E-04	9.89E-06	6.12E-02	12.02	5.35E-05	6.56E-04
42-323-32627	-9.27E-05	1.04E-04	4.14E-02	10.60	3.09E-05	-5.86E-04
42-323-32686	-4.05E-05	1.62E-04	3.78E-02	10.07	4.61E-05	-4.63E-04
42-323-33324	-3.47E-04	1.18E-05	5.17E-02	11.15	6.43E-05	-1.38E-04
42-323-33495	-3.54E-05	8.32E-05	3.49E-02	10.16	9.26E-05	5.98E-05
42-323-32798						
42-323-32669						
42-323-32812						
42-323-32807						
42-323-32969						
42-323-32618						
42-323-32844						
42-323-33032						
42-323-32918						
42-323-33474						
42-323-32944						
42-323-32617/ 42-323-32891						
42-323-32947						
42-323-32731						
42-323-32821						
42-127-33754						
42-323-32666						
Spring 1 – Venados Spring	1.25E-02	5.59E-04	4.28E-03	1.40	1.37E-04	6.80E-03
Spring 2 - White Fish	5.74E-05	5.81E-04	2.41E-04	0.44	9.23E-06	2.15E-04
Spring 2A - White Fish	6.14E-05	5.13E-04	2.37E-04	0.43	6.07E-06	2.18E-04
Spring 4 - Goteras	2.38E-04	4.28E-04	2.35E-04	0.21	9.54E-07	1.27E-04
Spring 4A - Goteras	9.94E-05	4.17E-04	2.36E-04	0.21	2.42E-06	1.15E-04
Spring 5 - Nogalera Grande Spring	1.12E-04	4.66E-04	3.43E-04	0.36	3.97E-07	2.22E-04
Spring 6 - Ranch House Spring at Faucet	2.02E-04	5.53E-04	2.31E-03	0.40	7.84E-04	3.93E-04
Spring 6A - Ranch Spring	1.20E-04	5.17E-04	2.38E-04	0.38	1.09E-05	2.66E-04
Spring 7 - Teo Techo	4.39E-04	2.26E-04	2.61E-04	0.35	7.23E-05	4.25E-04
Spring 7A - Teo Techo 2	7.91E-05	5.64E-04	7.55E-05	0.23	3.22E-06	4.77E-04
42-127-00636- Fitzimmons						
42-507-32727						

API/ Spring ID	Silver (ppm)	Cadmium (ppm)	Tin (ppm)	Antimony (ppm)	Caesium (ppm)	Barium (ppm)	Thallium (ppm)
42-323-33103							
42-323-32599							
42-323-32654							
42-323-32625/ 42-323-32960	3.51E-05	2.30E-05	-2.30E-05	5.68E-05	1.61E-02	1.14E-01	-5.67E-05
42-323-32627	1.26E-04	4.24E-06	-2.80E-05	5.63E-06	9.14E-03	3.11E-02	-5.01E-05
42-323-32686	7.51E-05	1.70E-05	-1.81E-05	8.31E-05	7.59E-03	2.27E-01	-4.64E-05
42-323-33324	6.92E-05	1.03E-05	-3.09E-05	1.37E-05	1.20E-02	3.50E-02	-5.87E-05
42-323-33495	7.19E-06	1.06E-05	-3.67E-05	2.90E-05	7.30E-03	2.76E-02	-5.91E-05
42-323-32798							
42-323-32669							
42-323-32812							
42-323-32807							
42-323-32969							
42-323-32618							
42-323-32844							
42-323-33032							
42-323-32918							
42-323-33474							
42-323-32944							
42-323-32617/ 42-323-32891							
42-323-32947							
42-323-32731							
42-323-32821							
42-127-33754							
42-323-32666							
Spring 1 – Venados Spring	-8.89E-06	1.44E-05	-1.31E-06	6.88E-04	1.90E-05	4.57E-02	-4.10E-06
Spring 2 - White Fish	1.27E-05	3.77E-06	-1.27E-05	1.93E-05	5.80E-06	1.92E-02	-1.61E-06
Spring 2A - White Fish	9.32E-06	2.83E-06	-1.04E-05	1.94E-05	3.84E-06	1.87E-02	-3.61E-06
Spring 4 - Goteras	6.63E-06	1.15E-06	-1.38E-05	1.60E-05	7.50E-06	1.86E-02	9.06E-07
Spring 4A - Goteras	6.80E-06	1.01E-06	-1.45E-05	1.24E-05	7.52E-06	1.86E-02	-9.91E-09
Spring 5 - Nogalera Grande Spring	4.94E-06	2.54E-06	-1.34E-05	1.68E-05	7.86E-06	1.86E-02	-2.60E-06
Spring 6 - Ranch House Spring at Faucet	1.32E-05	5.93E-06	2.07E-05	5.13E-05	5.05E-06	1.57E-02	-3.71E-06
Spring 6A - Ranch Spring	5.42E-06	3.29E-06	-6.11E-06	1.64E-05	3.30E-06	1.69E-02	-4.80E-06
Spring 7 - Teo Techo	-1.78E-07	3.81E-06	-8.51E-06	3.88E-05	2.60E-06	2.58E-02	-6.68E-06
Spring 7A - Teo Techo 2	2.17E-06	2.34E-06	-1.40E-05	1.02E-05	2.38E-06	1.85E-02	-6.93E-06
42-127-00636- Fitzimmons							
42-507-32727						0.036	

API/ Spring ID	Lead (ppm)	Bismuth (ppm)	Thorium (ppm)	Uranium (ppm)	Date Analyzed	δD (vsmow) per mil (parts per thousand)	$\delta^{18}O_{(vsmow)}$
42-323-33103							
42-323-32599					2021		
42-323-32654							
42-323-32625/ 42-323-32960	2.00E-05	3.61E-06	-2.69E-05	-3.52E-06	04/28/2022	-36.550	-5.670
42-323-32627	-7.73E-07	-2.77E-07	-2.37E-05	-3.29E-06	04/28/2022	-37.630	-6.180
42-323-32686	3.60E-04	5.24E-06	-1.81E-05	5.60E-06	04/28/2022	-37.310	-6.000
42-323-33324	4.72E-06	8.12E-07	-2.14E-05	-3.43E-06	04/28/2022	-37.300	-5.900
42-323-33495	3.79E-05	2.77E-05	-2.90E-05	-5.69E-06	04/28/2022	-38.140	-6.150
42-323-32798					2021		
42-323-32669					2021		
42-323-32812					2021		
42-323-32807							
42-323-32969					2021		
42-323-32618							
42-323-32844					2021		
42-323-33032					2021		
42-323-32918					2021		
42-323-33474					2021		
42-323-32944					2021		
42-323-32617/ 42-323-32891							
42-323-32947							
42-323-32731							
42-323-32821							
42-127-33754					2021		
42-323-32666							
Spring 1 – Venados Spring	3.55E-05	3.57E-06	-1.09E-05	7.53E-04	04/28/2022	140.613	33.590
Spring 2 - White Fish	4.09E-06	9.12E-09	-7.10E-06	6.29E-04	04/28/2022	-27.804	-5.047
Spring 2A - White Fish	9.20E-06	-1.30E-06	-7.45E-06	6.44E-04	04/28/2022	-26.604	-4.493
Spring 4 - Goteras	1.42E-06	-1.88E-06	-7.26E-06	4.50E-04	04/28/2022	-30.947	-5.392
Spring 4A - Goteras	8.22E-07	-1.88E-06	-6.73E-06	4.53E-04	04/28/2022	-31.160	-5.310
Spring 5 - Nogalera Grande Spring	2.87E-06	-1.45E-06	-7.23E-06	4.69E-04	04/28/2022	-30.939	-5.413
Spring 6 - Ranch House Spring at Faucet	6.14E-04	-2.87E-08	-7.69E-06	7.74E-04	04/28/2022	1.106	1.975
Spring 6A - Ranch Spring	2.87E-05	-7.94E-07	-8.16E-06	5.57E-04	04/28/2022	-27.395	-4.805
Spring 7 - Teo Techo	2.12E-05	1.71E-07	-5.30E-06	4.20E-04	04/28/2022	5.205	3.290
Spring 7A - Teo Techo 2	2.85E-06	-1.59E-06	-8.68E-06	5.00E-04	04/28/2022	-27.248	-4.985
42-127-00636- Fitzimmons							
42-507-32727	0.011						

API/ Spring ID	Date Analyzed	δ 13C (per mil_{vpdb})	DIC (mg/L)	DIC as HCO3	Ratio	Depth True	Date Completed
42-323-33103							
42-323-32599							
42-323-32654							
42-323-32625/ 42-323-32960						6723	08/13/2002
42-323-32627						6616	08/29/2002
42-323-32686						6567	09/03/2003
42-323-33324						6606	09/09/2009
42-323-33495						6584	03/13/2018
42-323-32798							
42-323-32669							
42-323-32812							
42-323-32807							
42-323-32969							
42-323-32618							
42-323-32844							
42-323-33032							
42-323-32918							
42-323-33474							
42-323-32944							
42-323-32617/ 42-323-32891							
42-323-32947							
42-323-32731							
42-323-32821							
42-127-33754							
42-323-32666							
Spring 1 – Venados Spring	04/11/2022	-8.09	16.70	84.9	2.143		
Spring 2 - White Fish	04/11/2022	-12.16	44.18	224.6	1.308		
Spring 2A - White Fish	04/11/2022	-11.27	41.42	210.5	1.359		
Spring 4 - Goteras	04/11/2022	-13.30	27.26	138.5	1.364		
Spring 4A - Goteras	04/11/2022	-13.26	28.36	144.2	1.313		
Spring 5 - Nogalera Grande Spring	04/11/2022	-11.14	40.24	204.6	1.308		
Spring 6 - Ranch House Spring at Faucet	04/11/2022	-9.57	24.46	124.4	1.315		
Spring 6A - Ranch Spring	04/11/2022	-12.94	40.72	207.0	1.240		
Spring 7 - Teo Techo	04/11/2022	-6.73	35.30	179.4	1.201		
Spring 7A - Teo Techo 2	04/11/2022	-12.66	40.89	207.8	1.151		
42-127-00636- Fitzimmons							Date completed
42-507-32727							

API/ Spring ID	Date Analyzed	Formation	Date Analyzed
42-323-33103			
42-323-32599			
42-323-32654			
42-323-32625/ 42-323-32960	03/30/2022	Glen Rose	04/06/2022
42-323-32627	03/30/2022		04/06/2022
42-323-32686	03/30/2022	Glen Rose	04/06/2022
42-323-33324	03/30/2022	McKnight	04/06/2022
42-323-33495	03/30/2022	Edwards	04/06/2022
42-323-32798			
42-323-32669			
42-323-32812			
42-323-32807			
42-323-32969			
42-323-32618			
42-323-32844			
42-323-33032			
42-323-32918			
42-323-33474			
42-323-32944			
42-323-32617/ 42-323-32891			
42-323-32947			
42-323-32731			
42-323-32821			
42-127-33754			
42-323-32666			
Spring 1 – Venados Spring			
Spring 2 - White Fish			
Spring 2A - White Fish			
Spring 4 - Goteras			
Spring 4A - Goteras			
Spring 5 - Nogalera Grande Spring			
Spring 6 - Ranch House Spring at Faucet			
Spring 6A - Ranch Spring			
Spring 7 - Teo Techo			
Spring 7A - Teo Techo 2			
42-127-00636- Fitzimmons			
42-507-32727			

Note: Units are feet (ft), milligrams per liter (mg/L), millimoles (mmol), and part per million (ppm).
Source: CMR Energy, Texas Water Development Board, Railroad Commission of Texas, and Texas Bureau of Economic Geology. For questions regarding this data, contact the Texas Water Development Board's Brackish Resources Aquifer Characterization System (BRACS) department.

Table 6.1-2. R-2 Applications, chlorides, and oil in water over time

Permits and well numbers		07/02/2020		08/04/2020		09/10/2020		07/01/2021		08/01/2021		09/01/2021	
Comanche Ranch well number	Permit number	Chlorides (mg/L)	Oil in water (ppm)	Chlorides (mg/L)	Oil in water (ppm)	Chlorides (mg/L)	Oil in water (ppm)	Chlorides (mg/L)	Oil in water (ppm)	Chlorides (mg/L)	Oil in water (ppm)	Chlorides (mg/L)	Oil in water (ppm)
2-5H	01078	365	<5	356	<5	339	<5	ND	ND	ND	ND	ND	ND
2-117	01031	93	<5	96	<5	76	<5	74	<5	74	<5	73	<5
1-40H	01073			309	<5	206	<5	193	<5	190	<5	191	<5
4-11H	01041	345	<5	731	<5	671	<5	599	<5	576	<5	586	<5
3-2H, 1-111, 1-39	01034	267	<5	277	<5	255	<5	241	<5	427	<5	382	<5
2-111, 5-111H	01033	81	<5	87	<5	73	<5	69	<5	67	<5	69	<5
2-112H, 2-113H, 3-112H	01044	106	<5	137	<5	68	<5	81	<5	86	<5	85	<5
1-44H, 4-14H	01051	229	<5	249	<5	354	13.5	304	<5	210	<5	300	<5

Note: Units are milligrams per liter (mg/L) and part per million (ppm).
Source: CMR Energy. For questions regarding this data, contact the Texas Water Development Board's Brackish Resources Aquifer Characterization System (BRACS) department.

6.2 Appendix B. Responses to TWDB Comments on Draft Report

6.2.1 General Comments

1. Throughout the document, please remove the references to "Tasks" (such as in Section 1.3.1) and replace with "Sections" (for example: "These geologic studies are summarized in Section 2 – Geologic Background). Also, please remove the word "Tasks" from the Section headings, and update the headings as recommended below for the Table of Contents (for example, change "4 Task 4" to be "4 Discussion").
    a. **Made Change from Task to Sections.**
2. Please consolidate paragraphs of texts to fill entire pages between figures. Sections 2 through 4 have a lot of blank white space
    a. **Done.**
3. reduce the use of acronyms, such as "DFC" (for desired future condition).
    a. **Done.**
4. Follow county names with "County" for a single county, or "counties" for a list of multiple counties (this was not consistent throughout, and some lacked "County" or "counties" altogether).
    a. **Done.**
5. When referring to the Maverick Basin aquifer, use little 'a' aquifer, as it is not officially designated by the TWDB. (aquifer was capitalized on page 59, 76, and perhaps elsewhere).
    a. **Done.**
6. **Table of Contents:** Please re-label the four chapter headings to: (in the table of contents, and throughout the report): Introduction, Geologic Background, Data, Discussion.
    a. **Done.**
7. **List of Figures and List of Tables:** Please use paragraph indention Special: "Hanging" by 1".
    a. **Done.**

6.2.2 Specific Comments

1. Pg. 2, ¶ 1. States "The locations of the wells that were converted to water wells are shown in Figure 1.1-2". However, no wells have been converted to water wells as of yet, that I know of. Please reword to specify the P-13 wells are applications to convert to a water well, and the R-2 wells are where there is surface discharge of fresh to slightly saline produced water.
    a. **Done. Reworded.**
2. Pg. 3, ¶ 1. This paragraph is incorrect, the Maverick Basin aquifer is not part of the official Edwards-Trinity (Plateau) Aquifer. It has only been included in the Edwards-Trinity (Plateau) Aquifer brackish groundwater study. Please reword to:

"The tentatively named "Maverick Basin aquifer" was included in the Texas Water Development Board's brackish groundwater study of the Edwards-Trinity (Plateau) Aquifer, as the Glen Rose Formation is continuous from the Edwards-Trinity Plateau down into the Maverick Basin. Following this study and any other necessary work, the Texas Water Development Board will consider whether the Maverick Basin aquifer should be designated as a new minor aquifer, incorporated into another official aquifer, or neither."

    a. **Done. Reworded.**

3. Pg. 3, ¶ 2. Please make the first sentences more concise. (delete the words "previously" and "tentatively"). Second sentence mentions "Conagua references". Please list these references instead of saying "cited in Sanchez and others".
    a. **Done.**
4. Section 1.2: Titled "Relevant Publications and Presentations", though none of the references are publications. Please rename this section to "Publicizations" and delete the first sentence.
    a. **Done.**
5. Pg. 5, ¶ 2. First sentence: Please replace "All three counties…" with "Maverick, Zavala, and Dimmit counties…".
    a. **Done.**
6. Section 1.4.2., first sentence. Please do not capitalize "aquifer" in "Allende Piedras Negras aquifer".
    a. **No longer capitalized.**
7. Section 1.5.1, ¶ 1. Please delete second sentence: "The TWDB does not currently consider the Edwards-Trinity (Plateau) Aquifer…".
    a. **Deleted.**
8. Please rename Table 1.5.2-1 to Table 1.5-1, to be consistent with the naming convention used for the Figures, and update the table name referenced in the text.
    a. **Renamed.**
9. Please mention in the Table 1.5.2-1 caption that the units are in acre-feet.
    a. **Added.**
10. Please make sure that Table 1.5.2-1 is on one page (it is currently split between two).
    a. **Changed.**
11. Section 2.2. Please rename to "Geologic history". "Geologic Background" is the overall name for Section 2.
    a. **Renamed to Geologic History.**
12. Please make the beginning of the Chittim Rift section more concise. As an example, you could say: "A specific section of these redbed strata were deposited within the "Chittim rift" (Figure 2.2-1), a northwest-trending graben or half-graben complex formed during Triassic-Jurassic rifting, which is overlain by a thick Mesozoic section in Maverick County, as shown in Figure 2.2-2 (Scott, 2004)."

   a. **Adjusted for brevity.**

13. Please rename "Figure 2-4" to the correct figure number (there is no Figure 2-4).
    a. **Done.**
14. Figure 2.2-2. In the caption, please clarify which reference the figure came from. Is it Ewing, 2016, modified from Scott 2004?
    a. **It is. Change made.**
15. Pg. 14, second sentence: Please change "Edwards-Trinity Plateau Aquifer" to "Trinity Group".
    a. **Done.**
16. Figure 2.2-7. In the caption, please add "; Sligo and equivalents", like in the previous figures.
    a. **Done.**
17. Pg. 17, last sentence (going into Pg. 18). Please correct reference to Figure 2-10 to correct figure number (there is no Figure 2-10).
    a. **Done**.
18. Figure 2.2-9. It looks like the axial trace of the Chittim Anticline is out of place. Please fix if so.
    a. **Fixed.**
19. Pg. 20, ¶ 2, fourth sentence. Please correct "Figure 2.3.2" to "Figure 2.3-2".
    a. **Corrected.**
20. Pg. 28, ¶ 2, third sentence. Please correct "Figure 2-16" to "Figure 2.3-3".
    a. **Corrected.**
21. Pg. 29. Please correct "Figure 2.3-3" to "Figure 2.3-4" (the figure that is referenced).
    a. **Corrected.**
22. Figure 2.3-7. Please move this figure to after the text in Section 2.3.3 (it can stay on page 30). Currently it appears before it is mentioned in the text.
    a. **Done.**
23. Figure 2.3-8. Please spell out "SGM" in the caption.
    a. **Done.**
24. Pg. 31, last ¶. Please make the following changes: 1) explain why recharge from the north is unlikely, and 2) Change 120 kilometers to equivalent miles.
    a. **Added an explanation.**
25. Figure 2.3-8. The paragraph text in section 2.3.4 refers to "Serrania del Burro" and "Serrania del Burro Mountains", whereas the figure refers to "Sierra del Burro". Please choose one to be consistent throughout/
    a. **Chose Serrania del Burro Mountains or Serranias del Burro which implies the mountain range.**
26. Pg. 40, ¶ 2. Uncapitalize "Northern", for northern Maverick County.
    a. **Uncapitalized.**

27. Pg. 44. Uncapitalize “Southeast”.
    a. **Done.**
28. Pg 46, first sentence. Please change from “shows” to “have”.
    a. **Done.**
29. Figure 3.5-1. Please reword the caption to say: “Petroleum wells in the Glen Rose Formation with water cuts over 90%”, and remove the part explaining BOE, which is not shown on the map.
    a. **Done.**
30. Figure 3.5-2. Please make the same changes to the text as Figure 3.5-1 above.
    a. **Done.**
31. Section 3.6, ¶ 1. References Table 1.5.2-1, but that table is of water deficits and not isotopes. Please add the table with the isotope data (Table 3.6-1).
    a. **Added reference to Appendix 1, Table 6.1-1.**
32. Section 3.8, ¶ 1. Mentions “TDS” for Hugh Fitzimmons well as 780 mg/L. Please replace “TDS” with “chlorides” (it is 780 mg/L chlorides).
    a. **Removed, called in table.**
33. Figure 3.8-1: Please add Glen Rose Produced Water Quality for API 42-507-32727, located in SW Zavala County, to this map and to Table 1.1 (1,531 mg/L TDS).
    a. **Done: TDS 1,531 mg/L: Chlorides 261 mg/L.**
34. Section 3.8, ¶ 2. References Table 1.1 for water quality and isotopes data. However, this table is missing. Please add the table with the data (Table 3.8-1?).
    a. **Added reference to Appendix 1, Table 6.1-1.**
35. Section 3.8, ¶ 2. References Table 1.2 for time series data for some surface discharge wells. However, this table is missing. Please add the table with the data (Table 3.8-2?).
    a. **Added reference to Appendix 1, Table 6.1-2.**
36. Section 3.8, ¶ 2. References Table 1.2 for “Oil in Water” data. However, this table is missing. Please add the table with the data (Table 3.8-3?).
    a. **Added reference to Appendix 1, Table 6.1-2.**
37. Section 3.9, ¶ 1. References Plate 1 as Figure 3.9-2. Please choose to reference this figure either as a Plate or a Figure, but not both. Plate 1 can be included as a larger page at the end of the document, or separate file. Or Figure 3.9-2 can remain as is.
    a. **It’ll be figure 3.9-1.**
38. Figure 3.9-2. Same comment as above – please either include this figure as Figure 3.9-2, or a separate Plate 1.
    a. **It’ll be figure 3.9-2.**
39. Pg. 76, ¶ 1, first sentence. Typo (“to” instead of “two” for “two parameters”) and extra period at the end.
    a. **Done.**

40. Pg. 76, ¶ 5. Please explain what age of the water the "lack of tritium" implies (older than how many years?)
    a. **Done.**
41. Section 4.4.4, last sentence. Extra period after "(Figure 4.4-5)", before the comma.
    a. **Deleted.**
42. Some publication years have parentheses around them, whereas most do not. Please remove the parentheses from the years that have them to standardize with the others.
    a. **Standardized.**
43. Please list the references in alphabetical order.
    a. **Done.**
44. pg 18. The Edwards Group comprises (instead of comprise.)
    a. **Done.**
45. pg 24. The Coherency processing emphasizes discontinuous events such as faults, and in Figure 2.3-4 it is apparent that the porosity anomalies occur mostly along faults that comprise a shear zone (Scott, 2004).
    a. **Done.**
46. pg 28. The following 3 cited sentences are direct quotes from Scott 2004 and should cited as such, or paraphrased instead:

    The thin sections showed the presence of authigenic quartz, iron sulfides, saddle dolomite, and replacive dolomite (Scott, 2004).

    Porosities in the 30% range were not uncommon and the porosity was frequently filled with bitumen and pyrobitumen (Scott, 2004).

    Prominent in the seismic data are numerous vertical interruptions which cut through the reflectors (Scott, 2004).

    a. **Paraphrased**
47. pg 31. "However, the lithologies in the basin do not support the possibility of clay conversion (since there are no such clays present in the limestone units), and oxygen isotope data obtained from surface discharge wells refute the notion that the water is juvenile, i.e. the isotope values appear to be meteoric (will be discussed in Section 3).". The origin of the water from one of three sources--clays, magma, or recent precipitation--is being discussed. Consider rephrasing for clarity so we know we are talking about 3 possibilities. Define "juvenile" as waters of magmatic origin earlier in the paragraph. Replace i.e. with therefore.
    a. **Done.**
48. pg 36. "Most leases call the Maverick Basin aquifer area the Comanche-Halsell (6500) field." Change to: Many of the Maverick basin aquifer wells are in the Comanche-Halsell (6500) field.
    a. **Done.**
49. pg 46. There are some high water cut wells not on this main arc; two to the southeast in a seismic anomaly, and three directly to the south where there is no or

unknown seismic anomaly. Change underlined portion to "the presence of seismic anomaly is unknown".

   a. **Done-reworded.**

50. pg 49. Royce Macey (change to Massey)
    a. **Done.**
51. The oxygen isotopes from each site are very similar, the oxygen isotope averages are within one per mil. (Change comma to semicolon).
    a. **Reworded sentence.**
52. last paragraph on pg 49—the number of significant figures varies from ones to the hundredths (1 to .01); there should be a consistent number of sig figs within the text and on Figure 50.
    a. **Done**
53. pg 53. "There is also a drill stem test provided by the RRC on a Hugh Fitzsimmons well (4212700636)". RRC obtained this information from a lawyer, who got it from Balcones Energy Library. This well does not have an API.
    a. **Done-API is 4212700636.**
54. Pg 55. Please write out Spontaneous Potential (SP) and Gamma Ray (GR) the first time they are mentioned.
    a. **Done.**
55. pg 55. "On most logs, a rightward deflection, or increase in value, of the spontaneous potential or gamma ray log indicates the bottom of the Glen Rose". Rewrite as positive spontaneous potential deflection or increase in gamma.
    a. **Done.**
56. pg 55. "From conversations with Mr. O'Brien at Saxet Petroleum" should be referenced as (Name, Personal Communication, Date) in text.
    a. **Done.**
57. pg 58, Figure 3.10-1: "Figure 3.10-1 is a type log from well 42323326170000". Omit the four zeros at the end of this API number.
    a. **Done.**
58. Figure 3.11-1: Please have the water line dashed and the oil line solid, or vice versa.
    a. **Dashed lines would blur the ability to interpret overlapping lines.**
59. pg 79/ Figure 4.4-5: The Zavala County permit within the Glen Rose protection zone is to re-inject fresh produced water, not saltwater. This well will require an aquifer exception and RRC is in the process of gathering these documents and working with the operator and EPA. The API is 4250732727 and its permit has water quality data showing TDS of 1531 mg/L and chlorides 261 mg/L. The well is active and injects approximately 12,000 bbl/month per H-10 data. The permit is available online by searching API "507-32727" here: https://webapps2.rrc.texas.gov/EWA/uicQueryAction.do;jsessionid=E98PpLkjarOzN9CRGsScC85meBwQhopmq3b6s33Qn7KqlKlg4-Bu!501031245

   a. **The active injection permit is for 4250732745. There are multiple permits for 4250732727, one is inactive, which is shown.**

60. pg 81. Produced Water Consortium should be cited as Texas Produced Water Consortium. However, their mission statement is to provide support with respect to "Texas Oilfield Waste Produced Water." Although there may be some opportunity to collaborate with the group, the Glen Rose produced water that is the subject of the study is UQW/USDW quality and not considered oilfield waste.
    a. **Changed name.**
61. In addition to the 3-mile UQW designation around Glen Rose wells in the InTera report, RRC has proposed an additional 3-mile USDW buffer for a total of 6-mile buffer around known UQW Glen Rose wells. This resulted in permit review of 4 injection or disposal (H-1 or W-14) wells permitted in the Glen Rose (either shut in, active, or permitted-not yet active) within the USDW protection boundary in Dimmit County.
    a. **Understood, this white paper is not meant to be a reporting avenue for the RRC's policies, so we will leave this out with the understanding and qualification that our boundary is approximate and not official.**
62. Additional well data per Cris Astorga in Maverick County, to the north, as emailed 7/9/24: "The Exploration Co., Alkek # 1-232, API: 42-323-32524, Drill Stem Test: This DST of the Glen Rose Reef (4970-5094) was mechanically successful. Recovery consisted of 60 bbls water with chlorides ranging from 5,000 to 8,000 ppm. The sample chamber contained 2300 cc's water. Chlorides of 12,000 ppm and 200 PSI. Schlumberger Test." This well is located approximately 26 miles north of the nearest data point in Maverick County. RRC would designate this well USDW quality and likely recommend extending the USDW buffer to the north to encompass this well and a 3-mile radius around it.
    a. **A survey of the literature would better inform this decision. Aconcha and others (2008) did a detailed study on the patch reef trend in the area of 4232332524. The reservoir comprises a series of patch reefs that are variably gas-charged or dry. This is totally unlike the Maverick Basin aquifer. Additionally, the Glen Rose Formation wells in this area do not have a high water cut, and there is no evidence of fresh or slightly saline water in this area from the production data. A singular well with moderately to very saline water quality is insufficient evidence to include this area in a USDW buffer.**