HYDROSTRATIGRAPHIC MODEL OF THE TRINITY AQUIFER FOR PORTIONS OF BELL, BURNET, TRAVIS AND WILLIAMSON COUNTIES

Prepared for:

Central Texas Groundwater Conservation District
Clearwater Underground Water Conservation District
Southwestern Travis County Groundwater Conservation District

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February 2025 – Project #4303CTG01

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

SECTION 1: INTRODUCTION AND BACKGROUND

Unprecedented rapid growth is often used to describe the demographic changes currently taking place across Texas. Since 2012, Texas' population has increased by nearly 4 million with the central Texas region experiencing a nearly 32% population increase over that same period (Texas Comptroller, 2024). The Austin-Round Rock-Georgetown metro is continually cited as one of the fastest growing areas in the country (Bureau, 2023). Across the Texas Hill Country there is persistent westward expansion as large acreage estates are subdivided to meet the growing demand of the housing market. Combine this rapid growth with the impact of Samsung committing to a new facility outside of Taylor, the continued development of the I-35 business corridor from Austin to Waco, and relentless drought, the demand on existing water supplies is stretched.

To accommodate for growth within central Texas, water is a necessity. To meet this demand, there is significant interest in developing new groundwater supplies. Doing so will require responsible management strategies as regional declines in aquifer water levels and well yields highlight that groundwater demand has outpaced supply in many local geographies (Ridgeway and Petrini, 1999). Groundwater Conservation Districts (GCDs) are front and center in this discussion as they work to balance the protection of property rights with conservation and development of groundwater resources (2 Tex. Admin. Code §36.0015).

Socioeconomic impacts should not go unnoticed either with the average cost of drilling a new well or lowering a well pump near all-time highs. In 2023, water well drillers reported drilling over 30 dry holes across Travis, Williamson, Bell and Burnet counites, part of an upward trend over the last decade (Texas Department of Licensing and Regulation Submitted Driller Reports, 2024). Dry holes are not only disheartening, but also costly. These economic costs permeate through the social fabric of communities across the central Texas region, forcing many landowners to invest in alternative water strategies such as rainwater harvesting.

Through this project, we aim to integrate, build upon, and ultimately enhance existing regional datasets with new hydrogeologic data. Specifically, this work bridges prior studies in southern Travis, Burnet and southwestern Bell counties. Included is a detailed stratigraphic analysis which uses innovative modeling techniques to better define the hydrogeology of the Trinity Aquifer within the study area. This comprehensive effort further ensures that the region has complete access to data for future scientific initiatives, regional and joint planning, groundwater permitting, management, and supporting policy decisions.

Funding and support for this study was provided by the Central Texas, Clearwater Underground Water and Southwestern Travis County GCDs. These 3 GCDs entered into an inter-local agreement that provided the opportunity for this collaborative study of the Trinity Aquifer in central Texas. In-kind services were also made available by Southwestern Travis County GCD. Separately funded studies by Travis and Burnet counties also provided key information and science used to inform the results of this study. This includes the drilling and installation of a monitor well in northern Travis County and a Burnet County Groundwater Availability Study.

This study focuses on the Trinity Aquifer within portions of Bell, Burnet, Travis and Williamson counties. Prior to this study, much of the research in the area included disparate geographies or region-based analysis. This patch-work type analysis has allowed for data gaps to persist, as seen in Williamson County where groundwater studies are limited. While no other stakeholders funded the project, this study's supporters hope that policy makers, water resource engineers, and planners will benefit from this new analysis of the Trinity Aquifer. Since the inception of this project, the Williamson County Commissioner’s Court has provided substantial funding for additional groundwater research in Williamson County.

1.1 STUDY AREA

The study area covers approximately 1,900 mi² of central Texas, encompassing portions of Travis, Williamson, Bell and Burnet counties (Figure 1). The eastern study area boundary coincides with Interstate 35, while the western edge is defined by the extent of the Trinity Aquifer (as published by the Texas Water Development Board). In Bell County, the northern boundary is defined by the southern edge of Fort Cavazos and US Interstate 14. Within Burnet County, the northern study area boundary is defined as the Burnet and Lampasas county line. The southern edge follows the county line between Travis and Hays counties.

The study area is distinctively located along the eastern edge of the Texas Hill Country where it abuts against the Balcones Escarpment. This picturesque geography lies within the Edwards Plateau region and is characterized by entrenched limestone plateaus that have been dissected by local streams and river systems (Kelley et al., 2014). Across the study area, elevations are generally higher in the west and lower to the east.

1.1.1 Trinity Aquifer

The focus of this study is the Trinity Aquifer. The Trinity Aquifer is defined as a major aquifer system by the Texas Water Development Board (TWDB), and extends across 61 counties from north-central to central Texas where it serves as a significant source of groundwater supplies for the region (Figure 2; George et al., 2011). Major aquifers are defined as those which provide a large volume of water over a large area.

The Trinity Aquifer is composed of several sub-units which vary based on geography and depth. These include the Antlers, Glen Rose, Paluxy, Twin Mountains, Travis Peak, Hensel, Cow Creek, and Hosston (Kelley et al., 2014). Within the study area the aquifer outcrops in the west and subcrops to the east. The principal water bearing units within the study area are the Middle Trinity Aquifer (consisting of the Hensel and Cow Creek formations) and Lower Trinity Aquifer (consisting of the Sligo and Sycamore/Hosston formations).

1.1.2 Local Groundwater Conservation Districts

Administration through groundwater districts is the State's preferred approach for groundwater management. Groundwater conservation districts are required to develop a management plan and rules to govern the groundwater resources within their jurisdiction. These powers and duties are derived from and conferred under Chapter 36 of the Texas Water Code and are to be administered using the best available science and data (2 Tex. Admin. Code §36.0015).

The study area includes the Southwestern Travis County GCD and portions of the Barton Springs-Edwards Aquifer Conservation District, Central Texas GCD, and Clearwater Underground Water Conservation District (Figure 3).

Participation in joint planning through the respective Groundwater Management Area (GMA) is an added responsibility for GCDs. Representatives of each GCD serve as voting members of the GMA for planning purposes. The primary objective of joint planning is to establish desired future conditions (DFCs) for the relevant aquifers within each management area. Currently, GCDs are participating in the fourth round of joint planning which factors in new science, pumpage, and data collected since the prior planning period. The next set of DFCs will be adopted in 2026 a. For administrative areas without a local GCD, such as Williamson County and northern Travis County, local interests must be represented by the other GMA members.

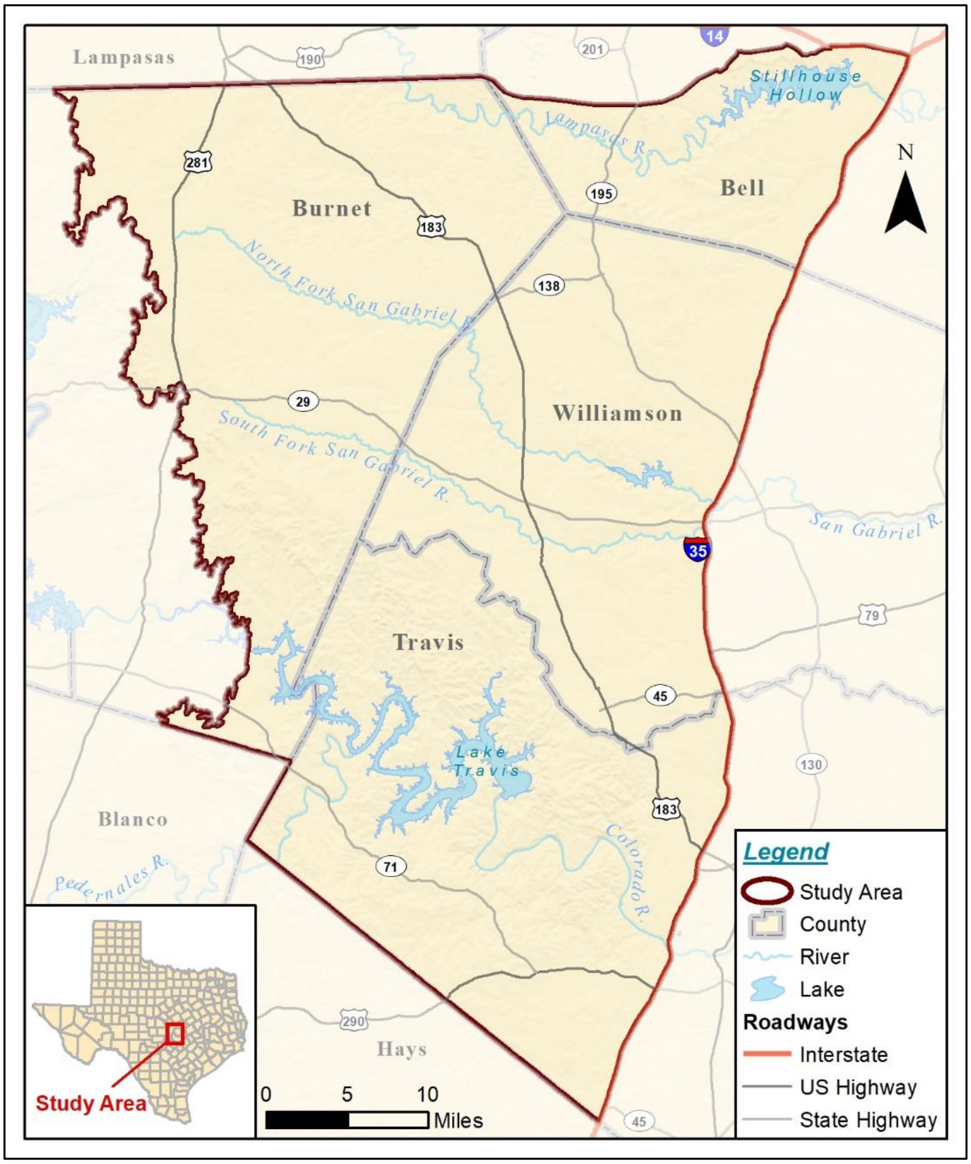


Figure 1 – Study area overview map.

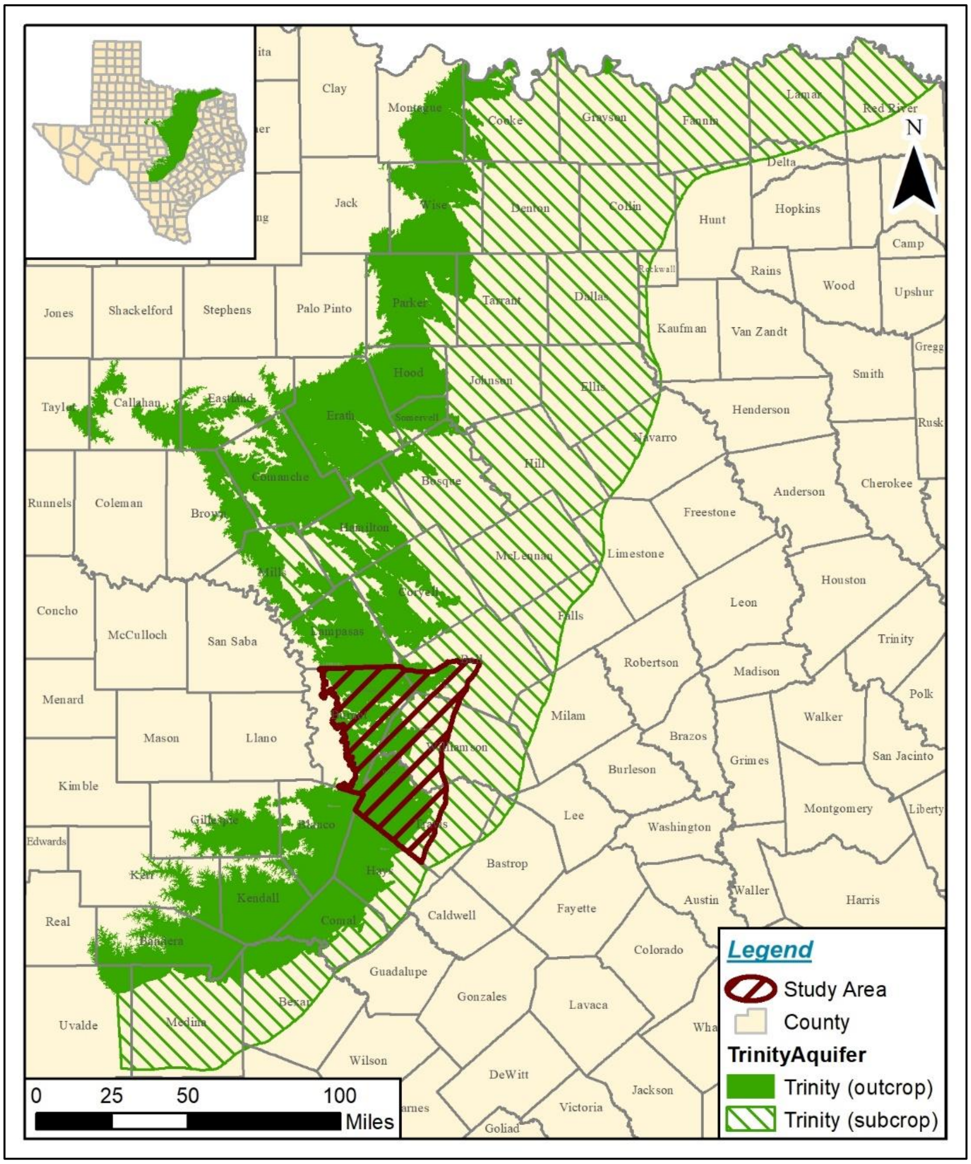


Figure 2 – Trinity Aquifer as defined by the Texas Water Development Board (TWDB, 2024).

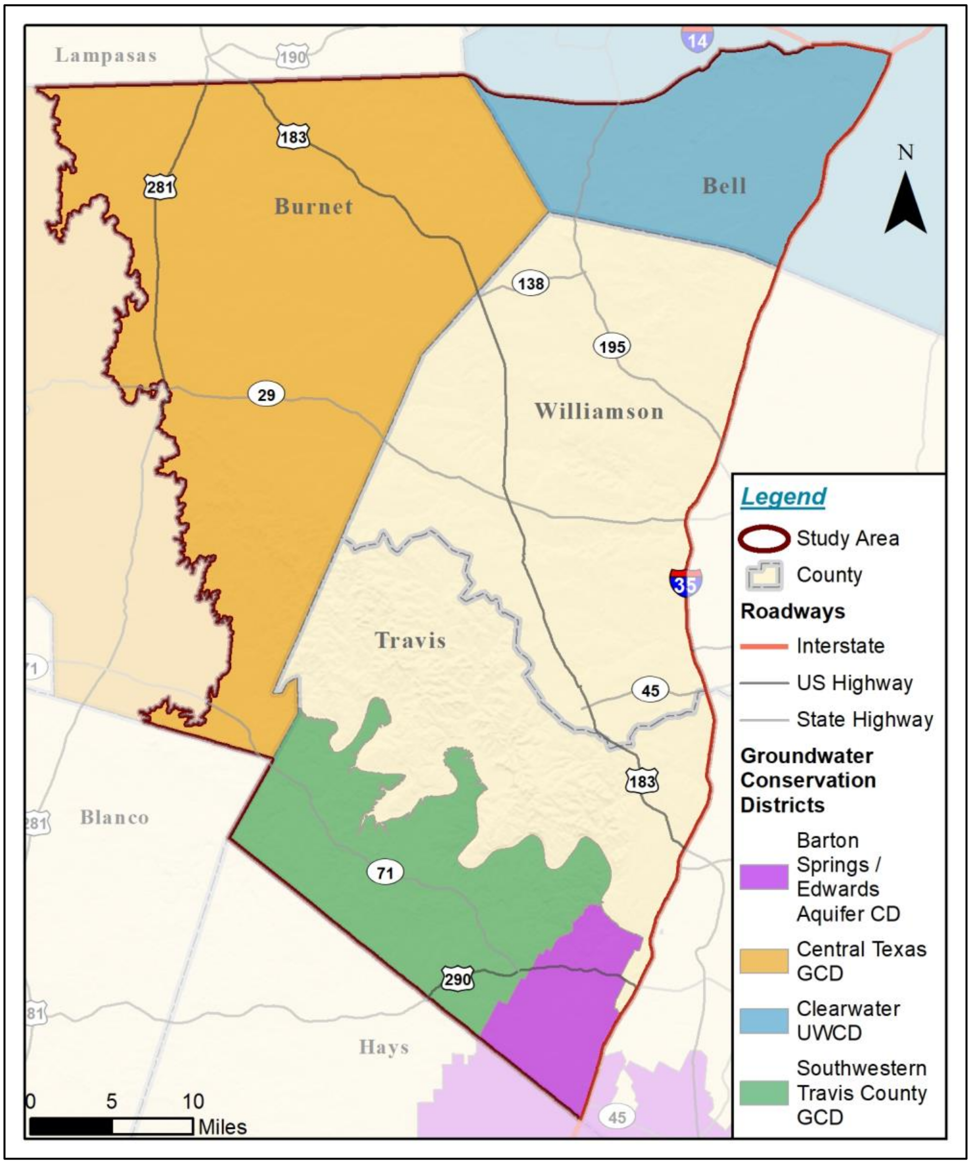


Figure 3 – Groundwater Conservation Districts in the study area.

1.2 REGIONAL STRUCTURE

Within central Texas, regional tectonics and deep-seated structural controls had a significant impact on the Cretaceous paleogeography (Corwin, 1982; Hunt et al., 2020; Rose, 2016). Hill (1901) was one of the first to recognize this connection and coined the term "Wichita paleoplain" to describe the erosional landscape which underlies the Cretaceous-age rocks. Numerous authors have identified correlations between this ancient landscape and the overlying Cretaceous depositional systems through stratigraphic pinchouts (Lozo, 1951; Corwin, 1982; Tucker, 1962; Rose, 2022; Hunt, 2024), changes in depositional patterns (Boone, 1968; Klemt et al., 1975; Loucks, 1976; Hayward, 1978; Hall, 1976; Clause, 2024; Wierman et al., 2020; Hunt, 2024), and local faulting (Standen and Clause, 2021; Hunt et al., 2020b; Paine et al.,2022).

The geologic structures most closely related to the study area are the: (1) Llano Uplift, (2) Ouachita Frontal Zone, (3) San Marcos Arch, (4) Belton High, (5) Round Rock Syncline, (6) Lampasas Arch and (7) Balcones Fault Zone. Figure 4 provides a generalized overview for the location of these structural features. For the following discussion, a geologic time scale is provided as reference in Figure 5.

1.2.1 Llano Uplift

The Llano Uplift consists of Precambrian granite and metamorphic rocks that detail over 300 million years of deformation associated with the Grenville Orogeny (1.5 to 1 billion years ago) and formation of the supercontinent Rodinia (Mosher, 1998). Through time, these rocks have been folded, faulted, uplifted and substantially eroded (Cloud and Barnes, 1948; Barnes and Bell, 1977). The Llano Uplift is flanked by Cambrian-Ordovician rocks that record Paleozoic/Ouachita-related faulting (Rose, 2016; Standen and Ruggerio, 2007). In early Cretaceous time, the Llano Uplift was the promontory structure within the region and provided a source of clastic sedimentary materials to the surrounding areas (Adkins, 1933; Stricklin et al., 1971).

1.2.2 Ouachita Thrust Front

During the Paleozoic Period, collisional tectonism (South and North America) associated with the Ouachita Orogeny (360 to 271 million years ago) thrusted and folded crustal blocks against the denser Proterozoic crust of the Llano Uplift (Flawn et al., 1961). This event resulted in significant faulting and deformation along the southeastern margin of the Llano Uplift within what is known as the Ouachita Thrust Frontal Zone (Figure 6; Flawn et al., 1961).

1.2.3 San Marcos Arch

The San Marcos Arch is a broad pre-Cretaceous anticlinal structure (structural high) extending eastward from the Llano uplift (Kuniansky and Ardis, 2004). Its exact origins are debated (Hunt et al., 2020a), however its significance as an area of positive relief through Cretaceous time is well documented through the presence of high energy lime grainstone deposits, lateral facies changes and erosional surfaces that suggest shallower water when compared to the surrounding landscape (Rose, 1972; Corwin, 1982). The Cretaceous strata of the Edwards-Trinity Aquifer are also remarkably thinner when compared to surrounding East Texas and Maverick Basins (Ashworth, 1983).

1.2.4 Belton High
The Belton High is the term coined by Tucker (1962) to describe the pre-Cretaceous structurally high area in Bell and northern Williamson counties. Across this area, there are numerous pinchouts, lithofacies changes, and localized variations in structural gradients within the overlying Cretaceous strata.

1.2.5 Round Rock Syncline
The Round Rock Syncline is a pre-Cretaceous southeast plunging synclinal trough (structural low) in northern Travis and southern Williamson counties. It is bound by the Belton High to the north and San Marcos Arch to the south. Within the Round Rock Syncline, there is a greater accumulation of lower Cretaceous strata (Tucker, 1962).

1.2.6 Lampasas Arch
The Lampasas Arch is a pre-Cretaceous plunging anticlinal structure (structural high) extending eastward from the northern boundary of the Llano uplift. In early Cretaceous time, it provided an area of positive relief (Corwin, 1982).

1.2.7 Balcones Fault Zone
The Balcones Fault Zone developed more recently in the Cenozoic Era throughout the Oligocene and Miocene Epochs (33 to 5 million years ago) as the west Texas Trans-Pecos region was uplifted and the East Texas Basin subsided (Flawn, 1956). These opposing actions applied force against the structurally rigid Ouachita belt, resulting in the development of en echelon down-to-the-southeast normal faults, folds and fractures (Barker et al., 1994). The Balcones Fault Zone follows the curvature of the Ouachita structural belt axis and is likely influenced by planes of weakness within this structure (Flawn et al., 1961). Balcones faulting caused significant disruptions within the Cretaceous rocks of the study area by introducing secondary porosity through fracture systems, subsequently promoting regional karst development. Displacement along the Balcones Fault Zone has also been shown to impact local aquifer systems through the development of both relay ramp structures (Hunt et al., 2015) and fault block compartmentalization (Standen and Clause, 2021; Yelderman et al., 2020).

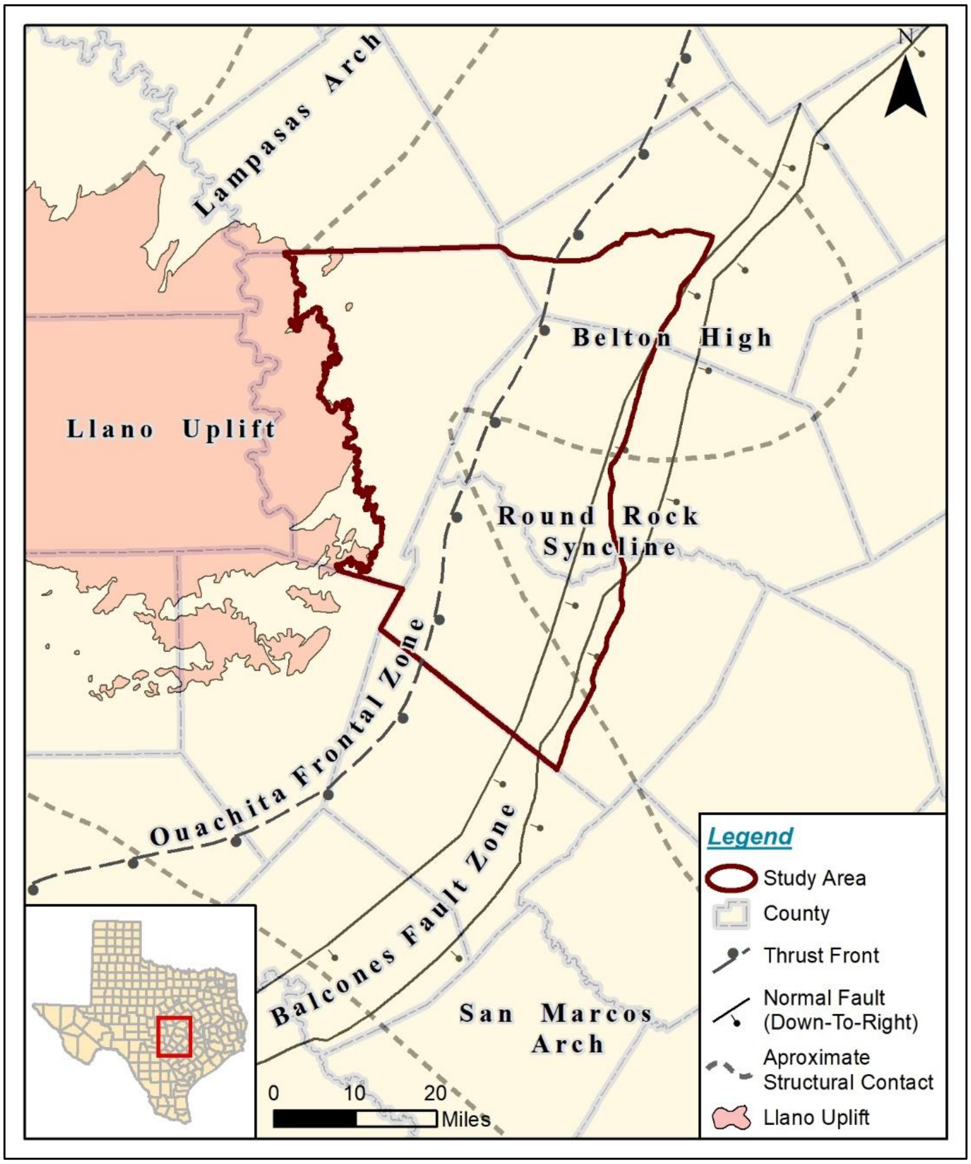


Figure 4 - Regional Structure of Influence within the Study Area. San Marcos Arch (after Phelps et al., 2014), Round Rock Syncline and Belton High (after Tucker, 1962), Ouachita Frontal Zone, Balcones Fault Zone, Llano Uplift and Lampasas Arch (after Ewing, 1990).

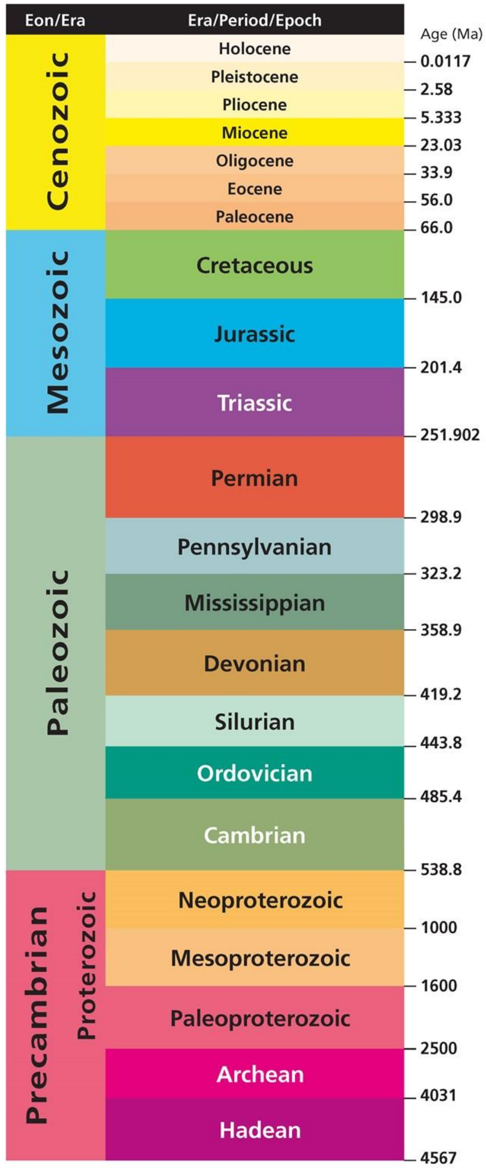


Figure 5 – Geologic Time Scale (from Cohen et al., 2013).

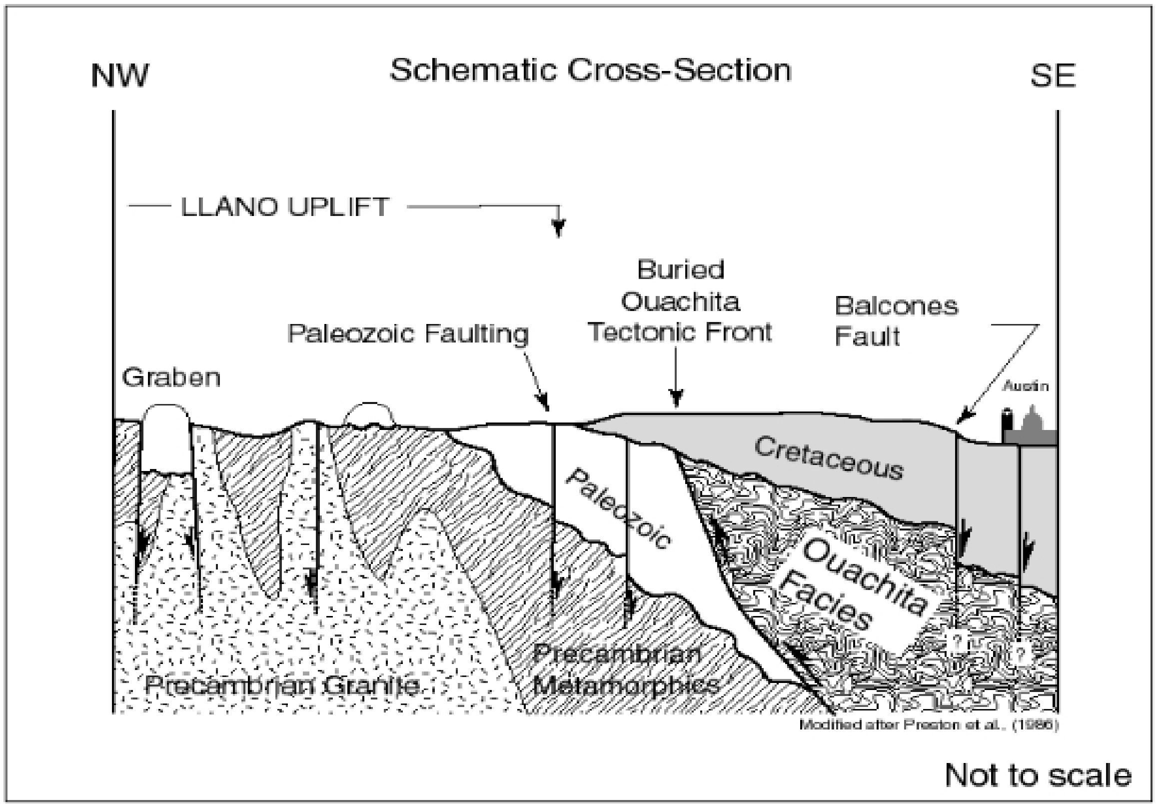


Figure 6 - Schematic cross-section and overview of the Ouachita Facies tectonic frontal zone. Cross section trace approximately extends from Llano to Austin (Hoh and Hunt, 2004).

1.3 GEOLOGY

According to the Geologic Atlas of Texas (GAT), the study area surface geology includes rocks that range in age from the Paleozoic Era (+251 million years ago) to the Quaternary Period (recent time) (Figure 7; Stoeser et al., 2007). These rocks are generally separated into five geologic systems: (1) undifferentiated Paleozoics, (2) Cretaceous Trinity Group, (3) Edwards and Associated Limestones, (4) Upper Cretaceous, and the (5) Quaternary (Table 1).

1.3.1 Undifferentiated Paleozoics

For simplicity, “undifferentiated Paleozoics” is a term that is used to describe the rocks which underlie the Cretaceous-age formations. In portions of Burnet County this relationship is somewhat complicated as there are numerous unconformities across this landscape (Rose, 2022). Elsewhere in the study area, the Cretaceous unconformably lies directly above the Lower Pennsylvanian Strawn Group, Smithwick Shale, Marble Falls Limestone, and Ouachita Facies (Duffin and Musick, 1991).

Prior to the deposition of the Cretaceous, the Paleozoic landscape underwent an extensive period of erosion which resulted in the development of an irregular “erosional surface”, classically referred to as the Wichita paleoplain (Hill, 1901). Although poorly defined, this paleotopography has been conceptualized as a series of alternating southeastward to eastward valleys and ridges (Boone, 1968; Hall, 1976; Ewing, 2016; Rose, 2022). The San Marcos Arch and Belton High serve as areas of positive relief while the Round Rock Syncline forms a topographic low within this surface (Tucker, 1962).

1.3.2 Cretaceous Age

The study area is predominately overlain by eastern dipping rocks of the upper Cretaceous Washita, and lower Cretaceous Fredericksburg and Trinity Groups. These rocks rest unconformably above the undifferentiated Paleozoics, except where they were removed by erosion in Burnet County. The units generally thin in a westward direction and thicken eastward. The Trinity Group is predominantly composed of interbedded sand, shale, and limestone units, while the younger Fredericksburg and Washita predominately consist of limestones, calcareous shales, sandstones, and clays.

Deposition of the Cretaceous rocks occurred as sea-level rose (transgression) across the central Texas landscape. Changes in overall depositional patterns, disconformities and rock type typically mark a hiatus or brief sea-level regression within this overall transgressive sea-level rise trend (Stricklin et al., 1971).

1.3.3 Trinity Group Stratigraphy

Within the study area the Trinity Group is composed of seven formations, stratigraphically from lowest to highest, these formations are the Sycamore/Hosston, Sligo, Hammett, Pearsall, Cow Creek, Hensel, and Glen Rose (Figure 8). The Trinity Group is also generally subdivided into Upper, Middle, and Lower sections made up of these seven formations.

1.3.3.1 Lower Trinity

The Lower Trinity sits unconformably above the undifferentiated Paleozoics across the entire study area. It is composed of the Sycamore/Hosston and Sligo formations. The Sycamore is the outcrop equivalent of the Hosston in southern Travis and Burnet counties and is predominately composed of terrigenous, clastic, fine- to course-grained feldspathic sandstone and cobble conglomerate (Hunt et al., 2024). The Hosston is the downdip equivalent to the Sycamore and is laterally extensive across the study area, except in western Burnet County (Partridge, 2011). For simplicity the Sycamore/Hosston will be referred to as the Hosston for the remainder of this report. The formation is composed of multi-colored pebbly, sandy conglomerate, generally poorly sorted, and cemented with calcite or silica cement, various colored shales, and some limestone (Hunt et al., 2024).

The Sligo formation is the upward carbonate equivalent of the Hosston and pinches out in a westward direction (Stricklin et al., 1971). Within the study area, it ranges in thickness from 0 to +100 feet and is composed of sandy to shaly dolomitic limestone and shale (Klemt et al. 1975).

1.3.3.2 Middle Trinity

The Hammett Shale is a gray to dark gray, calcareous or dolomitic silty clay of relatively uniform thickness (Lozo and Stricklin, 1956). The unit serves as a regionally extensive aquitard separating the Lower and Middle Trinity Aquifer units. The upper section of the Hammett Shale grades into the lower Cow Creek (Hunt, 2024). It is present across the study area, except in Burnet County where it laterally grades into the Pearsall.

The Pearsall is present in Burnet County where the Hammett and lower beds of the Cow Creek coalesce in a westward direction. It is commonly described as “redbeds,” as it is predominately composed of red to brown silty to sandy clay with interbedded sand and limestone lenses (Klemt et al., 1975).

Across the study area the Cow Creek transitions from the underlying Hammett Shale (Hunt, 2024). It can be generally described as a cream-colored to tan limestone, and is sometimes fossiliferous, sandy and dolomitic (Klemt et al., 1975). The Cow Creek can be subdivided into three unique carbonate facies, including lower, middle and upper sections (Stricklin et al., 1971). The lower Cow Creek beds are composed of low energy, lower porosity lower shoreface deposits primarily made up of calcarenite, dolomite and dolomitic shale (Stricklin et al., 1971). The middle Cow Creek is primarily composed of silty calcarenite upper shoreface deposits. While the upper Cow Creek is composed of high energy, high porosity grainstone and boundstone beach deposits (Loucks, 1977; Hunt, 2024). The Cow Creek formation is generally thicker and an important aquifer unit in Travis and Hays counties (Hunt et al., 2020a), whereas in Bell and Williamson counties it is usually thinner and not generally a productive aquifer unit (Standen and Clause, 2021).

The Hensel overlies the Cow Creek. Lithologically, the Hensel is composed of conglomerate, sand, sandstone, sandy to silty clay, shale, and sandy limestone lenses (Klemt and others, 1975; Brune and Duffin, 1983). Regionally, distinct differences in Hensel lithologic compositions are observed (Hunt et al., 2020a; Hunt, 2024; Standen and Clause, 2021). The conglomerates, mostly present in the basal portion of the Hensel, are pebbly, sandy, multicolored, poorly sorted, poorly- to well-cemented with calcite, opaline cement, or clay, and are often cross-bedded (Klemt and others, 1975; Brune and Duffin, 1983). Sands and sandstones in the Hensel are fine- to coarse-grained, gray, green, and buff to red-brown, poorly- to well-sorted, poorly- to well-cemented with calcite and occasionally with opaline cement, and often unconsolidated; they are mostly thinly-bedded to massive with occasional cross-bedding (Klemt and others, 1975).

The lower Glen Rose is composed of well-bedded, fossiliferous, sometimes sandy argillaceous limestones and mudstones (Hunt, 2024). Although considered part of the Middle Trinity, it was instead included with the Glen Rose (Upper Trinity) as part of this study to direct focus on the Middle Trinity Hensel and Cow Creek formations. This decision created an overall thicker Upper Trinity, and consequently thinner Middle Trinity unit within this study.

1.3.3.3 Upper Trinity

The Upper Trinity comprises the upper Glen Rose and Paluxy formations. The upper Glen Rose is a predominately argillaceous limestone and dolomite (Hunt, 2024), while the Paluxy is composed of friable, silty quartz sand and shale. The Paluxy and lower and upper Glen Rose were grouped as an undivided Glen Rose unit as part of this study. This was primarily done to focus the study on the more significant water producing intervals of the Middle and Lower Trinity aquifers.

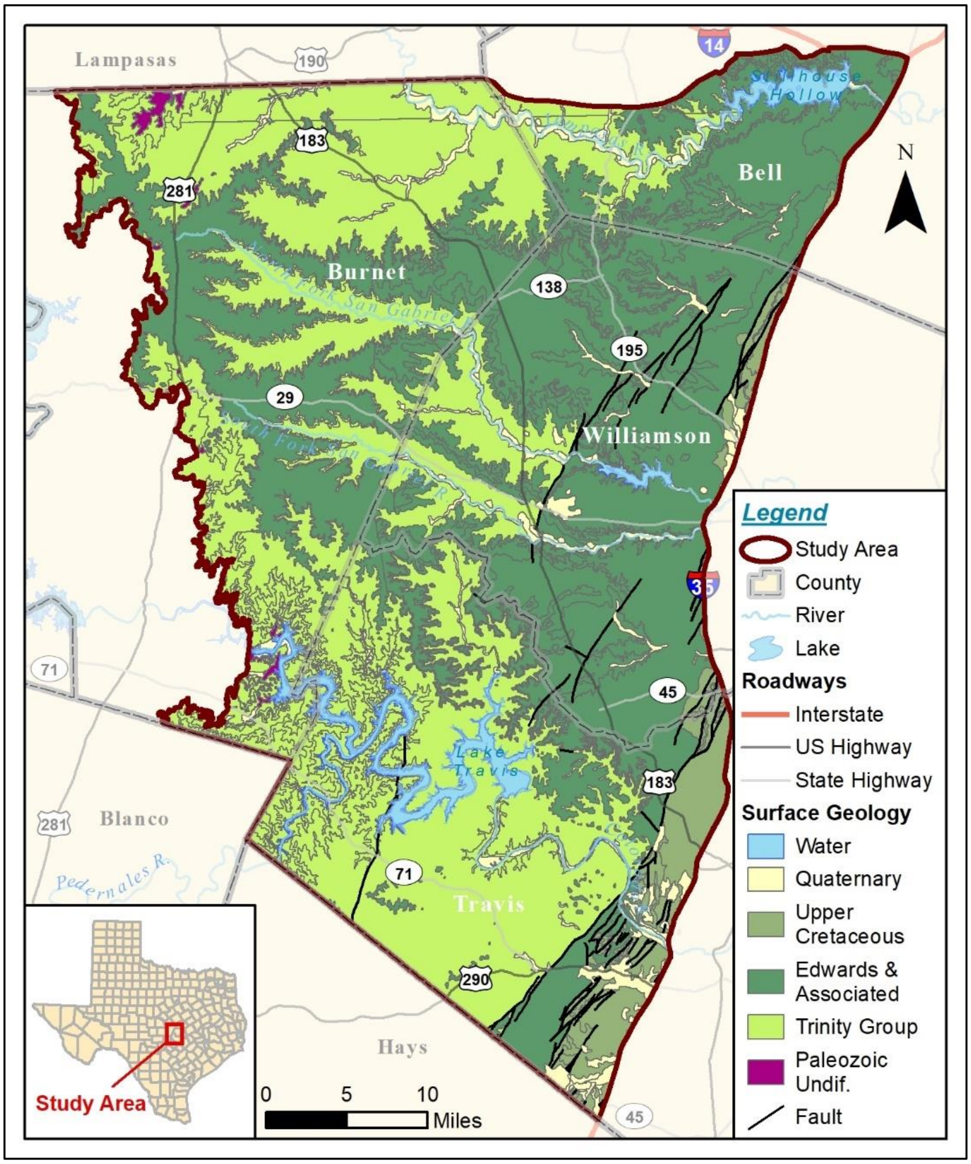


Figure 7 – Geologic Atlas of Texas Surface Geology (Stoeser et al., 2007).

Table 1 - Stratigraphic Column (after Klemt et al., 1975; Duffin and Musick, 1991 and Hunt et al., 2020).

System	Series / Epoch	Group	Stratigraphic Units			Lithologic Description	Hydrostratigraphic Model Layers
Q	-	-	Alluvium			Gravel, Sand, Silt and Clay	-
Cretaceous	Upper	Washita	Eagle Ford Formation			Massive multi-colored limestones, interbedded with shale, calcareous clays, and shales.	1 – Undifferentiated Cretaceous
			Buda Limestone				
			Del Rio Formation				
	Lower		Edwards and Associated Limestones		Georgetown		
		Fredericksburg			Edwards Formation		
					Comanche Peak Formation		
			Walnut Formation				
		Trinity	Upper	Paluxy Formation		Sand, and marl	
				Glen Rose Formation	Upper	Gray to buff limestone, dolomite, shale, and anhydrites.	2 – Glen Rose
			Middle		Lower		
				Travis Peak	Hensel Sand	Multi-colored sand, gravel, conglomerate, sandstone, sandy limestone and shale	3 – Hensel
					Cow Creek Limestone	Cream to tan, massive, often sandy, dolomitic, fossiliferous limestone.	4 – Cow Creek
					Pearsall Formation / Hammett Shale	"Redbeds" Red and multicolored shale and limestone / Gray to buff shale, limestone and dolomite	5 – Hammett/Pearsall
			Lower		Sligo Limestone	Gray Limestone, shale & sandstone	6 – Sligo
					Sycamore / Hosston	Lower Trinity Sand," poorly sorted multi-colored conglomerate, poorly sorted to well sorted fine and coarse grain sand and sandstones, streaks of shale and limestone	7 – Hosston
Paleozoic	Undifferentiated					Multi-colored clay, shale, sandstone, sands, limestone, conglomerate, dolomite, and metamorphic rocks	8 – Undifferentiated Paleozoics

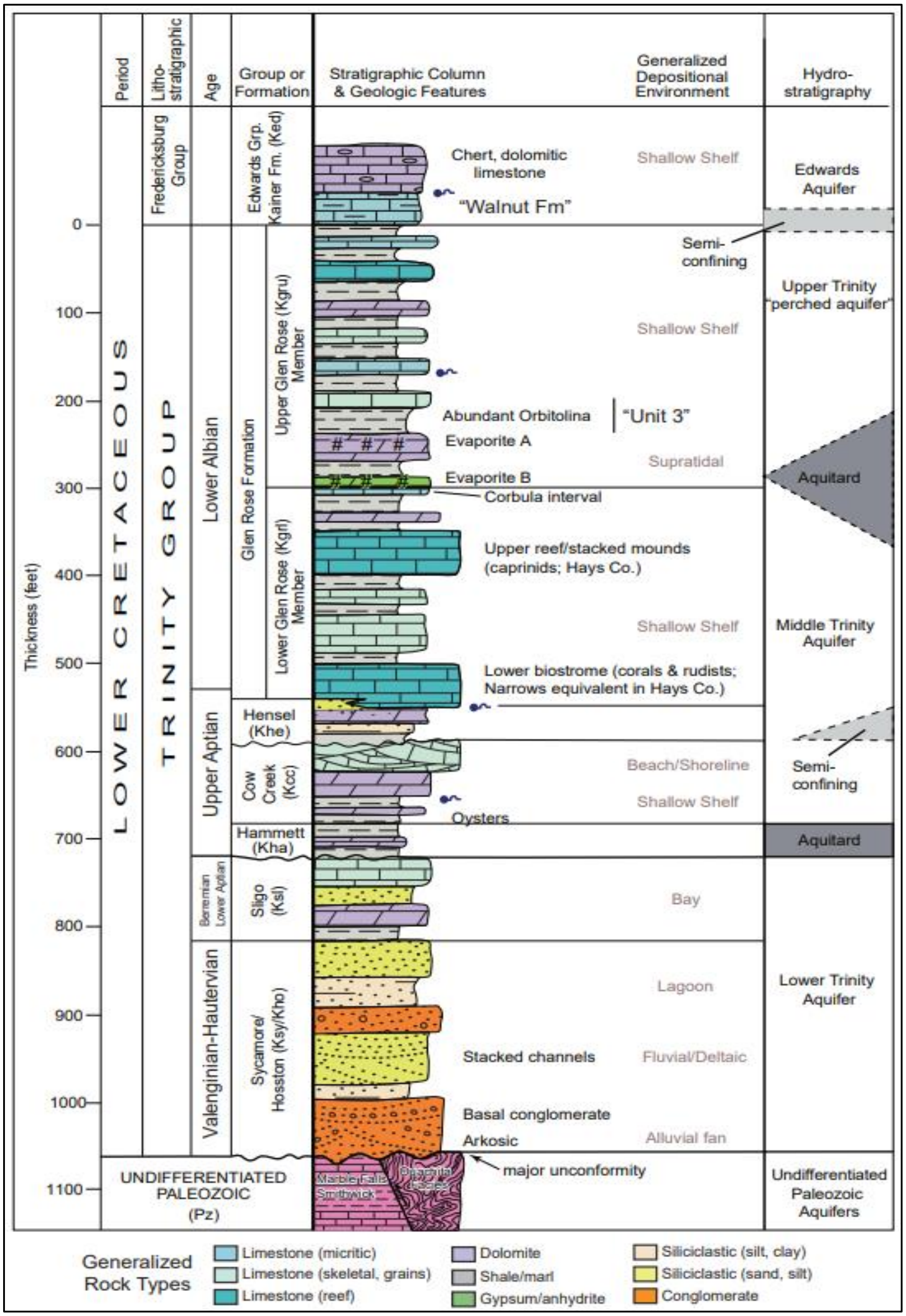


Figure 8 - Trinity Group Hydrostratigraphic Column from Travis County (from Hunt et al., 2020). Stratigraphic column illustrates changes in lithology across each formation. Hydrostratigraphy defines aquifer zones and confining aquitard intervals.

1.3.4 Trinity Group Nomenclature

There are numerous discussions surrounding the nomenclature and divisions of the Trinity Group. The group was first recognized as the “Trinity formation” by Hill (1888) as the “basal sands” that rest unconformably above the Paleozoics. Over the last century there have been many revisions to this early classification. The first revision was shortly thereafter by Hill (1889) who instead prescribed the name “Trinity Group” to this series and used Travis Peak to reference the “Water-bearing Beds.” Hill (1901) later subdivided the Travis Peak into the “Hensell [*sic*] sands”, “Cow Creek” and “Sycamore sands” sub-units, developed distinctions between the Paluxy Sand and Glen Rose, defined the “Antlers sand” as where the Paluxy Sand and Trinity Group coalesce, and recognized the “Bluffdale sands” as a northern lateral equivalent to the Hensel in north-central Texas.

Using deep subsurface geophysical data, Imlay (1945) expanded the definition of the Travis Peak and applied the names “Sligo” and “Hosston” to describe the lower Cretaceous geology. Imlay (1945) also introduced Pearsall as the downdip equivalent to the Sycamore, Cow Creek, and Hensel of the Travis Peak formation. The Travis Peak definition was again revised by Barnes (1948) who suggested that Glen Rose and Hensel be defined as a separate unit, known as the Shingle Hills formation. Lozo and Stricklin (1956) applied the term Hammett Shale to the subdivision of dolomitic shale between the Sycamore Sand and Cow Creek Limestone. Using this division, Lozo and Stricklin (1956) further subdivided the Trinity Group into a lower unit consisting of the Hosston and Sligo, a middle unit consisting of the Hammett Shale and Cow Creek limestone, and an upper unit consisting of the Hensel Sand and Glen Rose Limestone. In this work, it was also recommended that use of the Travis Peak formation be retired due to numerous intra-formation disconformities. Holloway (1961), while working in McLennan County, used the Pearsall to reference the geology which separates the overlying Hensel from the underlying Hosston. Fisher and Rodda (1966) proposed regional Trinity Group distinctions to account for the intra-formation disconformities discussed by Lozo and Stricklin (1956). Under this new framework the Twin Mountains formation was used to describe the clastic basal cretaceous rocks in north-central Texas, while maintaining the term Travis Peak for the central Texas region where the rocks are calcareous and more frequently composed of limestone and dolomite conglomerates.

To better understand the subsurface stratigraphy of the Trinity Group, Boone (1968) developed a depositional model which accounted for both vertical and lateral changes in stratigraphy and most notably mapped the lateral extent of the “Bluff Dale Sand,” as a lower Glen Rose equivalent. Klemt et al., (1975) developed the first hydrostratigraphic model of the Trinity Aquifer in central and north-central Texas while adopting the Travis Peak nomenclature and Pearsall as defined by Holloway (1961). It was shortly thereafter that Nordstrom (1987) used both the Travis Peak and Twin Mountains to describe the “water-bearing beds” within north-central Texas. Benyon (1991), attempted to clarify this division by establishing use of the Twin Mountains when describing the Trinity Beds in north-central Texas and Travis Peak in the central Texas region. This distinction was reinforced while developing the Texas Water Development Board Groundwater Availability Model (GAM) for the Northern Trinity Woodbine Aquifer (Harden & Associates, 2004), and again by Kelley et al., (2014).

1.3.4.1 "Hensel" and "Hensell" [sic] Misspelling

The Hensel Sand was first introduced by Hill (1901) as the "Hensell sand" in what many believe to be a misspelling. Much of this discussion and the related facts which support the misspelling theory were outlined by Stricklin et al., (1971), who points out that early geographic references by Hill (1890) and Hill and Vaughan (1898) were to that of Mr. Hensel's house at the Travis Peak Post office. This early reference of "Mr. Hensel" is to Herman J. Hensel the founder of Travis Peak, Texas (Smyrl, 1952), and who established his homestead in the Cow Creek Valley where the early stratigraphic type section was first referenced (Hensel Camp, 2024).

When identifying new geologic names, it is required that any new name is based on a nearby and permanent geographic locality (North American Commission on Stratigraphic Nomenclature: Article 3, 2005). Although misspelled, this appears to be what was attempted by Hill (1901). The North American Stratigraphic Code also states that the geographic component of a well-established stratigraphic name is not changed due to differences in spelling (North American Commission on Stratigraphic Nomenclature: Article 7, 2005). Robinson et al., (2020), recently acknowledged this spelling disagreement, but decided upon using "Hensell" as that is the spelling adopted by the USGS and is what is used in several recently published Texas Water Development Board (TWDB) reports and studies.

Within the study area, there is also a split among GCDs in the preferred spelling. Southwestern Travis County and Barton Springs/Edwards Aquifer GCD, use "Hensel", while Central Texas and Clearwater Underground Water GCDs use "Hensell". Among recent literature, this spelling disagreement also persists (Rose, 2020; Robinson et al., 2020). Through our literature review we determined that the "Hensel" spelling was predominately used initially among the geologic community, and only more recently was the "Hensell" spelling embraced across the groundwater literature. Most of the cited literature on which this study is based uses the "Hensel" spelling. For this reason, the "Hensel" spelling is used to better conform and maintain consistency with those referenced materials.

1.4 PRIOR GROUNDWATER STUDIES (TRINITY AQUIFER)

During the 19th and early 20th century, the Trinity Aquifer was known to support numerous artesian wells. Hill and Vaughn (1898) provide one of the earliest snapshots of Trinity Aquifer hydrogeology through their documentation of flowing wells across north central Texas. Hill (1901) inventoried many additional artesian wells and prescribed source aquifers. George et al., (1941) later conducted one of the first water well inventories on over 500 water wells within central Texas, collecting water level, chemistry and lithology information. Shortly thereafter, White and Livingston (1941) conducted a groundwater availability study for the Austin area and concluded that the local aquifers could not support large groundwater development projects. Follett (1956) provides an update to the data first collected by George et al., (1941) and expanded the initial study area to also include Hays and Williamson counties. Much of the data collected from these early efforts provided the foundation for later research and model development.

The first central Texas Trinity Aquifer geochemical model was developed by Henningsen (1962) who analyzed chemical differences and identified groundwater flow paths from separate northwest (Stephenville) and southwest (Llano) recharge sources. Later, Klemt et al., (1975) developed the first regional groundwater study of the Trinity Aquifer. This research closely examined the central and north-central portions of the Trinity Aquifer and provided clear distinctions between the water bearing beds and confining units of the aquifer. This study also first detailed the calcareous facies of the Travis Peak formation, and discussed how future pumping would cause significant water level declines within the Trinity Aquifer. Based on hydrologic relationships within the Trinity Aquifer, Brune and Duffin (1983) developed the lower, middle and upper Trinity Aquifer distinctions (which are still used today). Rapp (1988) later recognized that although separate hydrogeologic units did exist in the Trinity Aquifer, there was significant leakage of sulfate-rich water occurring from the Glen Rose into the Hensel where excessive drawdown had taken place.

In response to the 69th Texas Legislature which required the identification and study of critical groundwater areas in the state, Duffin and Musick released the *Evaluation of Water Resources in Bell, Burnet, Travis, Williamson and Parts of Adjacent Counties, Texas* (1991). In their report, they concluded that long-term water-level declines in the Trinity Aquifer constituted a critical problem for this study area. This study was later revisited and updated by Ridgeway and Petrini (1999), who maintained a similar stance while emphasizing the importance of surface water conversion in areas reliant on groundwater, especially within Williamson County.

In 1999, the 76th Texas Legislature instituted the GAM program, as the State of Texas began to shift from a water-demand to an availability-based allocation approach (Kelley et al., 2004) Consequently, the Hill Country Trinity (now Southern Trinity) and Northern Trinity and Woodbine GAMs were developed (Mace et al., 2000; Bene et al., 2004). The NTGAM was eventually updated in 2007 to account for increased pumping rates (Bene et al., 2007), and again in 2014 to incorporate new data, improve upon the initial GAM hydrogeologic framework, and implement a finer model grid (Kelley et al., 2014). The Hill Country Trinity GAM was updated by Jones et al., (2011) to update model layering and revise the recharge distribution. Both models are currently undergoing updates to account for new data and advancements in modeling techniques.

A substantial source for new data to support the improvement of these models has come from scientific studies and investments made by local groundwater conservation districts. Whether through permit review, water level collection, water chemistry sampling, geophysical logging or scientific studies and research, local GCDs have facilitated an advanced understanding and discernment of the Trinity Aquifer. The following section includes key Trinity Aquifer studies and research funded by and performed by local GCDs within the region.

Smith and Hunt (2008) and Smith and Hunt (2009) conducted research on a multi-port well to better understand vertical flow between the overlying Edwards Aquifer and underlying Trinity Aquifer. Through this research it was determined that the vertical flow of water between units is more likely the result of faulting than due to vertical leakage. Partridge (2011) developed a detailed depositional model for the aquifers within Burnet County. From this research, previously unknown Cretaceous unconformities were identified in both the Hensel and Hosston units. Standen (2014), using innovative modeling techniques, developed a detailed three-dimensional (3D) model of Bell County aquifers. This model allowed better discernment of well completion intervals. Hunt et al. (2015) discussed the significance and influence of the Balcones Fault Zone on local flow paths through the identification of relay ramp fault systems. Hunt et al. (2020a) released the Hydrogeologic Atlas of Texas which provided detailed hydrogeologic interpretations and data across southern Travis County. Detailed in this report is the significance of the Cow Creek as an important aquifer unit within Southwestern Travis County and possible influences of the "Sycamore River" on early Cretaceous depositional patterns. Hunt et al. (2020b) documents the influence of the Bee Creek Fault on local hydrogeology and suggests that it forms a hydrogeologic boundary within the Trinity Aquifer. Standen and Clause (2021) identified previously unknown faults within the Trinity Aquifer and hypothesized that the observed relative offsets could compartmentalize portions of the Hensel Aquifer. Through this research the relative insignificance of the Cow Creek Limestone as an aquifer within Bell County was highlighted, the calcareous facies of the Trinity Aquifer were mapped, and a west to east trend in aquifer characteristics was identified. Yelderman et al. (2020) later provided additional evidence for a Standen and Clause (2021) mapped fault through a multi-well aquifer pump test. This result also confirmed the existence of a local hydrologic boundary within the Hosston. Hunt (2023) studies the local hydrogeology of the Hamilton pool area in southern Travis County, which included the development of the conceptual framework for a local groundwater model. More recently, Keester et al. (2023), developed the Clearwater Groundwater Management Model, a local flow model for the aquifers of Bell County.

SECTION 2: HYDROSTRATIGRAPHIC MODEL

2.1 DATA AND METHODS

To initiate this study, the identification and review of previous works related to the study area was conducted. This process involved "data mining" pertinent geologic and stratigraphic data from the NTWGAM, local GCD studies, and various databases (Kelley et al., 2014; BSEACD, 2019; Standen and Clause, 2021; Hunt, 2023; INTERA, 2024).

Over 1,100 unique hydrostratigraphic well control points were extracted from these sources and were compiled to establish an existing well control dataset (Figure 9). This dataset functioned as the initial stratigraphic framework for this study. In this dataset, key limitations identified were: (1) data gaps in local well control; as in northern Travis and southern Williamson counties, (2) inconsistencies or variations in correlated formation tops (as defined in different data sources), and (3) missing formation tops within logged sections. Improving upon these limitations was a goal of this research.

To supplement the existing stratigraphic control dataset, a search was carried out to enhance data control coverage in areas with data gaps and to improve data resolution around areas where GAT faults are mapped. Supplemental stratigraphic control points were identified from the following sources: BRACS database, Bureau of Economic Geology (BEG) Geophysical Log Facility, local groundwater availability studies, water well driller's reports from the Texas Department of Licensing and Regulation (TDLR) submitted driller reports (SDR) database, Texas Water Development Board (TWDB) Groundwater Database (GWDB) scanned well records, and oil and gas cable tool and scout ticket well records.

2.1.2 STRATIGRAPHIC FRAMEWORK

Over 2,000 newly acquired well records and reports were collected and reviewed in addition to the aforementioned sources to develop the hydrostratigraphic framework. From these well records, over 500 new data points were identified as containing relevant and useful hydrostratigraphic data for this study.

The stratigraphic analysis presented in this report was dependent on the discernment between the water bearing aquifer units and the confining portions of the Trinity Aquifer. The analysis was completed by making interpretations for the top of each formation (e.g., Hensel) or confining unit (e.g., Hammett Shale). Different approaches and techniques were used, which were contingent on the underlying data type. As part of this analysis and listed in order of priority, we reviewed and evaluated the following data types: geophysical logs, drill cuttings, published reports, strip logs, cable tool lithology descriptions, water well reports, and oil and gas scout ticket records.

2.1.2.1 Geophysical Logs

Geophysical logs were used to assess the subsurface geology, determine the lateral extent, depth of occurrence, thickness, and vertical relationships between stratigraphic units. The term "geophysical logs" as used herein includes numerical and graphical results obtained from a variety of log tools. These log tools often measure spontaneous potential, gamma ray, resistivity, and neutron porosity. Each tool uniquely records variations in rock type and aquifer properties within the vertical wellbore, influenced by the physical properties of adjacent rock and/or fluids. These variations provide insights into the near-wellbore subsurface geology and were used to identify stratigraphic units in this study.

Stratigraphic contacts, defined as the top and/or base of key rock units, were interpreted for the following layers listed stratigraphically from lowest to highest: Undifferentiated Paleozoics, Hosston formation, Sligo formation, Hammett Shale, Cow Creek, Hensel, and Glen Rose formation. and. Our detailed review of geologic descriptions (Table 1) and key geophysical "type logs" from various studies (Hunt et al., 2020a; Hunt 2024; Standen 2014), facilitated the comprehension and correlation of stratigraphic units across the study area. A "type log" is a highly studied and documented log that is used as a reference for correlating data across an area (Hunt et al., 2020a).

A Trinity Aquifer "type log" example is provided by Hunt et al. (2020a) and is included as Figure 10. This log example demonstrates the different geophysical log responses associated with the gamma and resistivity log curves. This log provided the basis for many of our geophysical log interpretations within Travis County. As the gamma and resistivity curves move from left to right, downhole differences in sand and clay content can be inferred. Figure 10 demonstrates how these tools are used to identify the stratigraphic top and bottom contacts for the Hosston, Sligo, Hammet, Cow Creek, Hensel, and lower Glen Rose formations.

2.1.2.2 Petra™ Geologic Mapping

To facilitate the organization of geophysical log data, log calibrations, and well correlations for the interpretation of stratigraphic contracts and preliminary geologic mapping, we utilized the geologic modeling software Petra™. The typical Petra™ workflow involved: (1) importing and calibrating log data, (2) evaluating the spatial distribution of existing well control data, (3) evaluation of existing geologic tops, (4) in-filling of missing data in existing wells, (5) identification of data gap areas, (6) incorporation of acquired well control data, and (7) interpretation of geologic tops on acquired well control data.

The initial step involved importing the existing and acquired well control datasets into Petra™. Geophysical logs were imported in both raster and digital (.LAS) log formats. The predominant format assessed were raster logs, which can be more simply described as scanned images of paper logs. These raster logs often exhibited variations in image quality. Common quality concerns include crooked logs, which stem from logs scanned at an angle, and paper stretching due to jamming or slipping during scanning. Each log image was thoroughly reviewed, and quality concerns were manually addressed with log correction tools within Petra™. The less common digital (.LAS) log formats were provided in a format that is free of image quality concerns. Newer logs are more likely to be available in digital (.LAS) format.

Once log quality issues were resolved, each raster log underwent “calibration.” Log calibration captures pertinent log header information, identifies log run scales, and includes “depth registration”. Depth registration is a manual process that assigns depth points on the log image that are used to convert measured log depths to an elevation in reference to sea-level. Log calibration is tedious, yet also one of the unique benefits of using Petra™ as it allows for each log to be uniformly compared with respect to scale and sea-level elevation. The digital (.LAS) log formats are automatically calibrated and did not require further calibration within Petra™.

LRE prioritized reviewing all newly acquired geophysical logs. Geophysical logs from published reports and materials were not reviewed, except in the case when stratigraphic tops were missing across a logged interval or when conflicting interpretations between studies were identified. Newly acquired log data played a significant role in expanding our knowledge of the Trinity Aquifer.

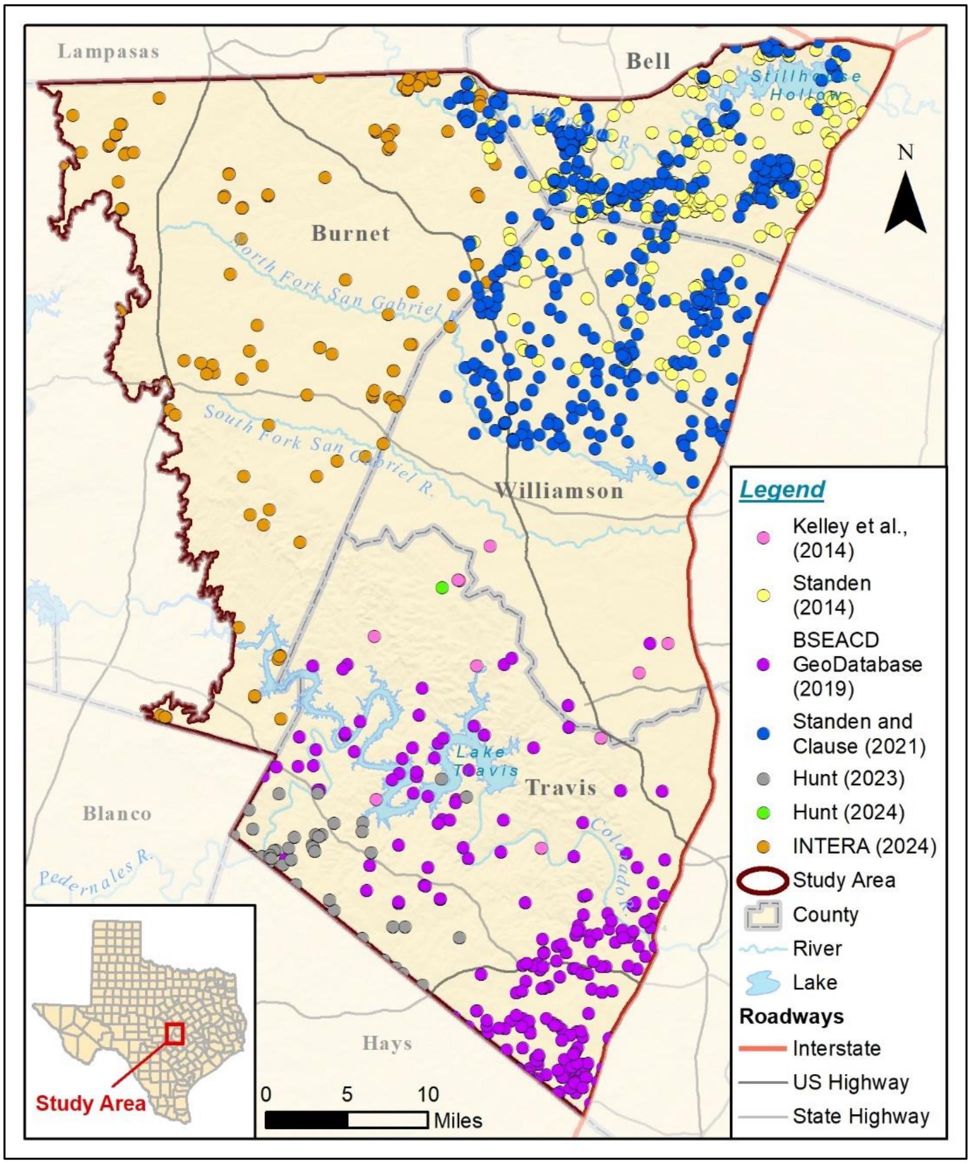


Figure 9 – Study Area Existing Hydrostratigraphic Well Control.

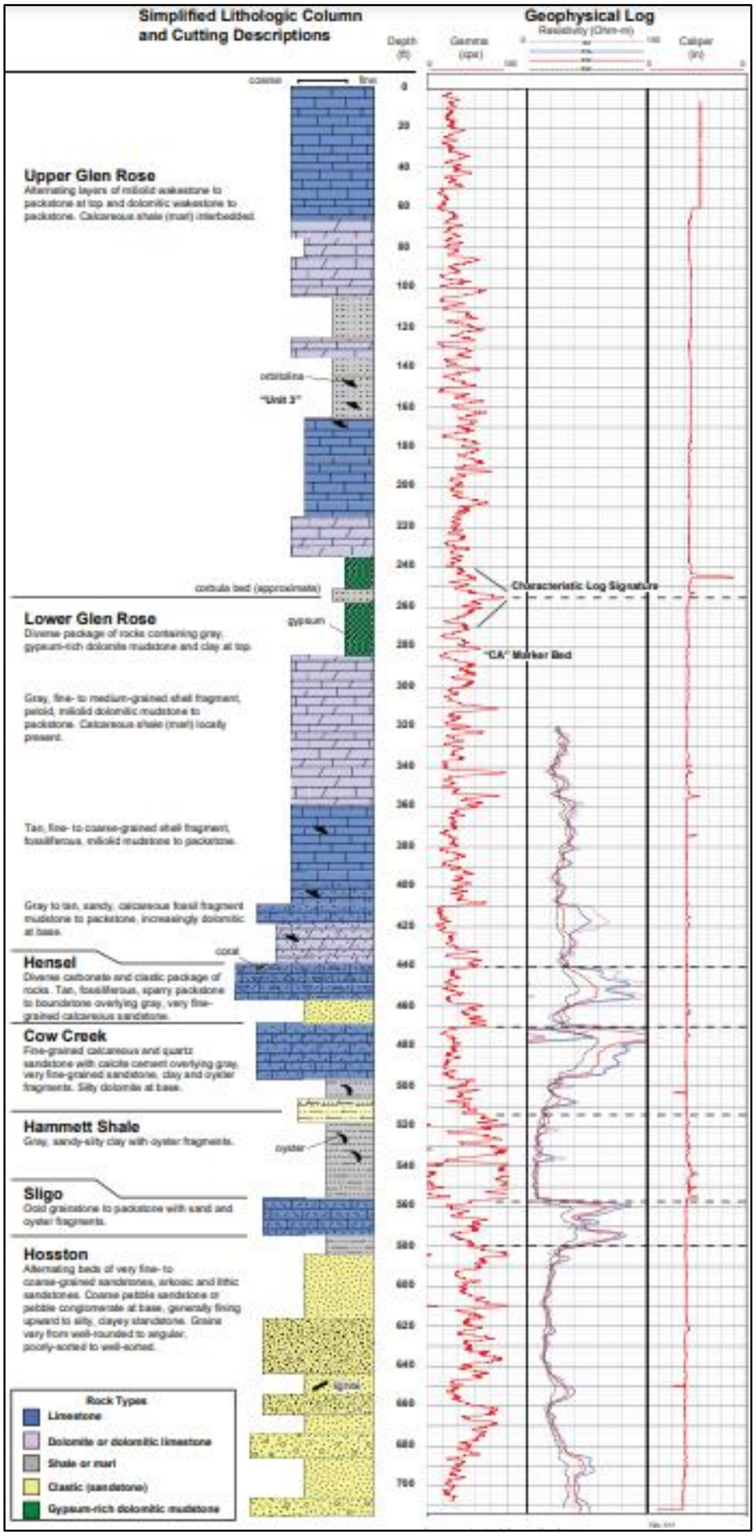


Figure 10 – Travis County Multiport Well Type Log Example (Hunt et al., 2020).

2.1.2.3 Driller Lithology Descriptions

Driller lithology descriptions are useful for stratigraphic analysis in areas with alternating lithology and distinct marker beds as seen in the Trinity Aquifer. Driller lithology descriptions were used to assess the subsurface geology, determine the lateral extent, depth of occurrence, thickness, and vertical relationships between stratigraphic units. This general sequence from bottom to top is as follows: shale, sand, clay/shale, limestone, sand, limestone, which respectively corresponds to the undifferentiated Paleozoics, Hosston, Hammett, Cow Creek, Hensel, and Glen Rose Group. When you introduce color, the distinction between layers can be more apparent as is the case for the dark grey shale of the Hammett formation, and the yellow, purple, and black clays and shales of the undifferentiated Paleozoics. Driller lithology reports from the TWDB GWDB, and TDLR SDR were compared against the lithologic descriptions in Table 1. A top of formation pick was recorded for each layer when the descriptions agreed. Table 2 provides a “type description” example from TDLR well report #664762 in Bell County.

In some instances, a reviewed drillers’ report did not provide useful information for one or more of the following reasons:

- We determined the water well driller to be an unreliable source for stratigraphic information due to inaccurate reporting (e.g., 300 feet of sand in the Glen Rose)
- Clumped lithology intervals across multiple units (e.g., sand and limestone 200-700 feet)
- Inaccurate locations (e.g., well address in Travis County and Lat/Long in Williamson County)

2.1.2.4 SWTCGCD Monitor Well: Fire Station #104, Leander, TX

Funded by and in collaboration with Travis County, the Southwestern Travis County GCD installed a new monitoring well in northern Travis County, Texas, to address a gap in data and understanding of the Middle Trinity Aquifer, particularly the Cow Creek.

A critical component of this work was installation of a dual completed monitor well and collection of drill cuttings, core, and geophysical logs. The well was drilled under the direction of Lane Cockrell, General Manager, SWTCGCD. Travis County provided funds to SWTCGCD for the well and site access, under the direction of Vicky Kennedy, P.G..

Brian Hunt, P.G., of the BEG under Research Agreement No.UTAUS-FA00002159 assessed the hydrogeology of this well and correlated data points of the Middle Trinity Aquifer from western to northern Travis Couty, Texas. Hunt (2024) provides the results of this analysis which include key geophysical log and rock core lithostratigraphic interpretations.

2.1.2.5 LRE Files - Lower Trinity Well Drill Cuttings

LRE files were referenced for pertinent data within the study area. This included lithology and formation data on an exploratory Lower Trinity irrigation well located at latitude and longitude coordinates 30.7824, -97.8163, approximately 4 miles south of Florence in Williamson County, TX. This well information was donated to LRE Water by Trinity Water Solutions, a local water well driller within Williamson County. This record provided both pertinent geophysical log and lithology drill cutting data for this study.

Table 2 - TDLR Report #664762 driller lithology description with interpreted stratigraphic units.

Top (ft.)	Bottom (ft.)	Description	Unit
0	26	Overburden	**Glen Rose**
26	615	Grey Lime and Shale	
615	637	Tan and grey sandstone, thin seams shale	**Hensel**
637	680	Tan sandstone, sand and conglomerate rock	
680	740	Grey and green shale, grey sandstone	**Cow Creek / Hammett**
740	780	Tan and white sand lime with Green staining, few black chert gravels	**Hosston**
780	815	Tan and Brown Lime with Black Chert Gravel	
815	832	Multi Color Conglomerate	
832	847	Grey and Yellow Shale	**Undifferentiated Paleozoics**

2.2 THREE-DIMENSIONAL (3D) HYDROSTRATIGRAPHIC MODEL

The 3D hydrostratigraphic model was constructed by Michelle A. Sutherland, P.E., of Envision Water, LLC, with oversight from LRE. Ms. Sutherland is established as one of the leading experts in the development of 3D hydrogeologic models in Texas and has performed similar services for numerous groundwater conservation districts and the Texas Water Development Board.

2.2.1 Model Framework

An 8-layer 3D hydrostratigraphic model was developed to specifically study the Trinity Aquifer within central Texas (Table 1). For this reason, the model does not review or subdivide the Paleozoics or Fredericksburg and Washita (Cretaceous) groups. These units are simply included as the undifferentiated Paleozoics and undifferentiated Cretaceous, respectively. This model also does not include the alluvial aquifer system, nor does it separate the upper from lower Glen Rose.

The 3D hydrostratigraphic model closely follows the stratigraphic framework used to develop the Updated Northern Trinity GAM (NTGAM). However, in this hydrostratigraphic model, layers are numbered differently. In addition, this hydrostratigraphic model includes the Cow Creek and Sligo formations as independent model layers, whereas the NTGAM does not. The hydrostratigraphic model also generally follows the framework used to develop the Hill Country Trinity GAM (HCTGAM) but includes more detail (Table 3). Divergences simply pertain to differences in the design structure for each model, and generally represent the same confining beds and aquifer units.

2.2.2 Three-Dimensional Model Development

LRE provided Envision Water, LLC with GIS files (Appendix C) containing the hydrostratigraphic well control dataset (Appendix A), faults, 10-meter resolution digital elevation model (DEM), base map layers, and supporting reference materials. Using Leapfrog Works by Seequent® software (“Leapfrog”), Envision Water, LLC developed the 3D Hydrostratigraphic model.

With the hydrostratigraphic well control dataset, the model layers were developed using a triangulated grid with a general target of approximately 5-10 grid triangles between neighboring data points. For this task, a modified “spline” interpolation technique was employed to minimize the overall surface curvature provided between high and low points. We have found this method better represents natural features (e.g. valleys and ridgelines). This technique is considered “modified” because the technique allows for user input of structural controls, and then resampling of the underlying “spline” mathematical equation along the triangulated grid cell sides. Ultimately, the goal was to create geologic surfaces that honored the data closely while maintaining a smooth and consistent layer appearance from one point to the next.

To model outcrop areas, the GAT was used to define the outcrops for each model layer (Figure 7). Digitized outcrops were converted into a series of points spaced at half-mile intervals. These points were added to each layer surface to provide for control at the land surface. This was necessary since the stratigraphic control dataset only provides subsurface values mostly within the downdip portions of the aquifer systems.

To account for the faulting within the study area, Envision Water, LLC began by integrating GAT faults as vertical planes into Leapfrog. LRE Water provided the GAT fault system shapefile, along with the GAT surface geology map that also referenced faults (Stoeser et al., 2007).

Within Leapfrog, structural control disks were used to guide the interpolation in areas of sparse stratigraphic data, along faults, and near outcrop areas. Mainly, this was to ensure that stratigraphic units were consistent with the surrounding data and structure.

While developing the 3D hydrogeologic model, several dozen outlier data points were identified. These points may be correct, however were in direct disagreement with nearby well control. For this reason, these well control points were removed from the 3D hydrogeologic model workspace, but still included in the Hydrostratigraphic Well Control Dataset. These points are listed in Appendix B for future review.

The development of the hydrogeologic model was an iterative process that required numerous cycles of trial and error based on study area size, outcrop areas, fault blocks, and the disparate allocation of stratigraphic control. Two additional factors which required significant consideration and that impacted model development included the model rendering time, and Leapfrog viewer functionality.

Rendering time is the time required by the computer to process and create a 3D representation of the stratigraphic data. It is dependent on the following factors: study area size, total number of modeled units and control points, and model resolution. The Leapfrog viewer is the freeware version of the model software that can seamlessly run on any computer with a viewer application file. As a model becomes more complex, it places an increased burden on a user's computer ('video card') from which the viewer file runs, and performance issues can be experienced. For these reasons, a triangulated grid structure was adopted for this initial phase of model development. One downside of this approach is that the model grid takes on a smoother structure that can allow for areas where stratigraphic control and the model may disagree.

Table 3 - Comparison of NTGAM and HCTGAM Model Layers to this study's Hydrogeologic Model layers.

NTGAM Model Layers			Hydrogeologic Model		HCTGAM Model Layers		
Younger Sediments	Layer 1	**X**	Not relevant for Model Development.				
Woodbine Aquifer	Layer 2	**X**	Not present within the study area.				
Washita / Fredericksburg	Layer 3	→	Layer 1		←	Layer 1	Edwards Group
Paluxy Aquifer	Layer 4	**X**	Not relevant for Model Development.		←	Layer 2	Upper Trinity Aquifer
Glen Rose Formation	Layer 5	→	Layer 2	Glen Rose			
Hensell Aquifer	Layer 6	→	Layer 3	Hensel	←	Layer 3	Middle Trinity Aquifer
Pearsall Formation	Layer 7	→	Layer 4	Cow Creek			
			Layer 5	Hammett			
Hosston Aquifer	Layer 8	→	Layer 6	Sligo	←	Layer 4	Lower Trinity Aquifer
			Layer 7	Hosston			
Represented as the base of Layer 8.		**X**	Layer 8	Undifferentiated Paleozoics	**X**	Represented as the base of Layer 8.	

SECTION 3: RESULTS

3.1 HYDROSTRATIGRAPHIC CONTROL

A total of 1,742 well control points were included in the hydrostratigraphic well control dataset (Appendix A). An unequal allocation of stratigraphic control across formations can be attributed to well location, formation depth, and log quality. For example, a well in western Travis County does not provide information on the Sligo since that formation is absent there. While a well drilled to completion in the Cow Creek formation does not provide information on the Hosston below. Figure 11 illustrates the spatial distribution of the hydrostratigraphic well control dataset. Visible are previously existing well control data points and newly acquired well control points.

3.2 GEOLOGIC CROSS SECTIONS

Five regional cross sections were constructed to illustrate stratigraphic correlations, formation depths, structural complexities, and aquifer distributions (Figure 12 - Figure 17). Additionally, cross sections provide a useful demonstration of the study area stratigraphy with respect to geophysical log data. Cross sections were generally developed in the direction of depositional dip (A-A' to C-C'), and strike (D-D' to E-E'). These cross sections allow for the visualization of geologic relationships between stratigraphic units and comparison of layers across geophysical log curves.

3.3 SOUTHWESTERN TRAVIS COUNTY GCD MONITOR WELL (FIRE STATION #104) LOG, CORE AND CUTTINGS CHARACTERIZATION

From this well analysis, several key deliverables were created. This includes a composite geophysical log with lithologic descriptions and stratigraphic interpretations (Figure 18), and geologic profile sketches of the rock core with lithologic descriptions and core photographs (Figure 19 - Figure 24), and interpretation of the core's depositional environments (Figure 25).

This analysis shows that the Hensel is primarily composed of siliciclastic sediments, most likely deposited in nearshore environments. In addition, the Cow Creek is missing the near and upper shoreface sequences commonly observed in areas to the south. Within the Hensel and Cow Creek, a coarsening upward sequence can be observed at this location (Hunt, 2024).

3.4 WILLIAMSON COUNTY LOWER TRINITY WELL DRILL CUTTINGS

This analysis includes the development of a composite geophysical log with lithologic descriptions, stratigraphic interpretations, and drill cutting photography (Figure 26). From this analysis, multi-colored siliciclastic and calcareous sand, gravel and conglomerates are observed within the Hensel. Near the top of the Hensel formation is a green shale that is also observable in the Southwestern Travis County GCD Monitor Well Core analysis and other core analysis within the Hamilton Pool area by Hunt (2023). The Cow Creek is composed of grey sandstone, dolomitic skeletal rudstone and shale. The Hosston appears as dominantly grey poorly to well-cemented sandstones, siltstone and dolomitic gravels with trace pyrite. Marked at the bottom is the undifferentiated Paleozoics which appear as black shale at this location.

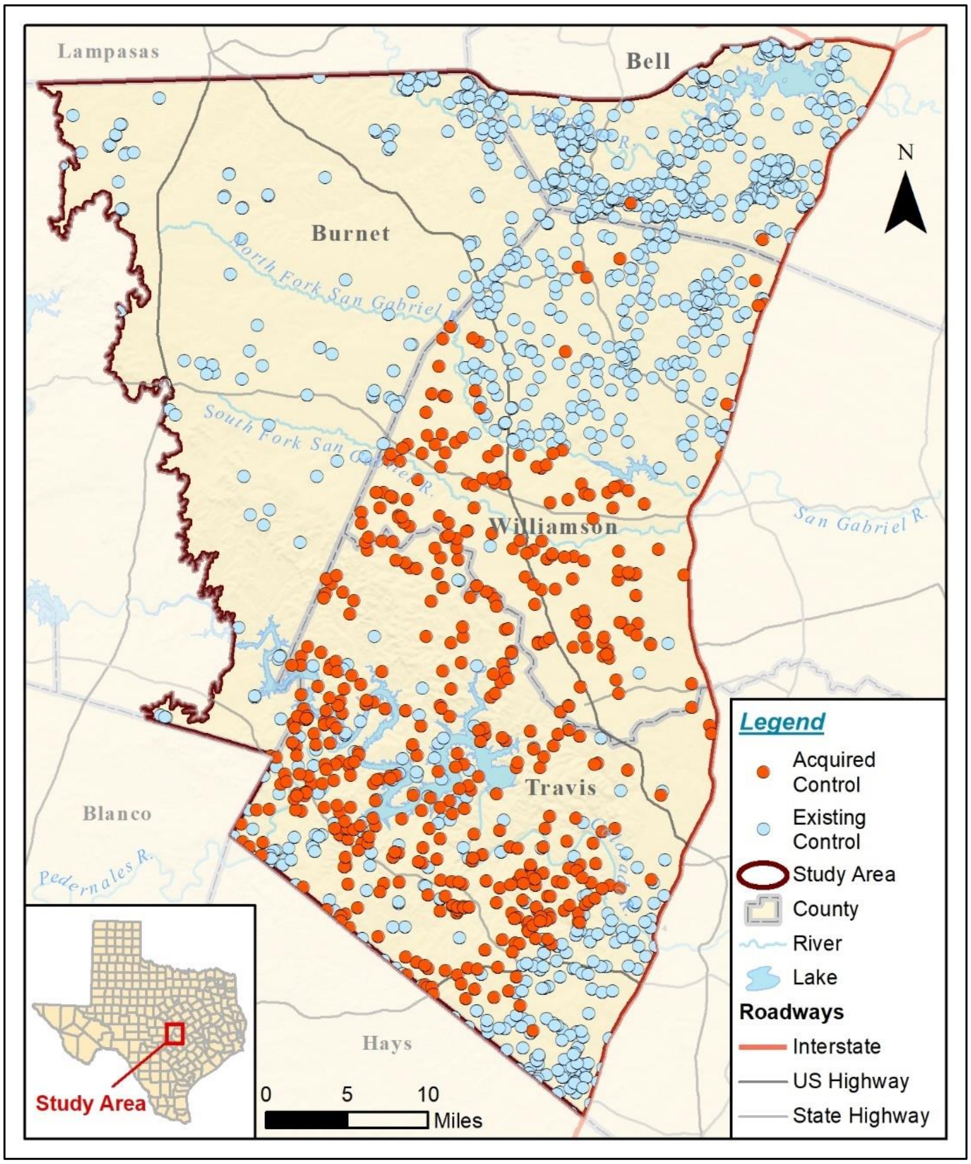


Figure 11 – Study Area Stratigraphic Well Control Dataset.

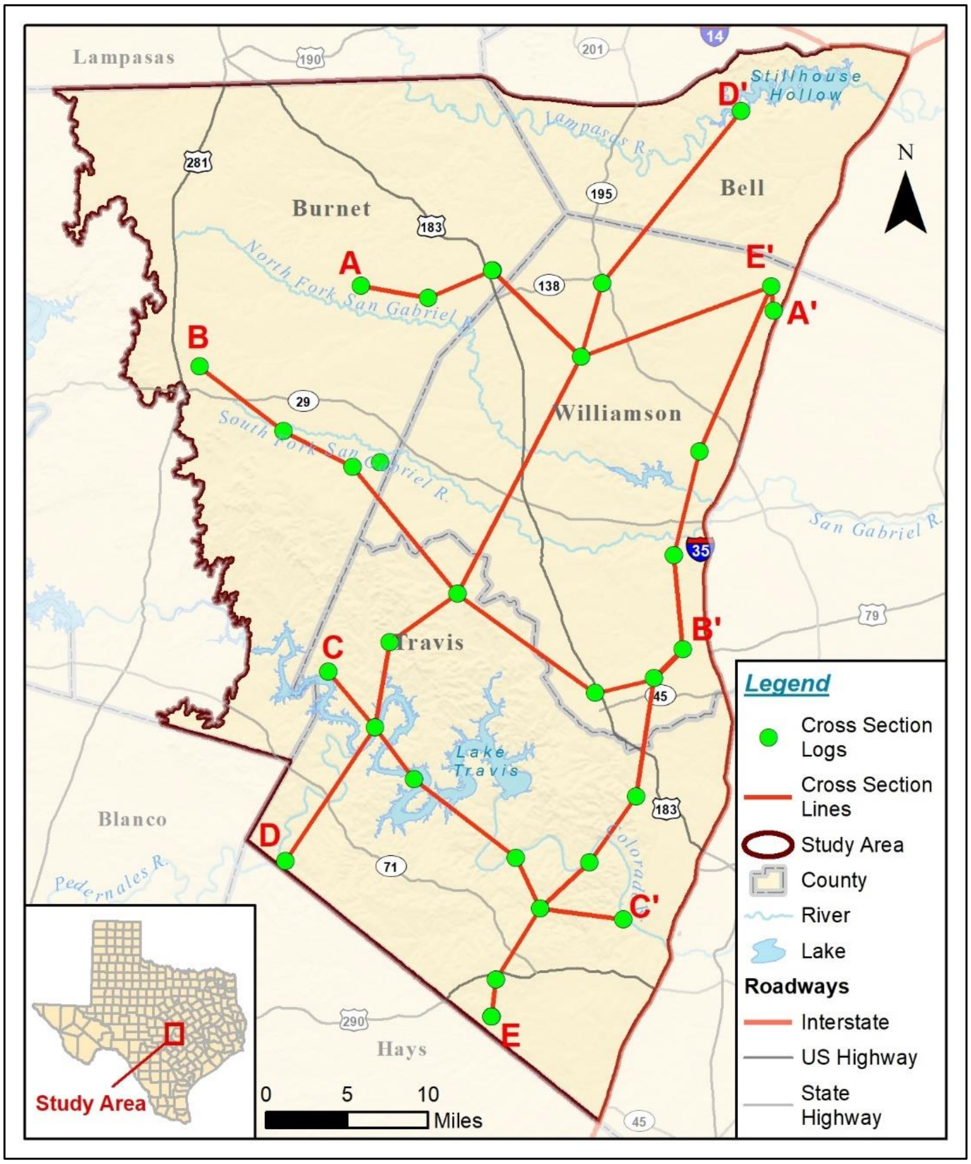


Figure 12 – Cross Section Lines

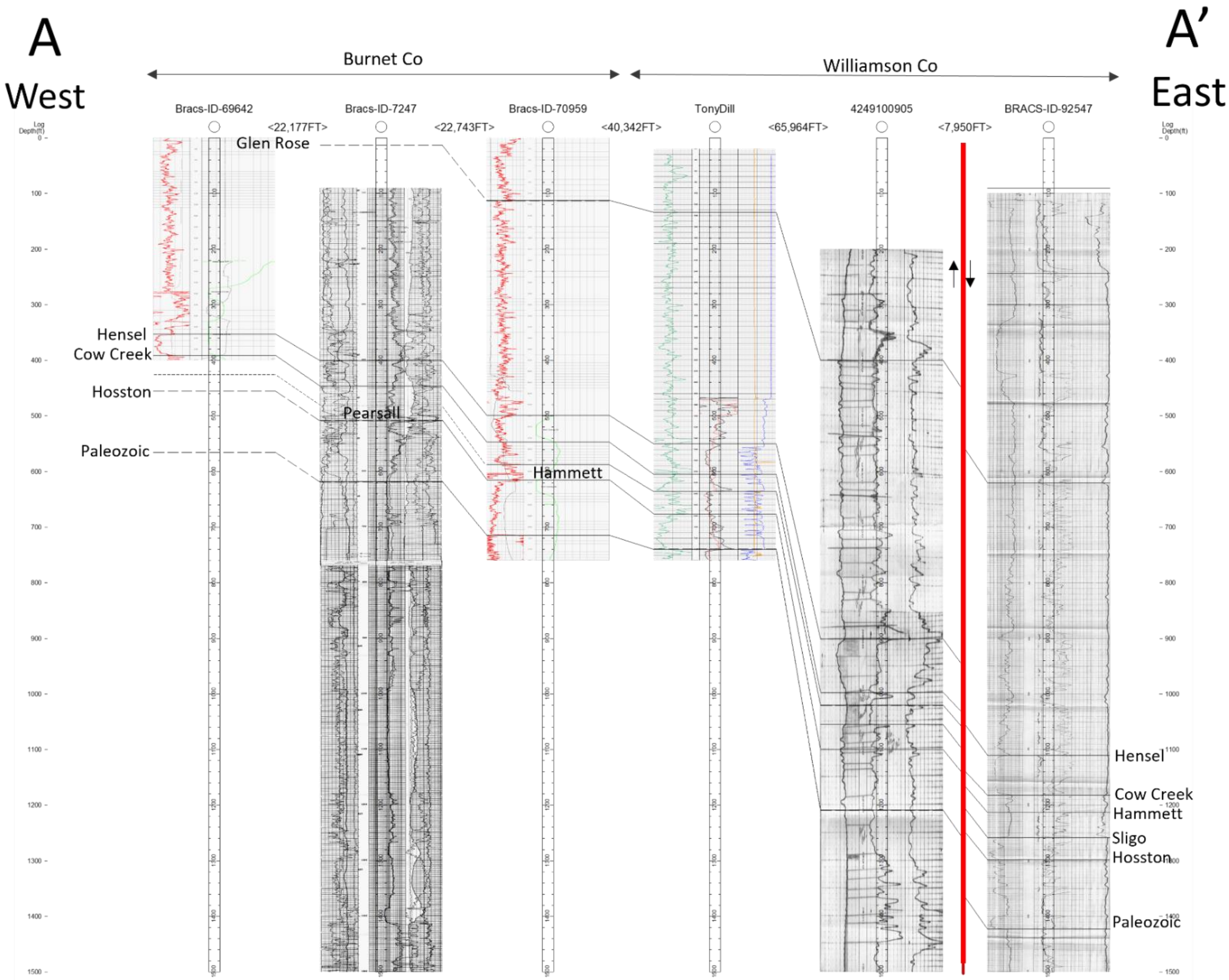


Figure 13 – Cross Section A-A'

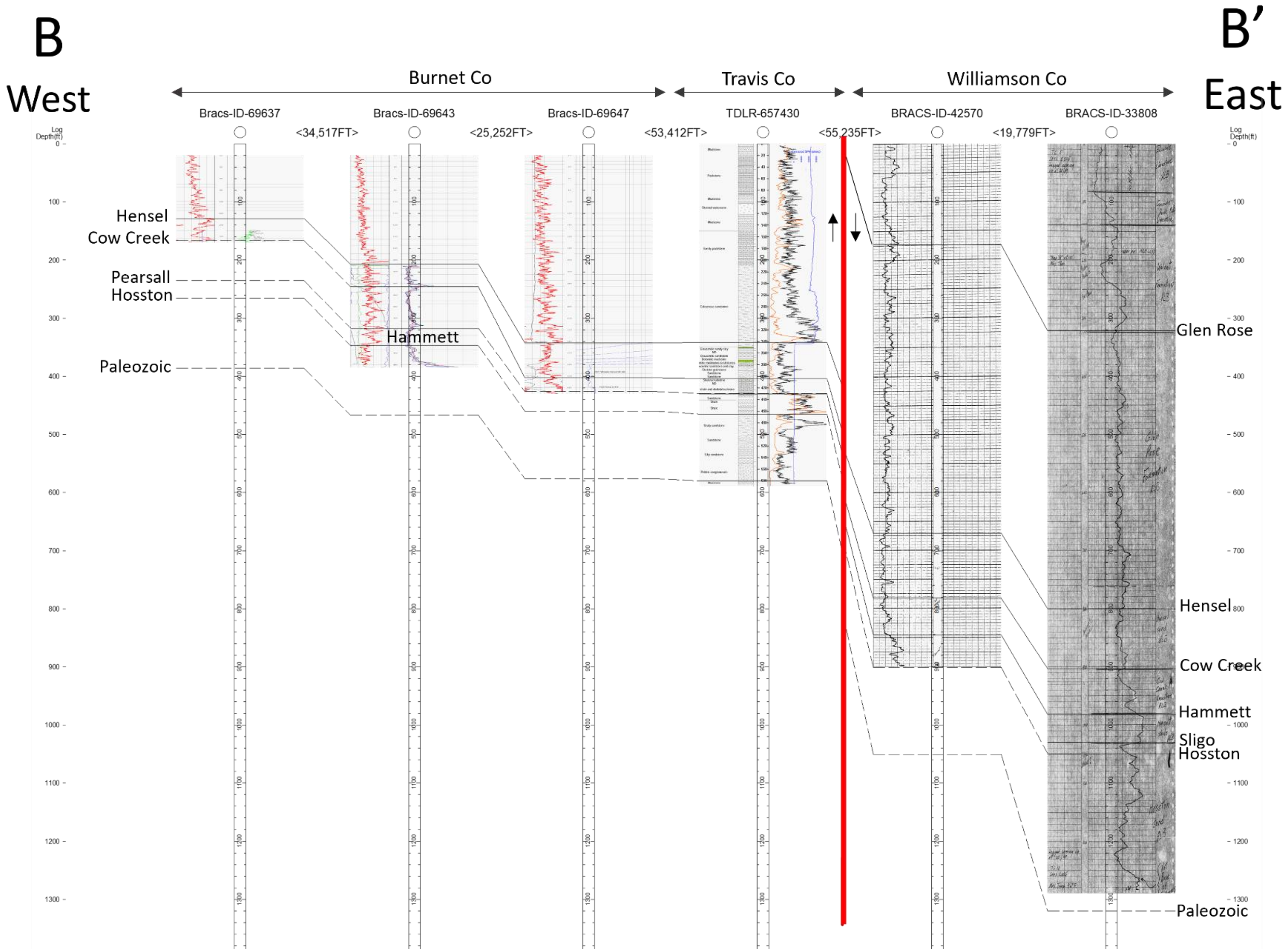


Figure 14 – Cross Section B-B'

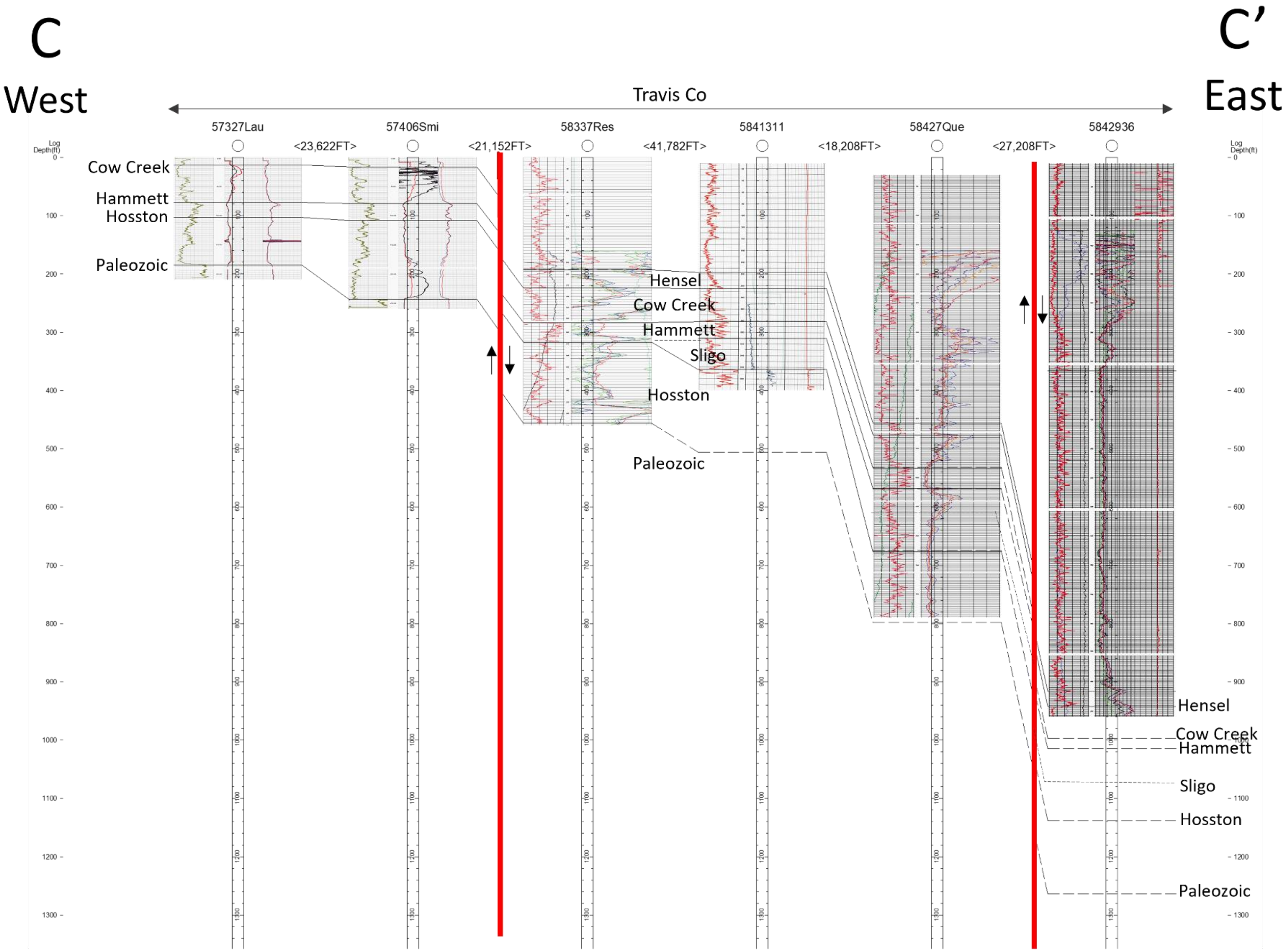


Figure 15 – Cross Section C-C'

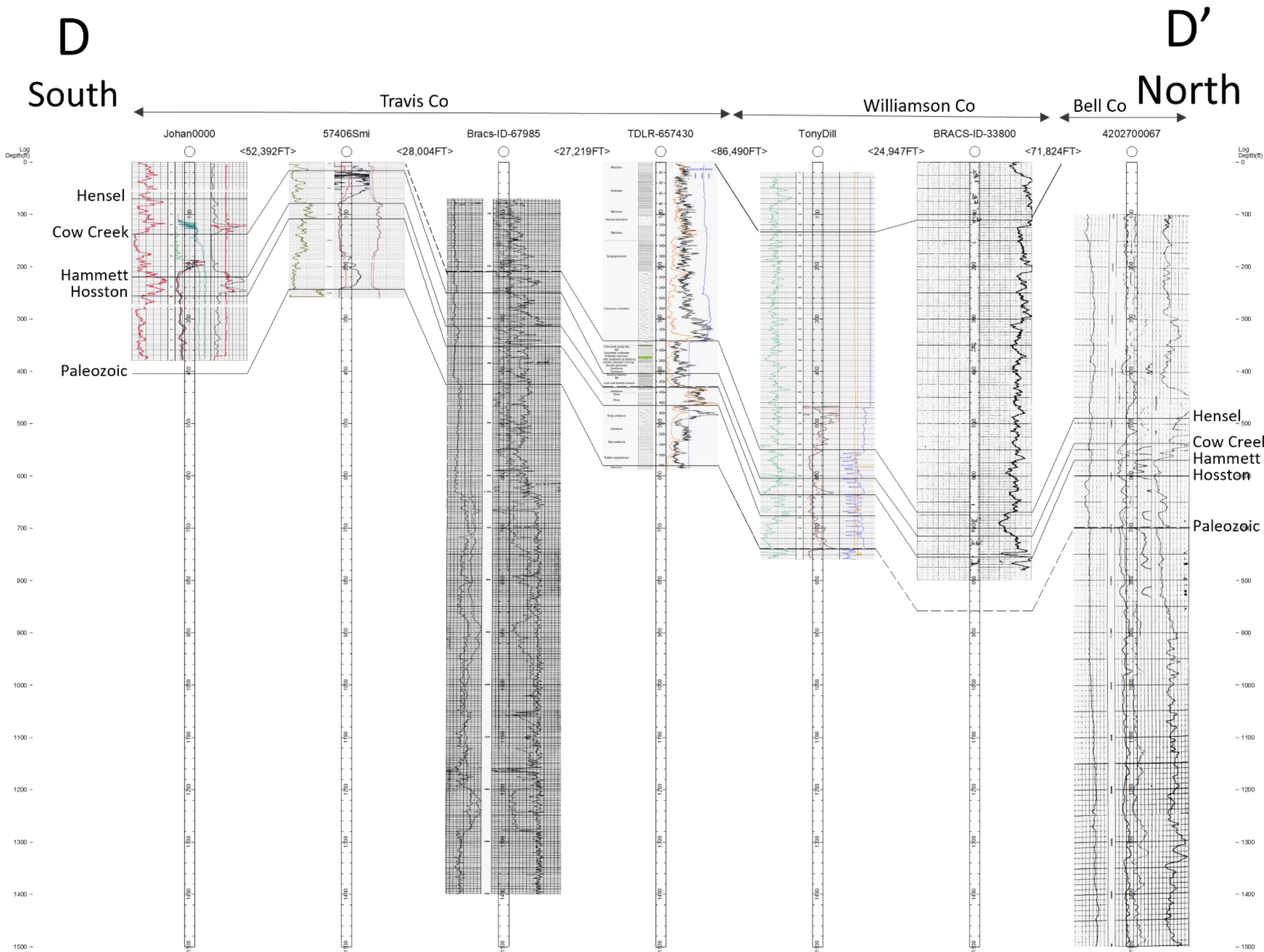


Figure 16 – Cross Section D-D’

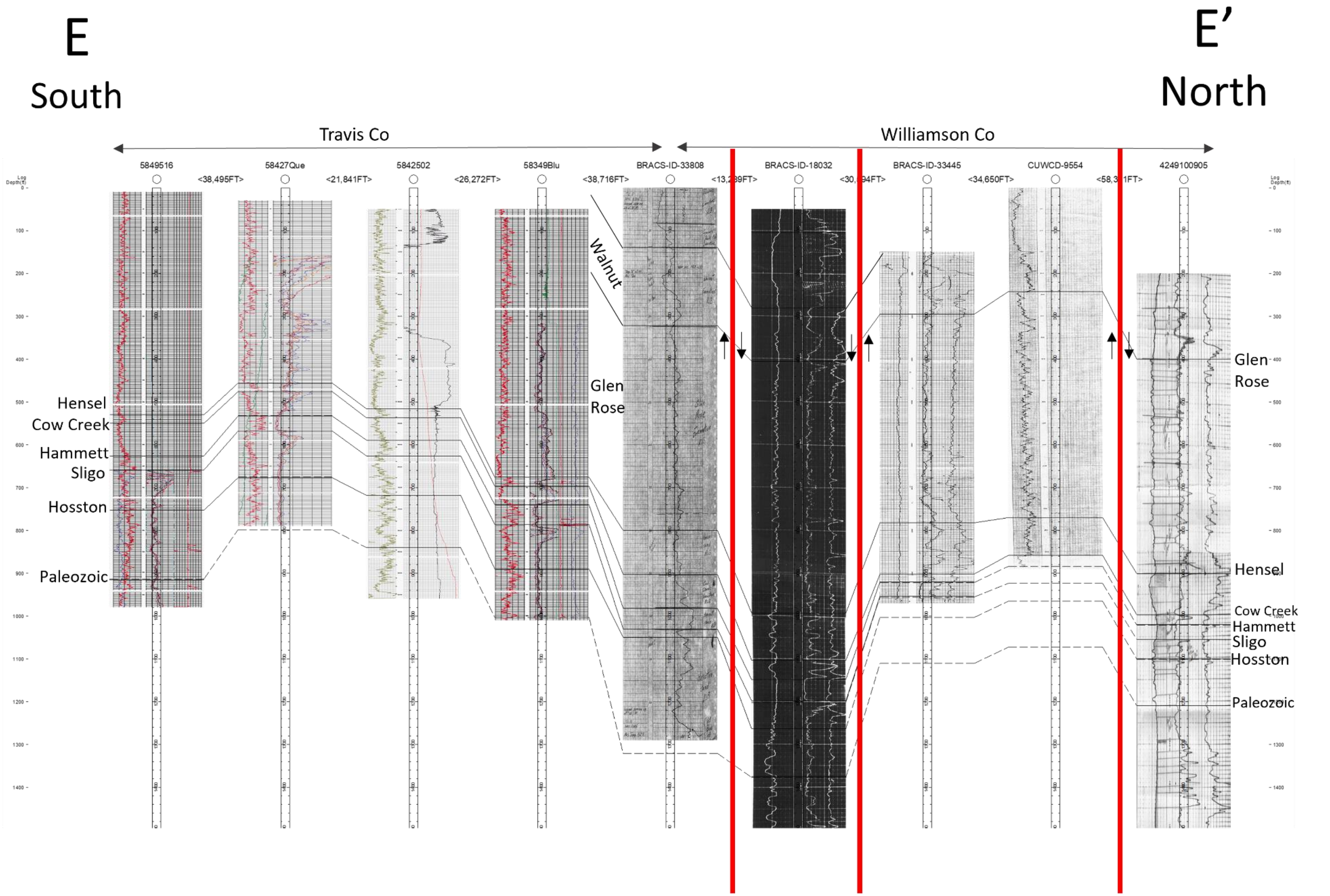


Figure 17 – Cross section E-E'

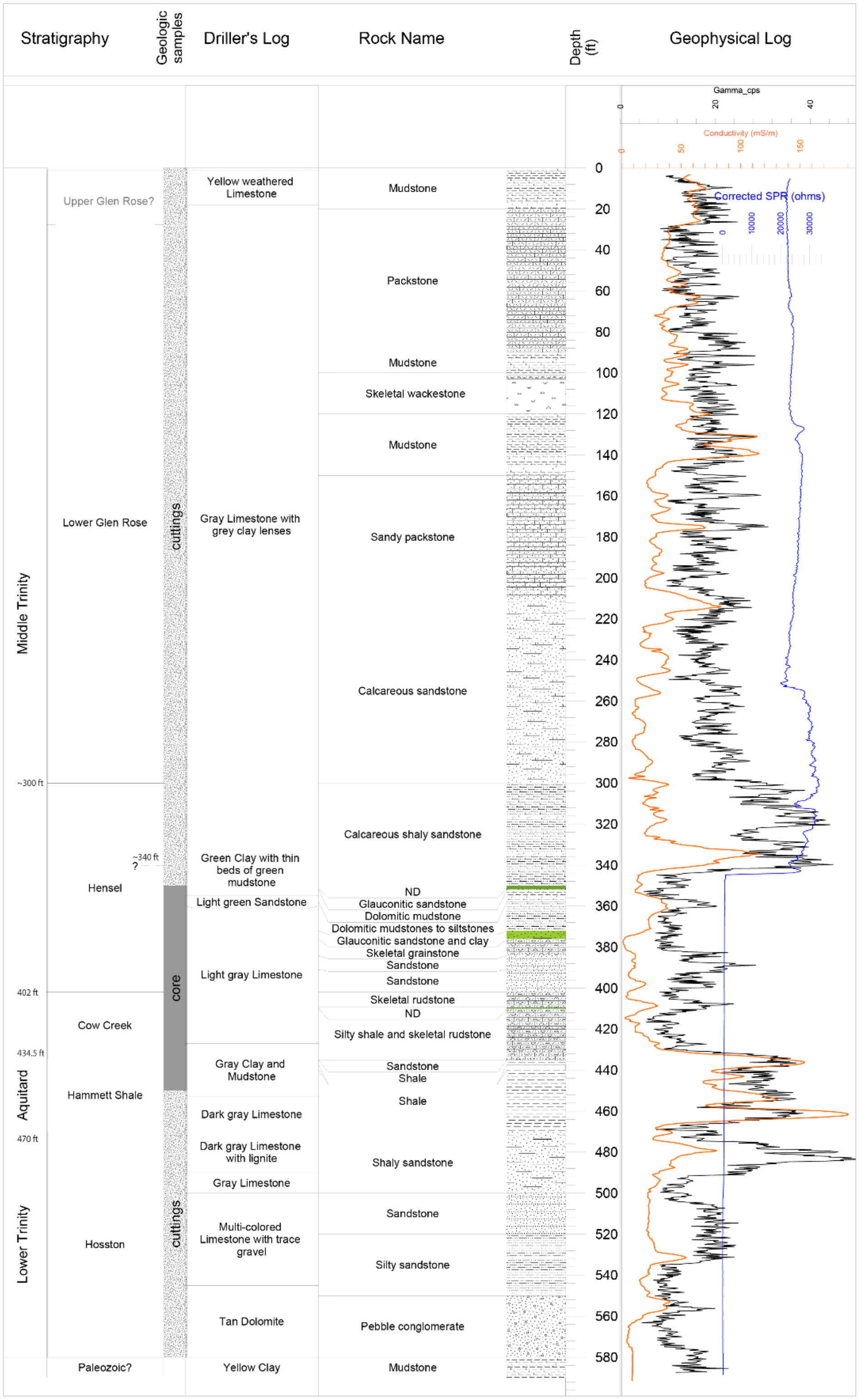


Figure 18 – Southwestern Travis County GCD (Fire Station #104) composite log with lithostratigraphic and stratigraphic descriptions (from Hunt, 2024).

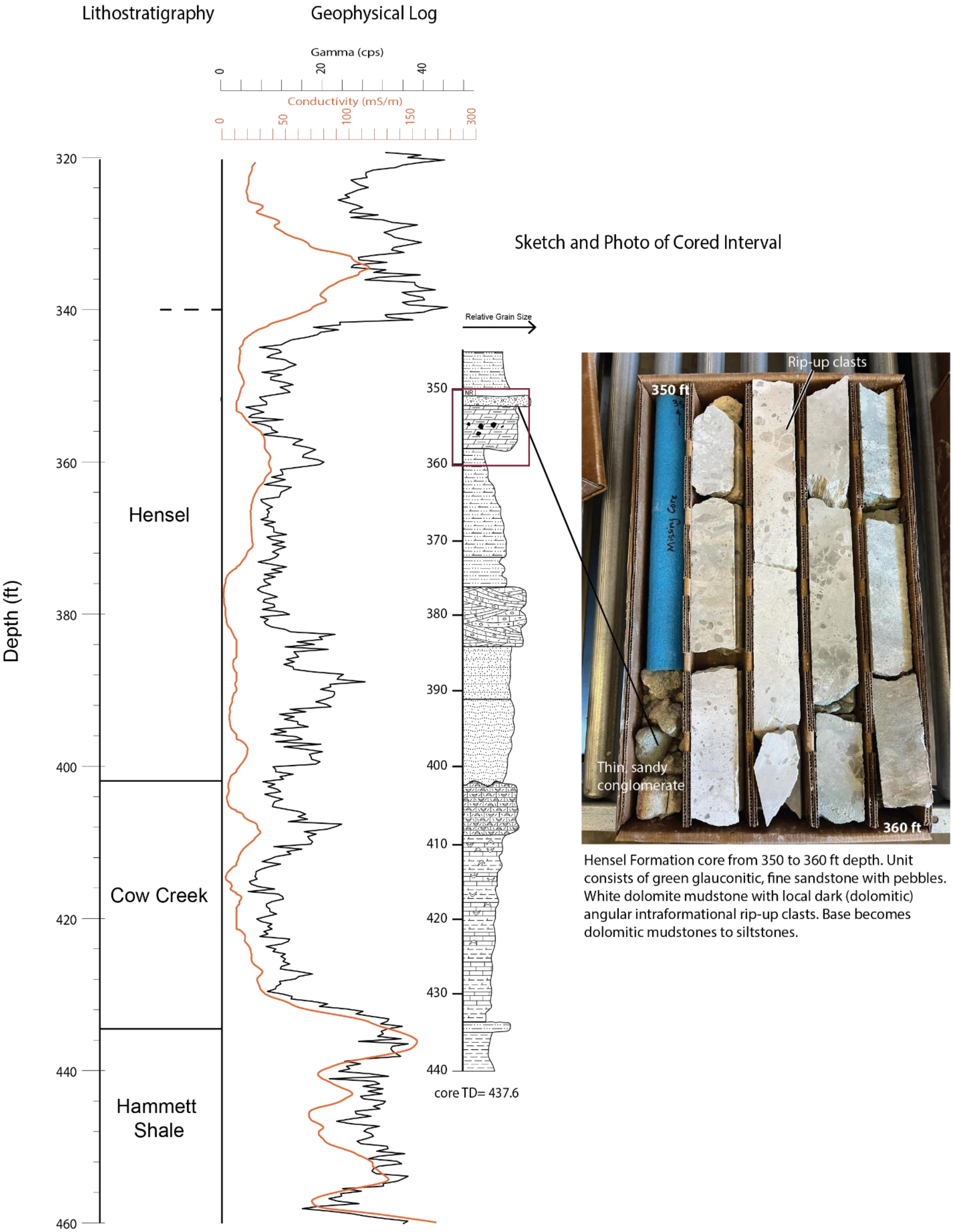


Figure 19 – Southwestern Travis County GCD (Fire Station #104) composite log with Hensel (Khe) cored interval 350 to 360 feet.

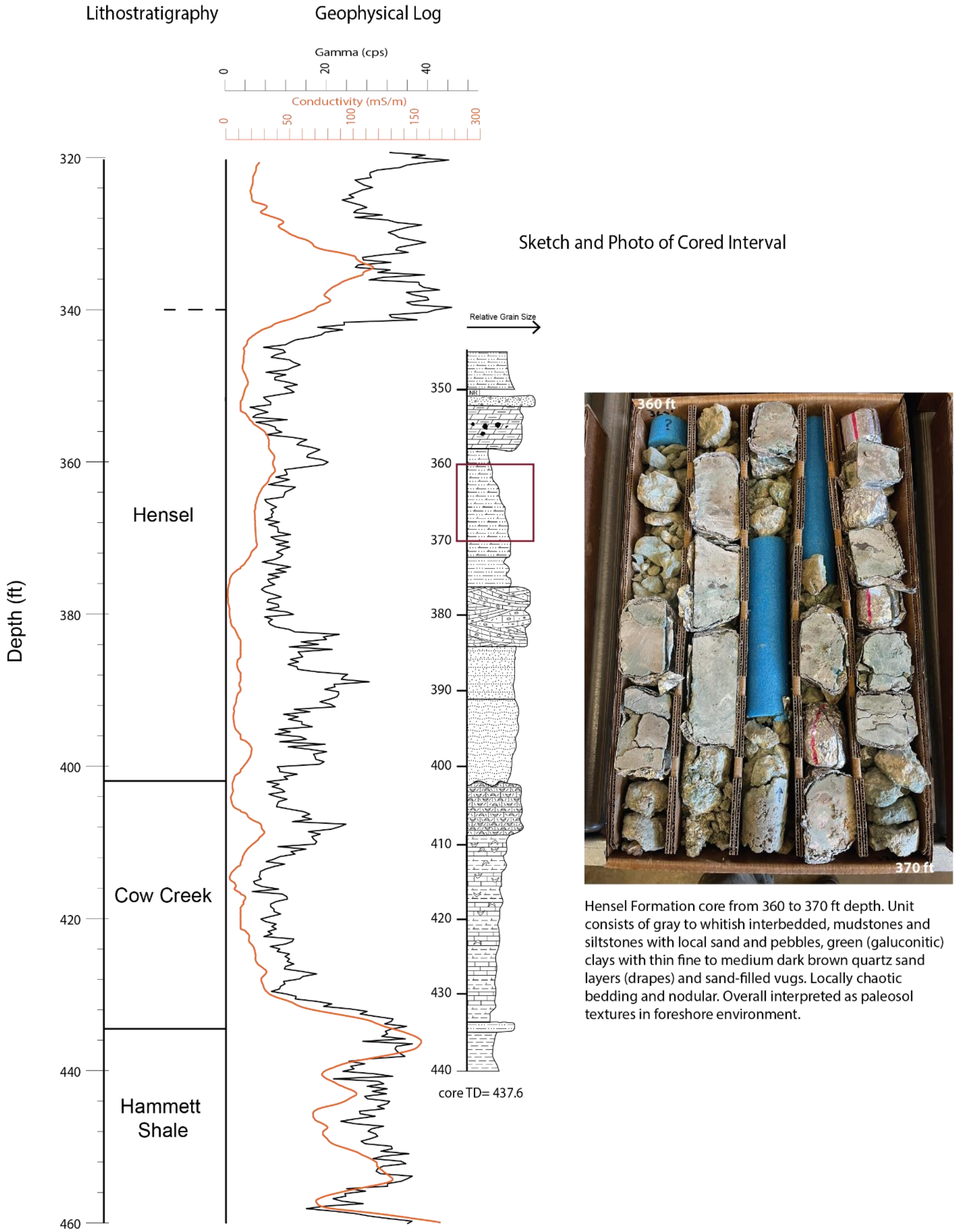


Figure 20 - Southwestern Travis County GCD (Fire Station #104) composite log with Hensel (Khe) cored interval 360 to 370 feet (from Hunt, 2024).

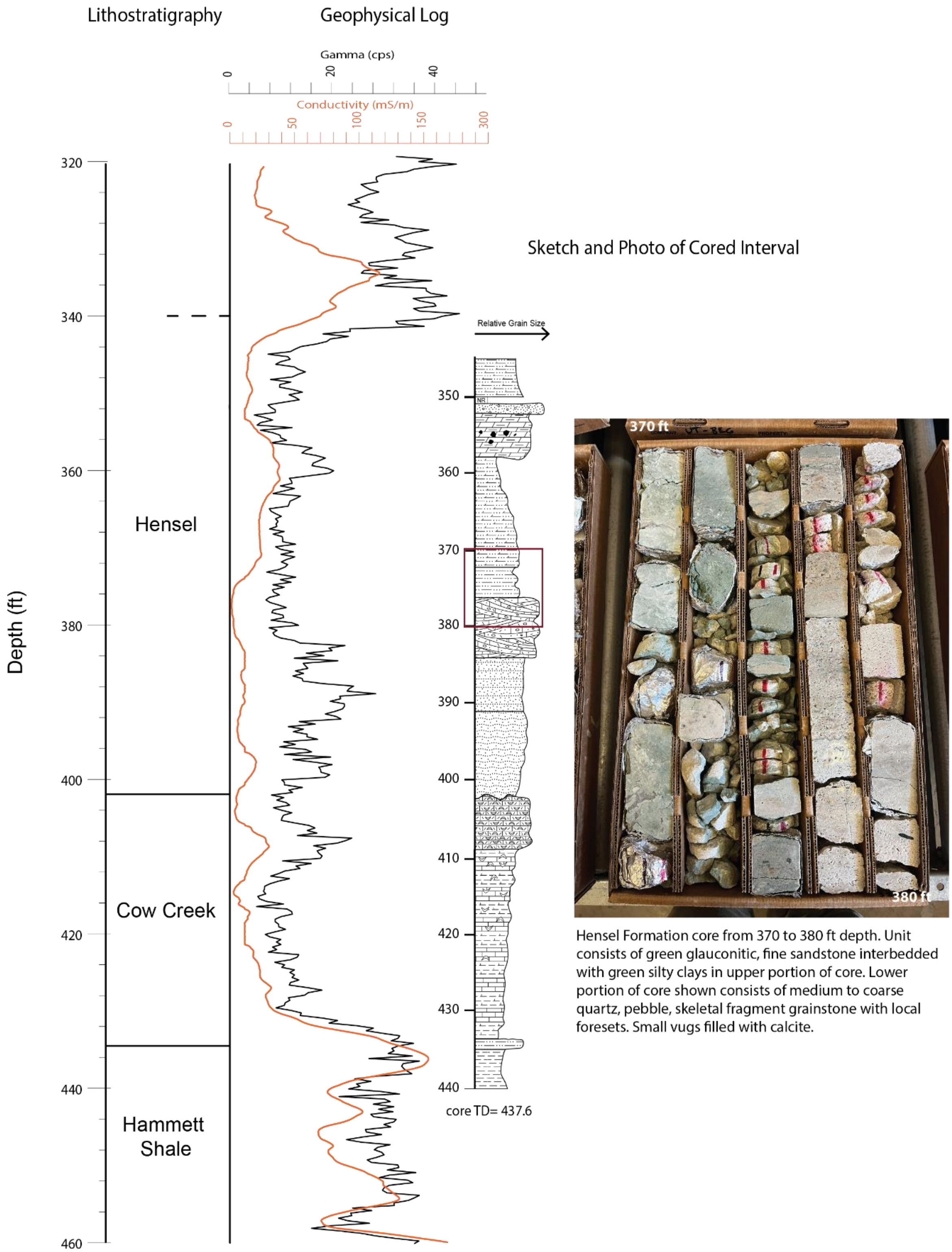


Figure 21 - Southwestern Travis County GCD (Fire Station #104) composite log with Hensel (Khe) cored interval 370 to 380 feet (from Hunt, 2024).

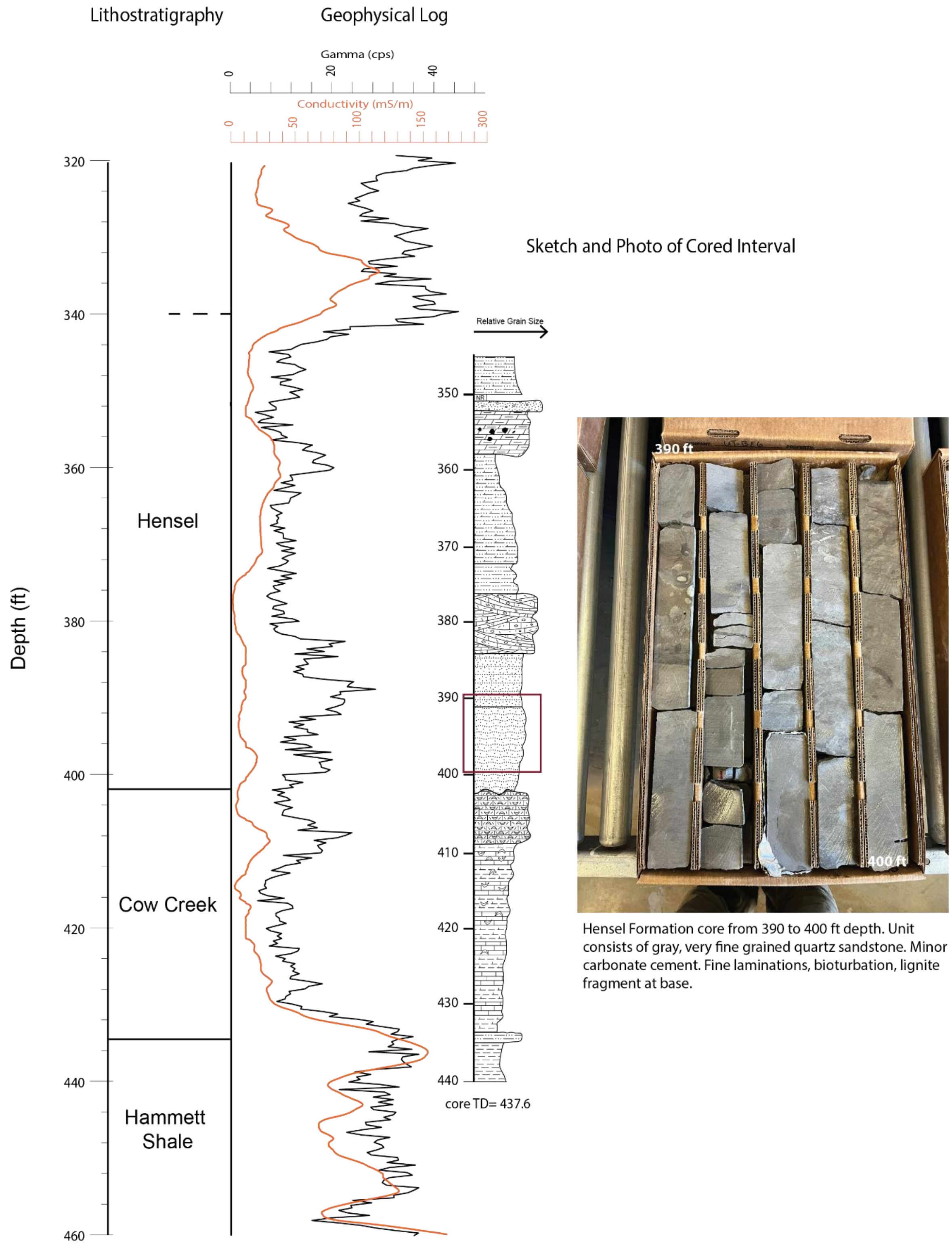


Figure 22 - Southwestern Travis County GCD (Fire Station #104) composite log with Hensel (Khe) cored interval 390 to 400 feet (from Hunt, 2024).

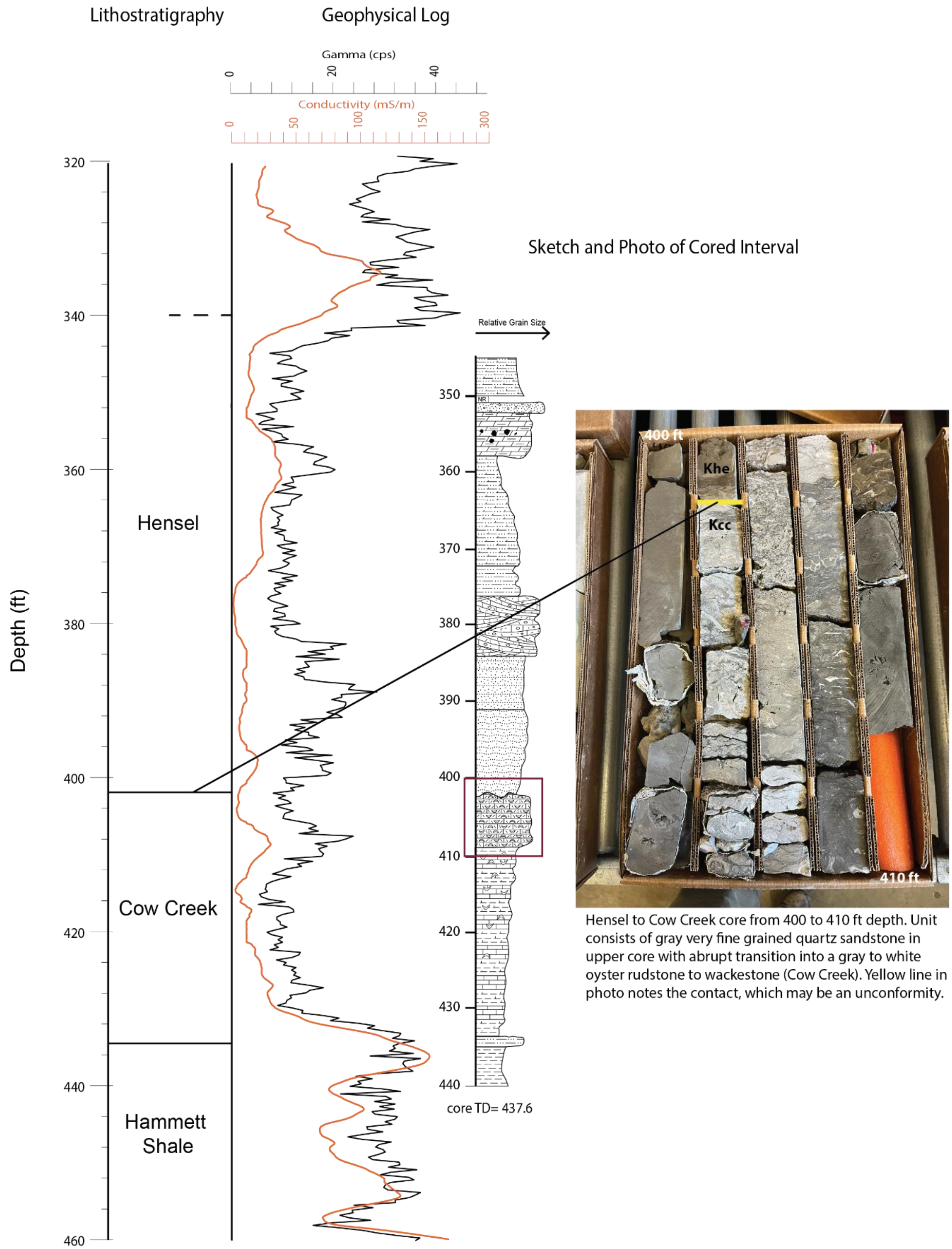


Figure 23 - Southwestern Travis County GCD (Fire Station #104) composite log with Hensel (Khe) and Cow Creek (Kcc) cored interval 400 to 410 feet (from Hunt, 2024).

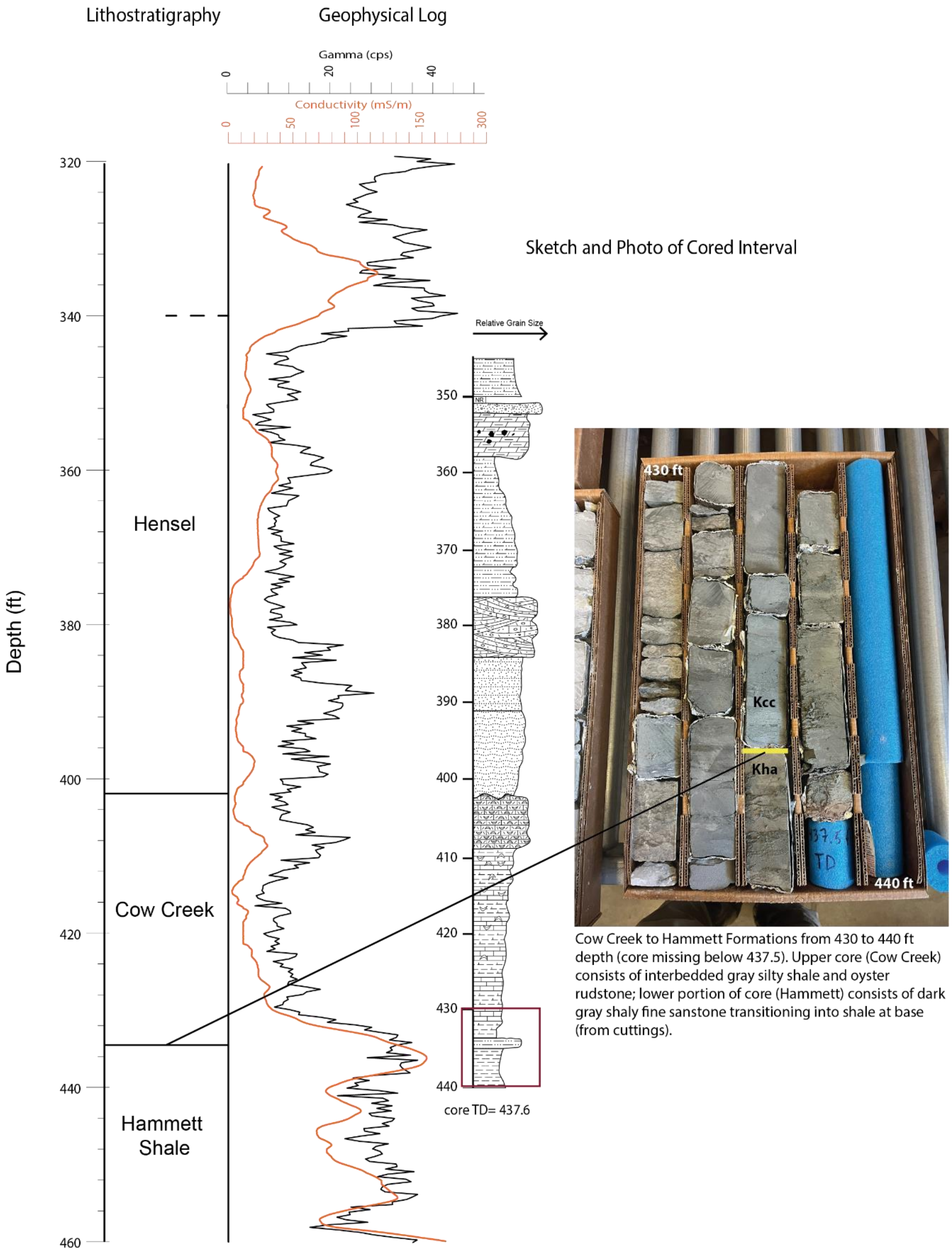


Figure 24 - Southwestern Travis County GCD (Fire Station #104) composite log with Cow Creek (Kcc) and Hammett (Kha) cored interval 430 to 440 feet (from Hunt, 2024).

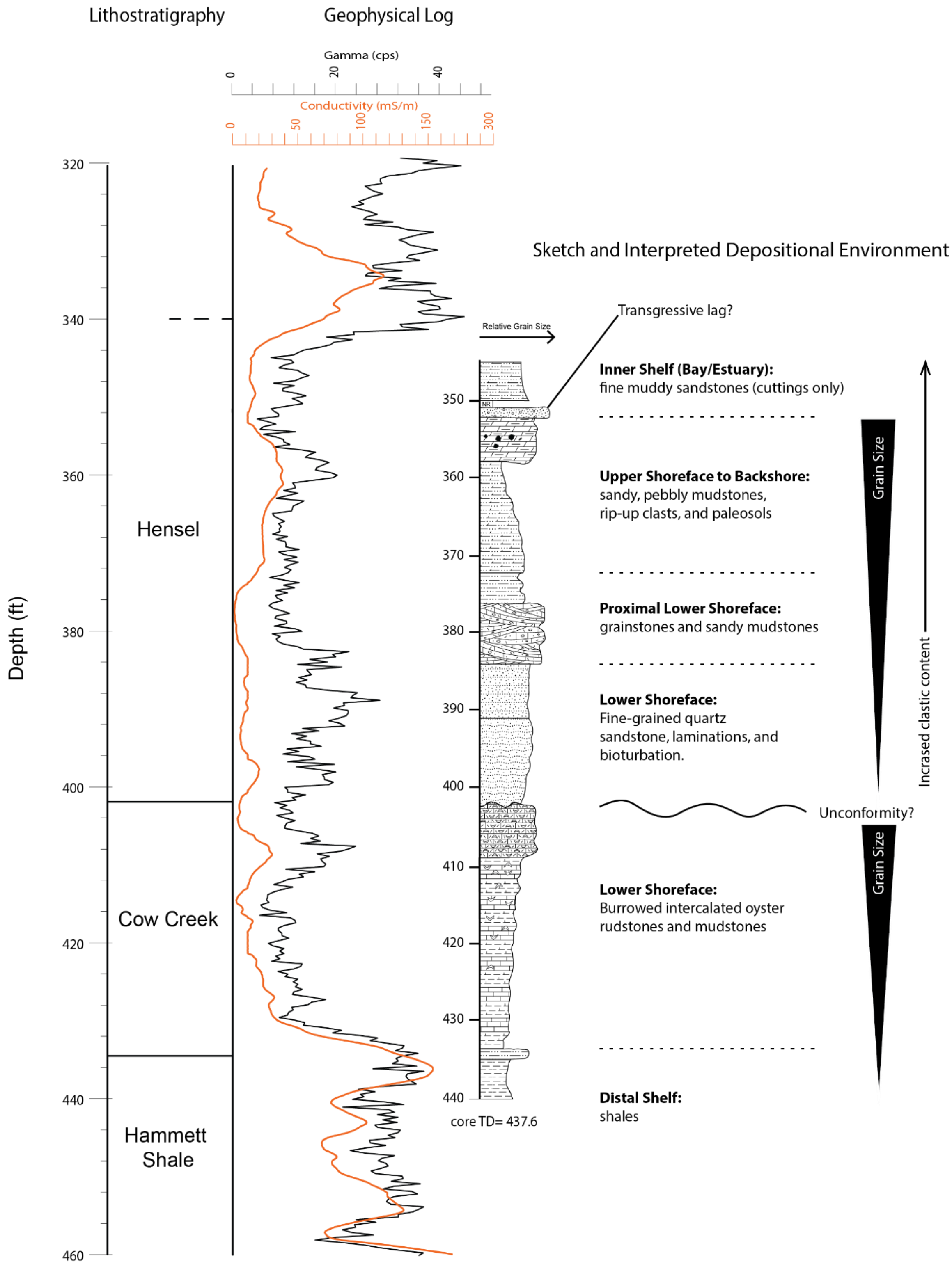


Figure 25 – Composite log with interpreted depositional environments (from Hunt, 2024).

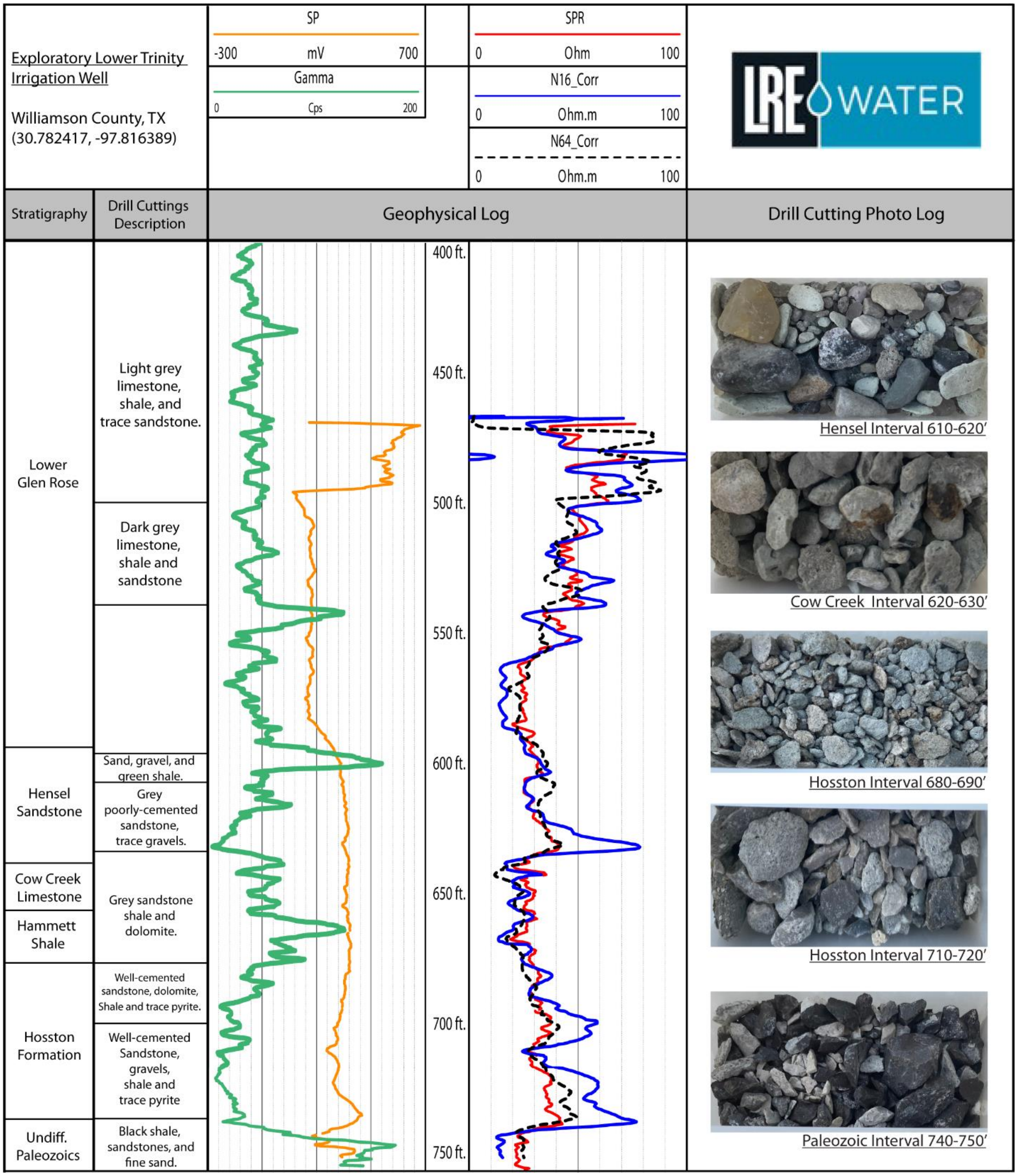


Figure 26 – Williamson County Lower Trinity Composite Log.

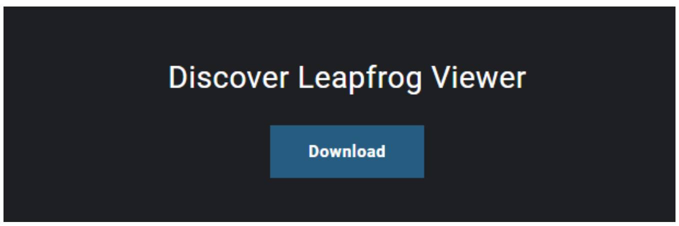
3.5 THREE-DIMENSIONAL (3D) HYDROSTRATIGRAPHIC MODEL ENVIRONMENT

The 3D hydrogeologic model is provided as a Leapfrog Viewer file (Appendix B), a free desktop application by Seequent®. Although free, the viewer file must be downloaded before use.

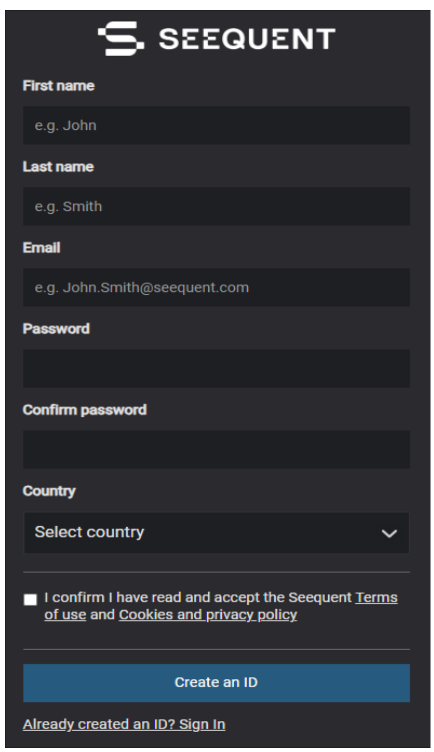
3.5.1 Model Viewer Download Instructions

Steps 1-6 (as of 8/2/2024) provide the necessary actions to download and install the viewer application file on any computer using a Windows operating system. After completing these steps, the viewer application file is available for use for up to 30-days, after which time the software license will need to be renewed. Renewal instructions are provided in Steps 4-6.

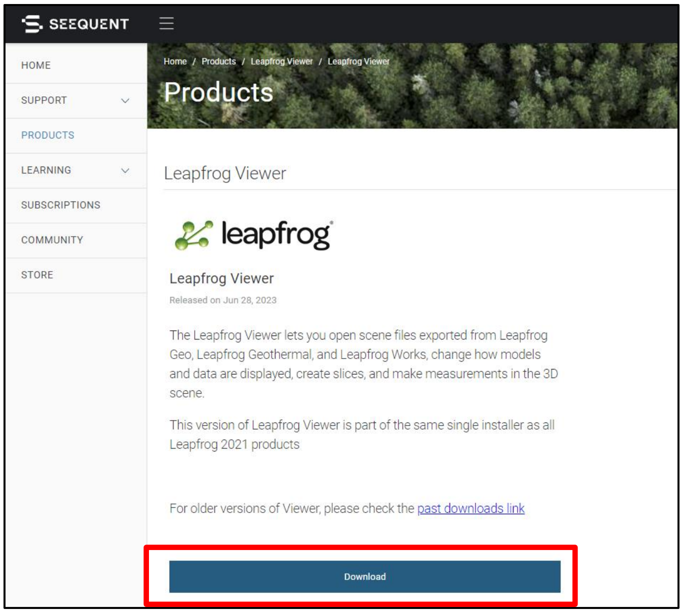
(Step 1) To open the viewer file, a user **must first** download the viewer application from https://www.seequent.com/products-solutions/leapfrog-viewer/.



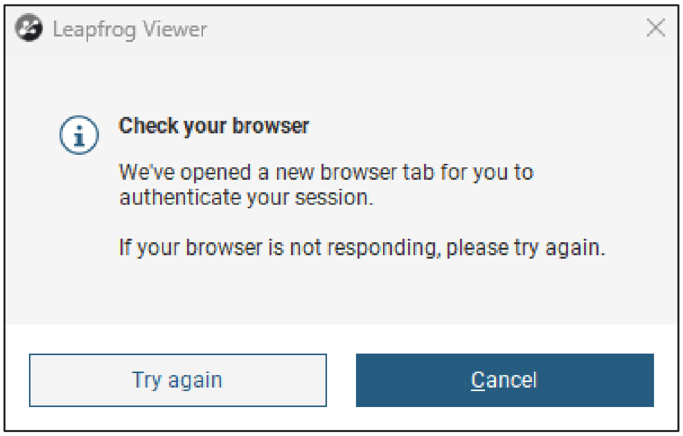
(Step 2) Upon attempting to download the file, a user **must** create an account which gives them unlimited access to the viewer application license.



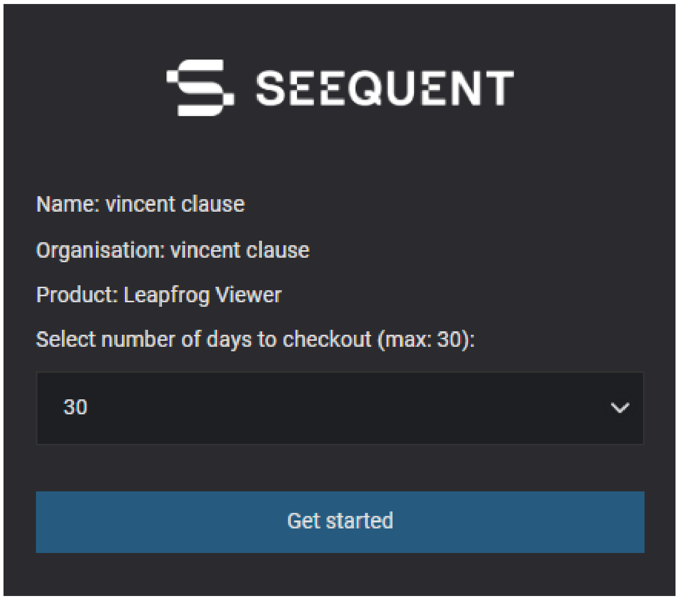
(Step 3) Once a new account is created, the user **must** log into the account and download and then install the leapfrog viewer application.



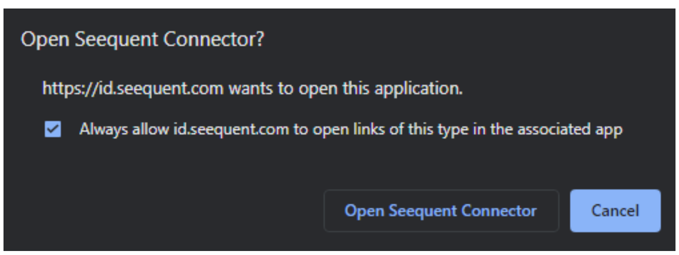
(Step 4) Upon opening the viewer application, the user will be prompted with a dialog box and **must** authenticate the software by navigating back to their internet browser and logging into their account.



(Step 5) A dialog box will open; and the user **must** check out a license. It is recommended that the user selects 30 days to limit the frequency that the license will need to be renewed.



(Step 6) Finally a user **must** authorize the Seequent Connector. After authentication, the application file is ready to use.



3.5.2 Three-Dimensional (Leapfrog) Hydrostratigraphic Model Environment

The 3D model leapfrog viewer includes three primary areas of functionality: (1) toolbar, (2) table of contents and (3) workspace (Figure 27).

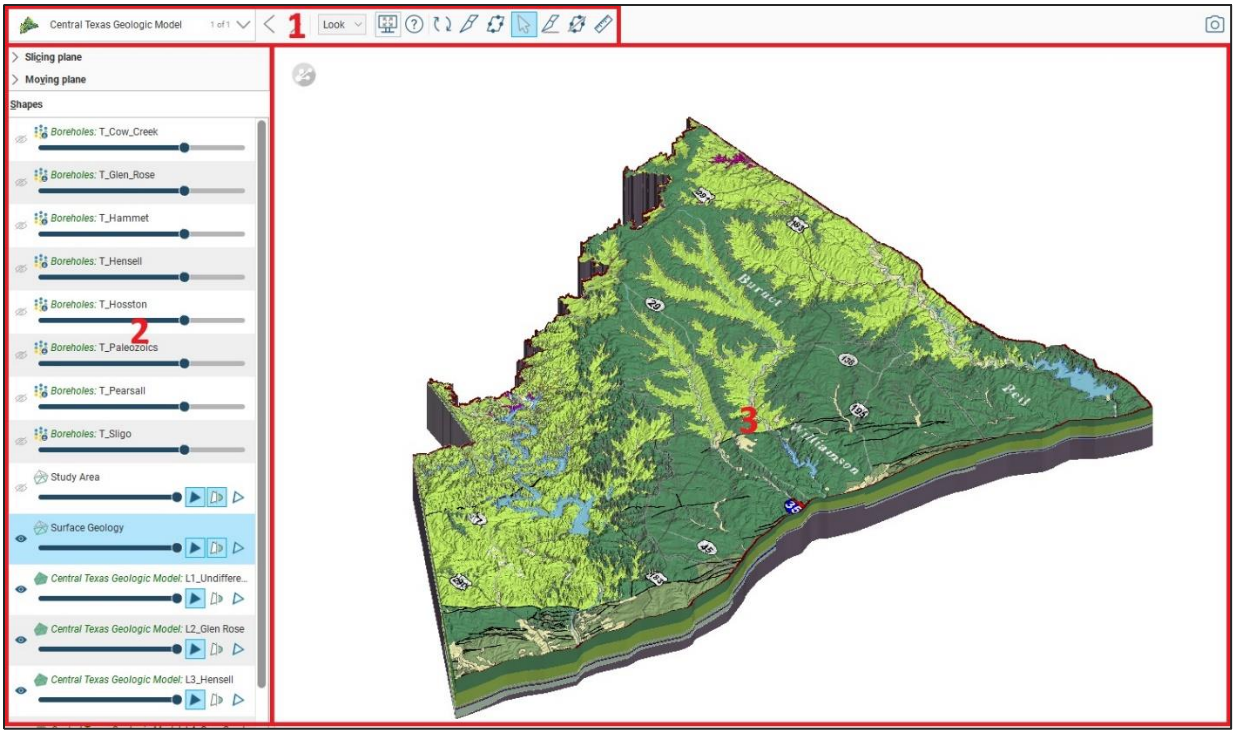


Figure 27 - 3D Hydrostratigraphic Model (Leapfrog Viewer).

3.5.2.1 Hydrogeologic Model Toolbar

The toolbar area (1) allows the user to navigate between predefined scenes by use of the drop-down menu. Additionally, this area provides access to the cross section and measuring tools which provide the ability to create on-the-fly cross sections and measure a vertical or horizontal distance anywhere in the model workspace. Tool tutorials can be found by clicking the help icon " ⓘ " located within the toolbar area.

3.5.2.2 Hydrogeologic Model Table of Contents

The table of contents (2) provides the ability to modify what is visible within the workspace area. It is within the table of contents that a user can change between base map layers, turn layers on and off, and adjust layer transparency. Modifications made within the table of contents are instantaneously visible within the model workspace area.

3.5.2.3 Hydrogeologic Model Workspace

The model workspace area (3) is where the user interacts with the model data by mouse click or with the cross section and measuring tools. Additional viewer functionality is available through keyboard 'hot keys' which can be found by clicking on the "Look" dropdown box located in model toolbar area.

3.5.3 Hydrogeologic Model Variance Analysis

A variance analysis was performed to compare the modeled formation surface depths to the stratigraphic picks that were used to develop the model. Model variance is used to demonstrate confidence and better understand where the model may be over or underestimating observed conditions. Variance is introduced by a variety of factors, and most frequently can be attributed to grid cell resolution as the model conforms to nearby data points while also considering distant trends. Figure 28 provides a simplified demonstration of this effect.

In Figure 28 grid cell A includes three equally spaced points that range in elevation from 695’ to 705’. Although the mean for these points is 700’ the modeled grid cell value is slightly higher at 701’. This is because it is also being influenced by the nearby points in cell B. Cell C has a modeled elevation of 694’ feet while the only point in this grid is located at 690’. This variance is introduced because the model considers the higher elevation within cell B and the trend that exists between those grid cells. Model variance is usually amplified in areas that demonstrate high slope gradients commonly attributed to structural controls such as a fault. Within the hydrostratigraphic model, grid cells are assigned elevations at the cell centers.

The mean variance for each modeled surface generally falls within a range of ±11 and ± 24 feet of the control point value. Higher model variance is usually correlated with areas of known faulting where the well control does not conform with the complexities of this system.

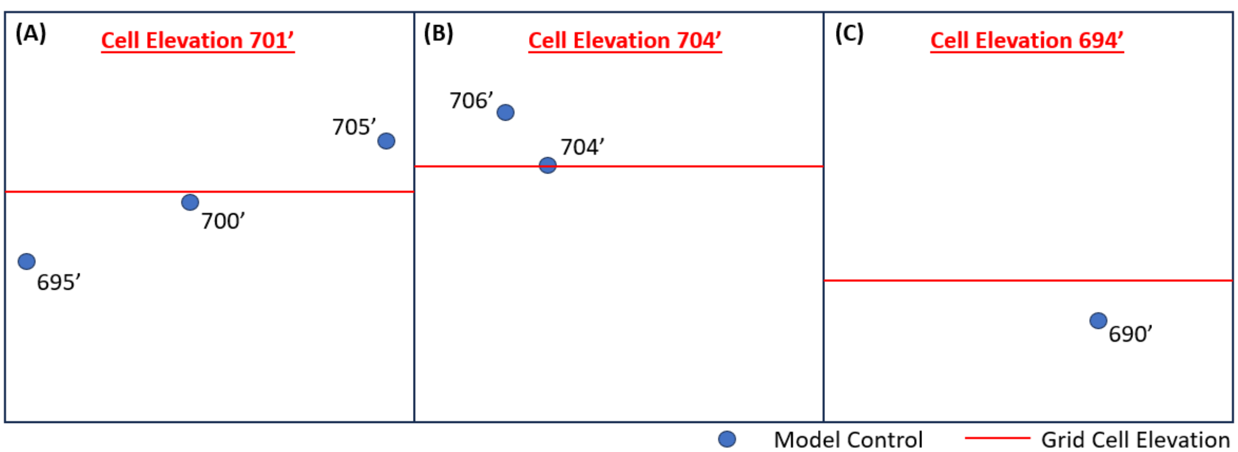


Figure 28 – Demonstration of model variance introduced by the grid cell resolution effect.

3.6 HYDROGEOLOGIC MODEL STRUCTURE AND ISOPACH DATA (LEAPFROG EXPORT DATA)

The 3D hydrogeologic model can provide users with information on target aquifer thicknesses and drilling depths. Figure 29 - Figure 34 illustrate the depth to the top of each Leapfrog model surface (excluding the Upper Cretaceous which is present at land surface). These surfaces only account for the depth of each unit when present below land surface, while associated outcrop areas are visible as gray.

Figure 35 – Figure 39 illustrate total thicknesses (“isopach”) for each Leapfrog model surface. The total thickness for the undifferentiated Paleozoics was not calculated, as this surface top serves as the model base.

In general, the depth to each layer increases in a southeasterly direction, with the deepest measured sections occurring along the eastern edges of the model area. Trends associated with unit thickness did vary across the study area, especially near the Balcones Fault. Within each layer, the distribution of unit thickness is variable around the Balcones Fault Zone. We believe this is a result of limited data control, coupled with an incomplete understanding of the faults within this area. Modeled thicknesses are also slightly irregular within the outcrop areas where the complexities of GAT surface geology may not properly conform to the local elevation trends. This was specifically an issue when modeling the Hammett, Cow Creek and Hensel since these units are relatively thin and are modeled using an uneven distribution of data points across the study area. Due to these model complexities, the Leapfrog model data in this area should only be used for general reference.

3.7 STRATIGRAPHIC SECTION OF THE MIDDLE AND LOWER TRINITY AQUIFER

To better understand the stratigraphic relationship between the Cow Creek and Hensel formation of the Middle Trinity Aquifer, a south-to-north stratigraphic section line along formation strike was developed (Figure 40; D-D’). This section line is flattened along the Hammett Shale and depicts generalized lithostratigraphic relationships within the Middle and Lower Trinity Aquifers.

Within the Hosston, there is a clear relationship between formation thickness and the underlying Undifferentiated Paleozoic unit. This observation is most notable when comparing the general thickness of the Hosston at TWDB SWN 5747313 (~150’) and BRACS ID 67985 (~70’). Based on our evaluation of driller lithology descriptions and collected drill cuttings, there is a noticeable difference in the Hosston lithology along the section line. Generally, the Hosston is composed of multi-colored sands, sandstones, gravels, and clays in Travis County. Whereas, in northern Williamson and into Bell counties there are more observations of siliciclastic sands and gravels.

Within the Cow Creek, there is an observable transition that occurs near the Travis and Williamson county line. Within this area the Cow Creek greatly thins as the foreshore and upper shore beds appear to grade into the overlying Hensel. As a result of this facies change the Cow Creek thins from approximately 80 feet in southern Travis County to approximately 25 feet in Williamson County. This facies change also coincides with the northern edge of San Marcos Arch as depicted by Phelps et al. (2014) and identified by Hunt (2024).

Within the Hensel, there is a notable transition from calcareous clastic facies in Travis County to more siliciclastic facies within Williamson and into Bell County. Paralleling the facies changes of the Cow Creek is an observable thickening of the Hensel in a northward direction. There is also an increase in siliciclastic fluvial channel gravel and sand deposits in a northward direction. Within Willamson County there is also an influx of gravel seam deposits occurring at different intervals within the Hensel.

3.6 PALEOGEOLOGIC MODEL OF THE MIDDLE AND LOWER TRINITY AQUIFER

Across the study area, lithology changes within the Middle and Lower Trinity Aquifer can be geographically defined. Previously identified lithology changes within the study area include the calcareous facies of the Middle and Lower Trinity (Klemt et al., 1975), western boundary of the Middle and Lower Trinity units (Partridge, 2011), Hensel clastic and marine facies changes in southern Travis County (Hunt et al., 2020a), Pearsall eastern extent (Standen and Clause, 2020), Sligo western extent (Stricklin et al., 1976) and changes in Cow Creek depositional patterns along the San Marcos Arch (Hunt, 2024). These previous observations have generally been made within local geographies or with limited well control.

For the first time, this study correlates and refines these facies changes across central Texas (Figure 41). Additionally, this study identifies an approximate depositional divide within the Hosston. South of the divide, the Hosston is primarily composed of multi-colored sandstone, shale and limestone deposits. North of this divide, the Hosston is predominately composed of siliciclastic sand, gravels and conglomerates, with some shale and limestone lenses. This general change in lithologies is consistent with the observations of Fisher and Rodda (1966) and the Twin Mountains nomenclature designation for the northern portion of the Trinity Aquifer.

3.7 REGIONAL WATER LEVELS

Using the TWDB GWDB, we attempted to develop recent 2024 winter water level surfaces for the Upper, Middle, and Lower Trinity aquifers. As a result of limited water level measurement data in Williamson and northern Travis County, this became an unreasonable task and was not completed for this study.

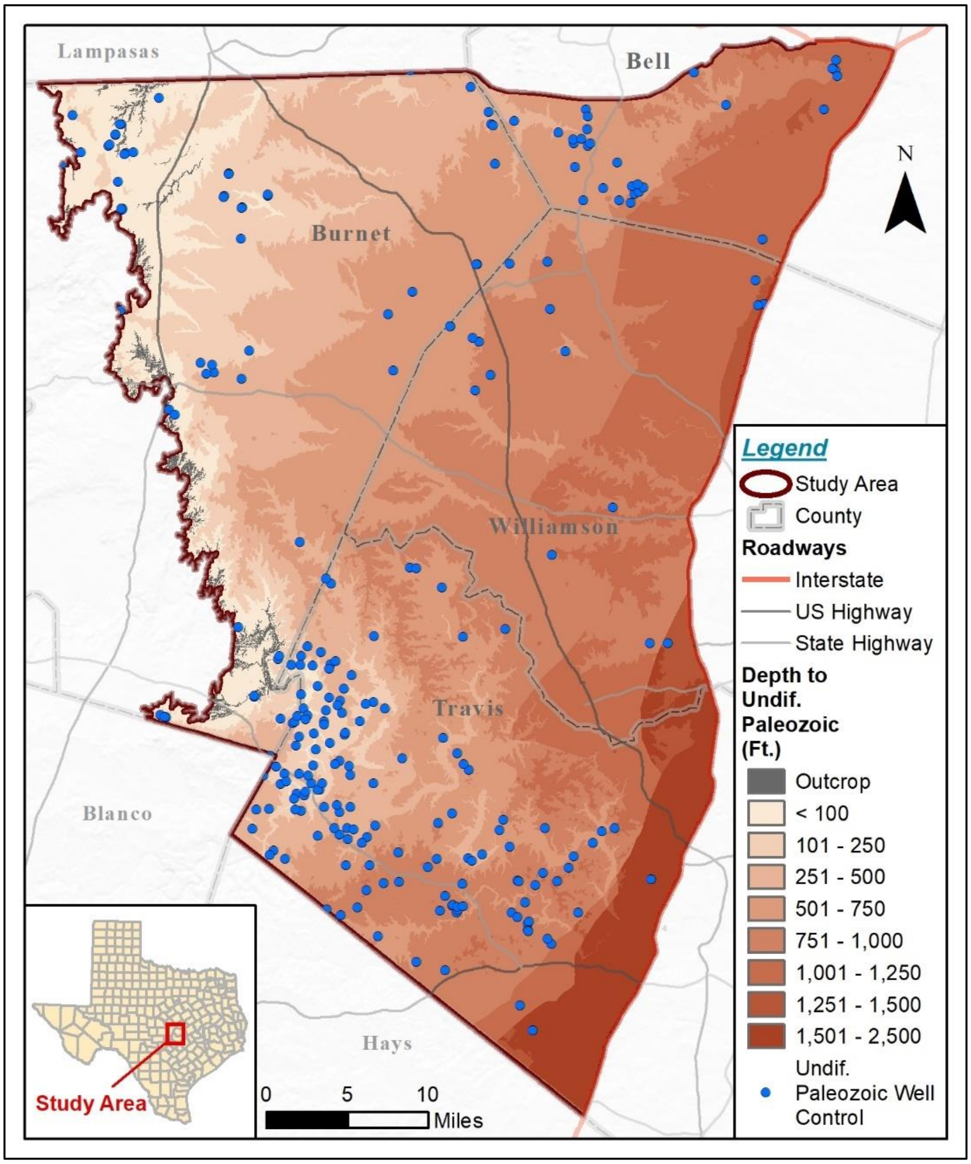


Figure 29 – Depth to Undifferentiated Paleozoic Surface (Leapfrog Model Export).

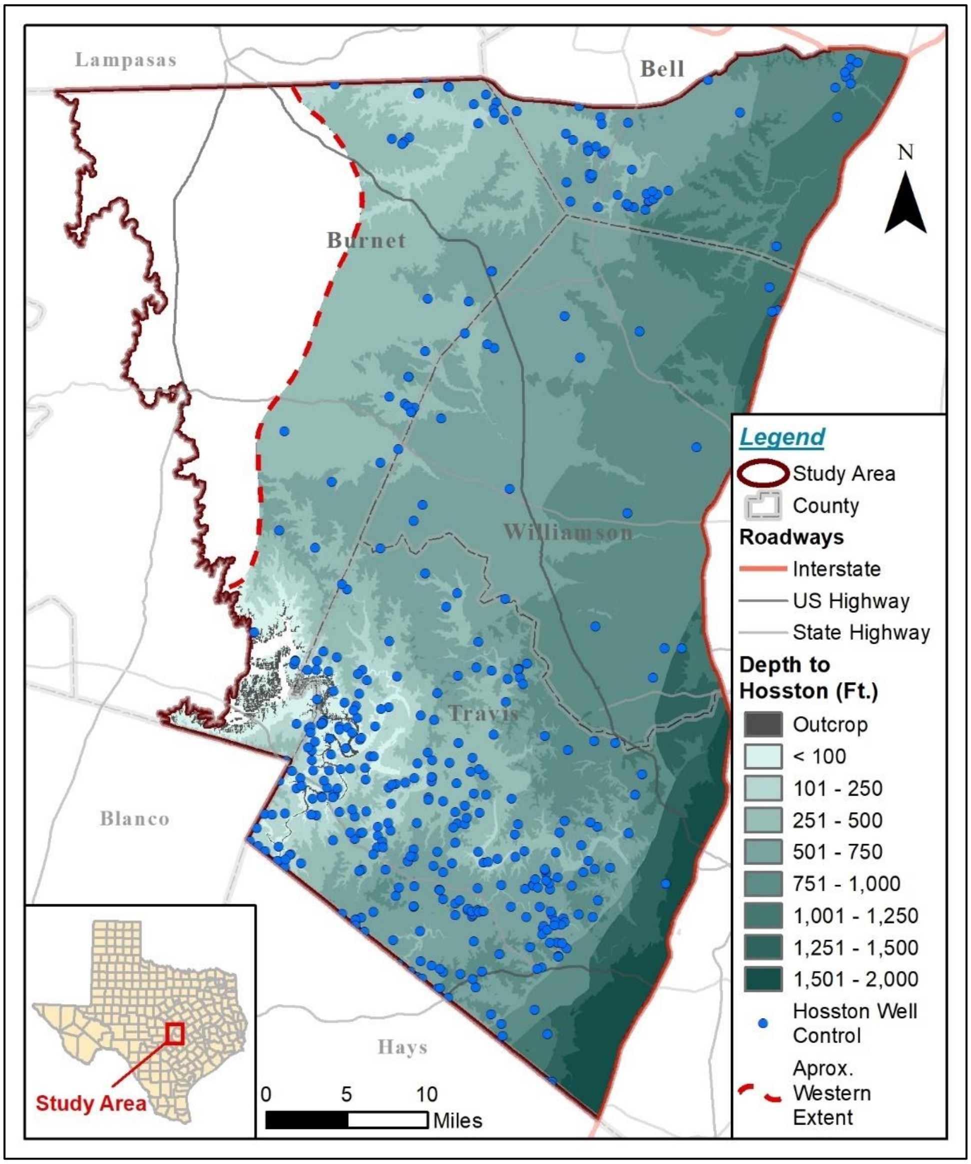


Figure 30 – Depth to Hosston Surface (Leapfrog Model Export).

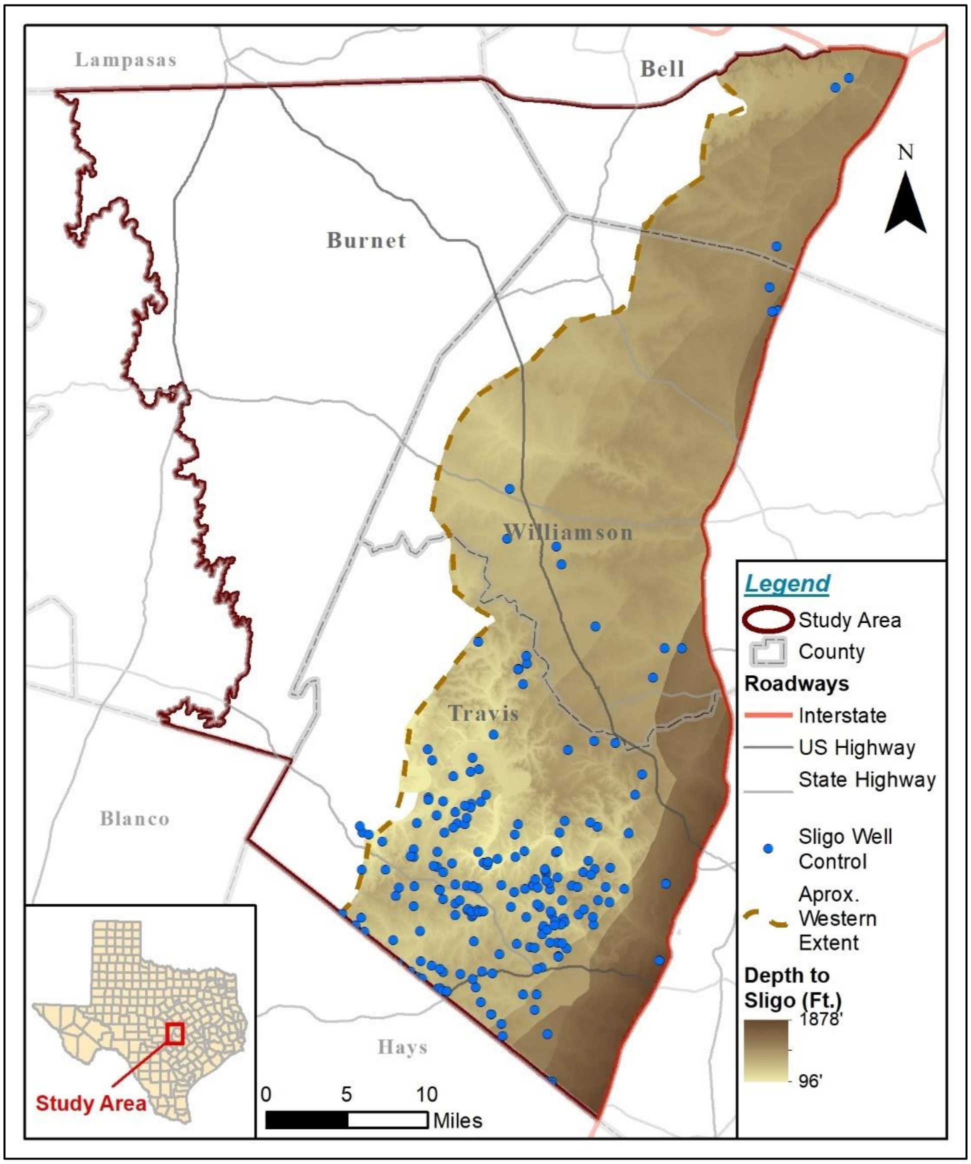


Figure 31 – Depth to Sligo Surface (Leapfrog Model Export).

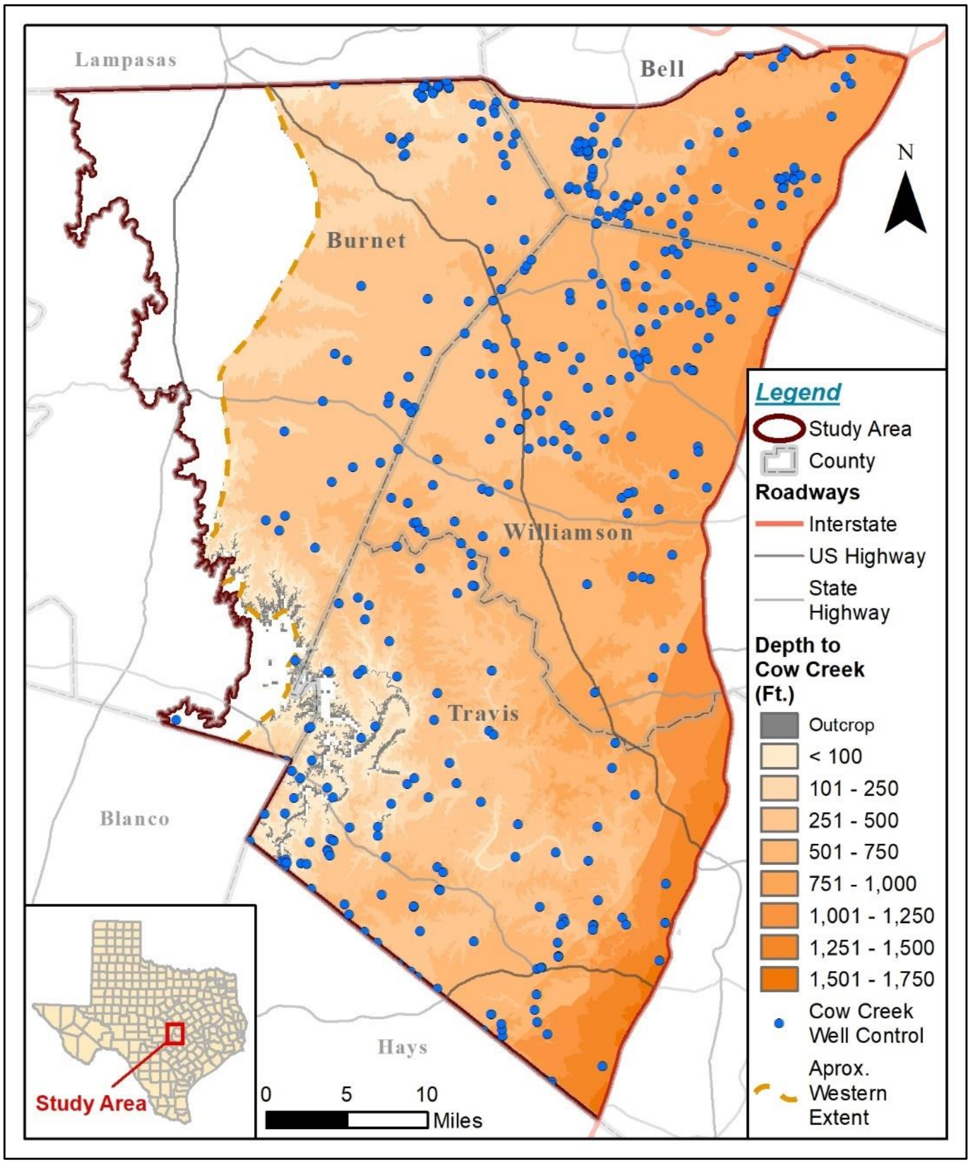


Figure 32 - Depth to Cow Creek Surface (Leapfrog Model Export).

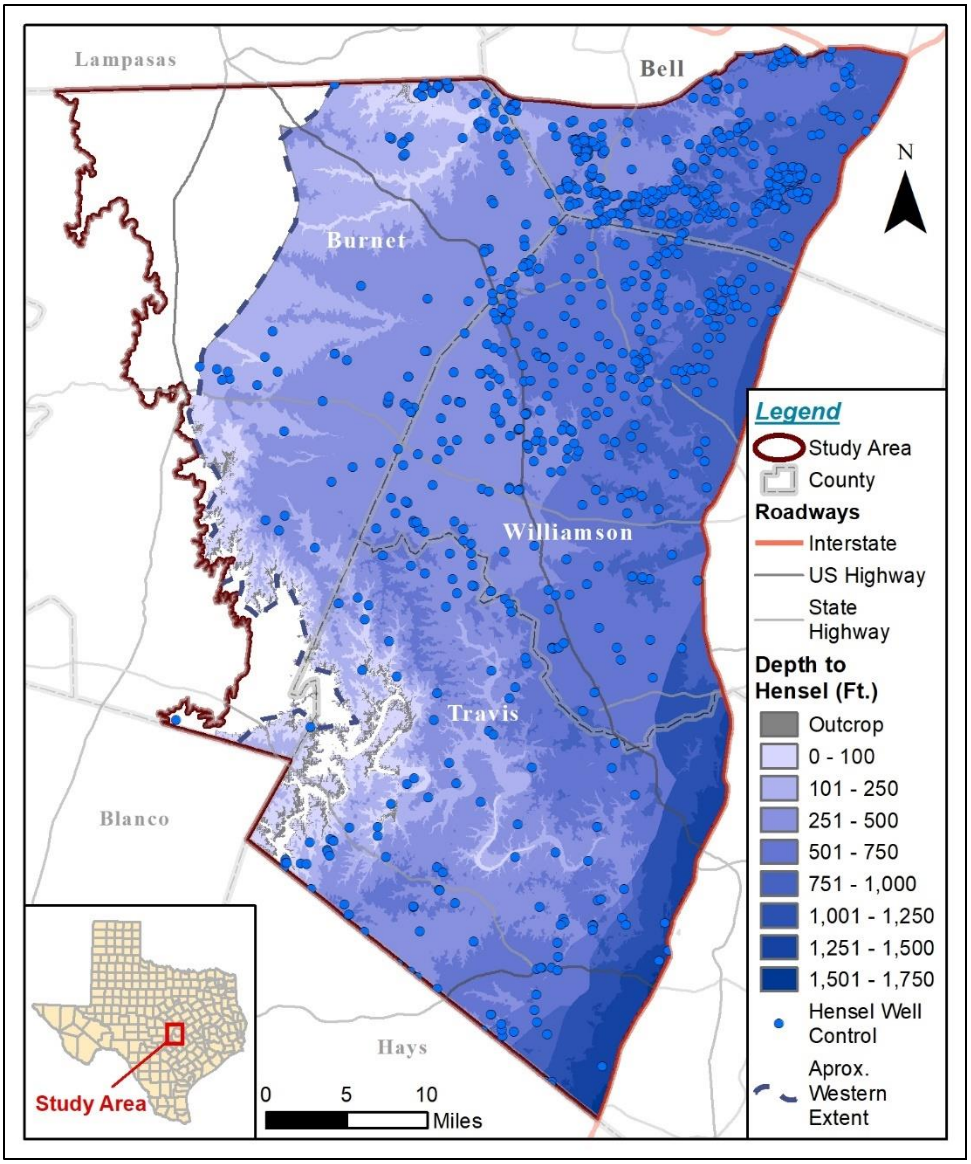


Figure 33 – Depth to Hensel Surface (Leapfrog Model Export).

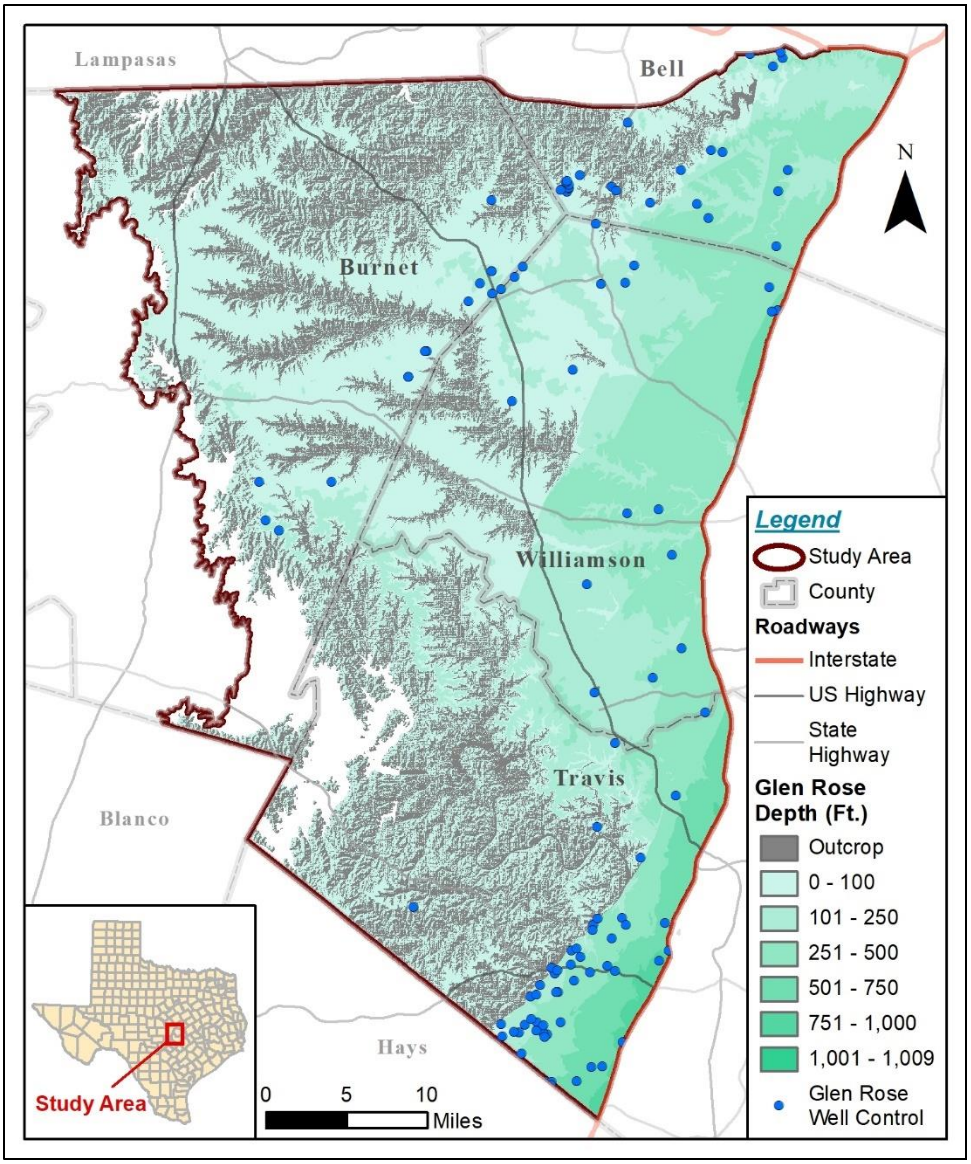


Figure 34 – Depth to Glen Rose Surface (Leapfrog Model Export).

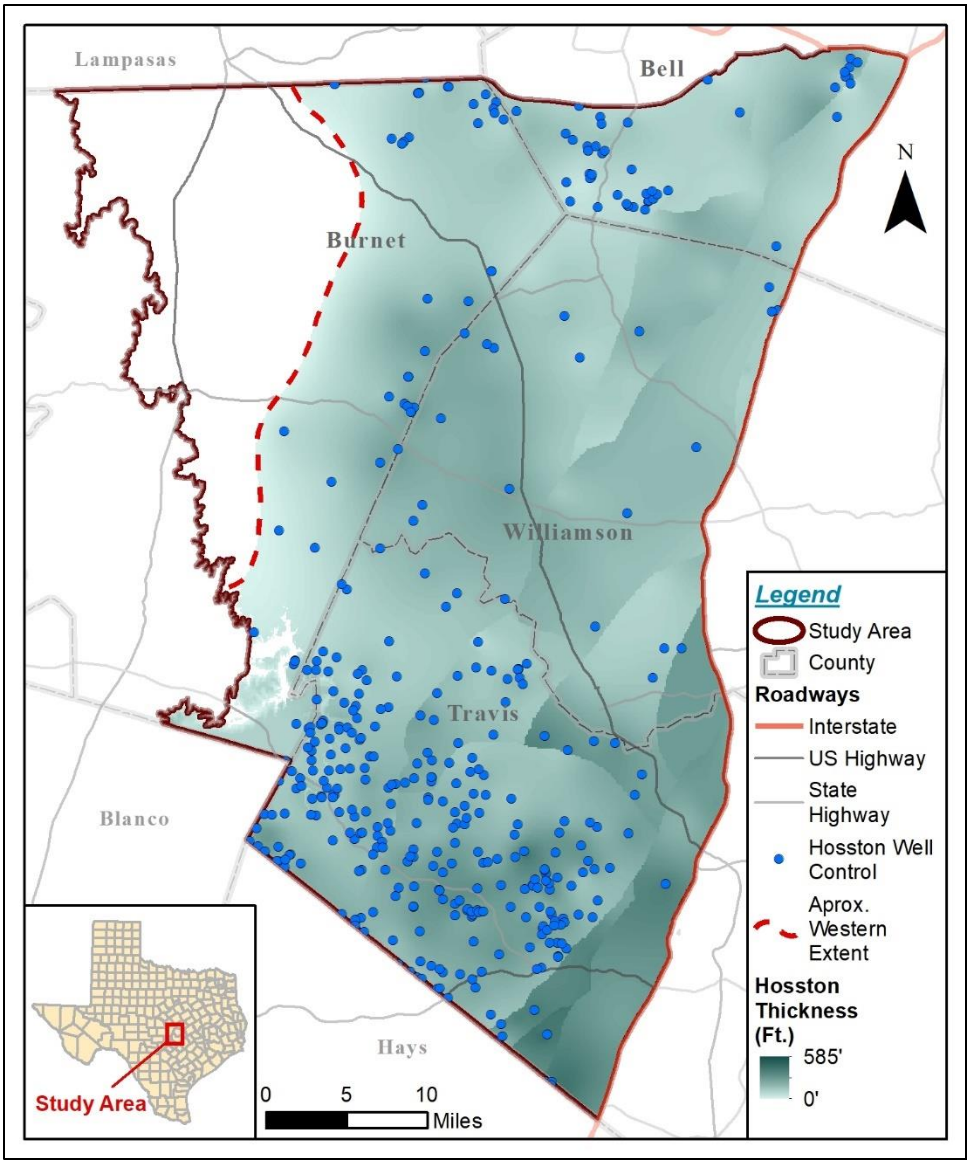


Figure 35 – Hosston Thickness (Leapfrog Model Export).

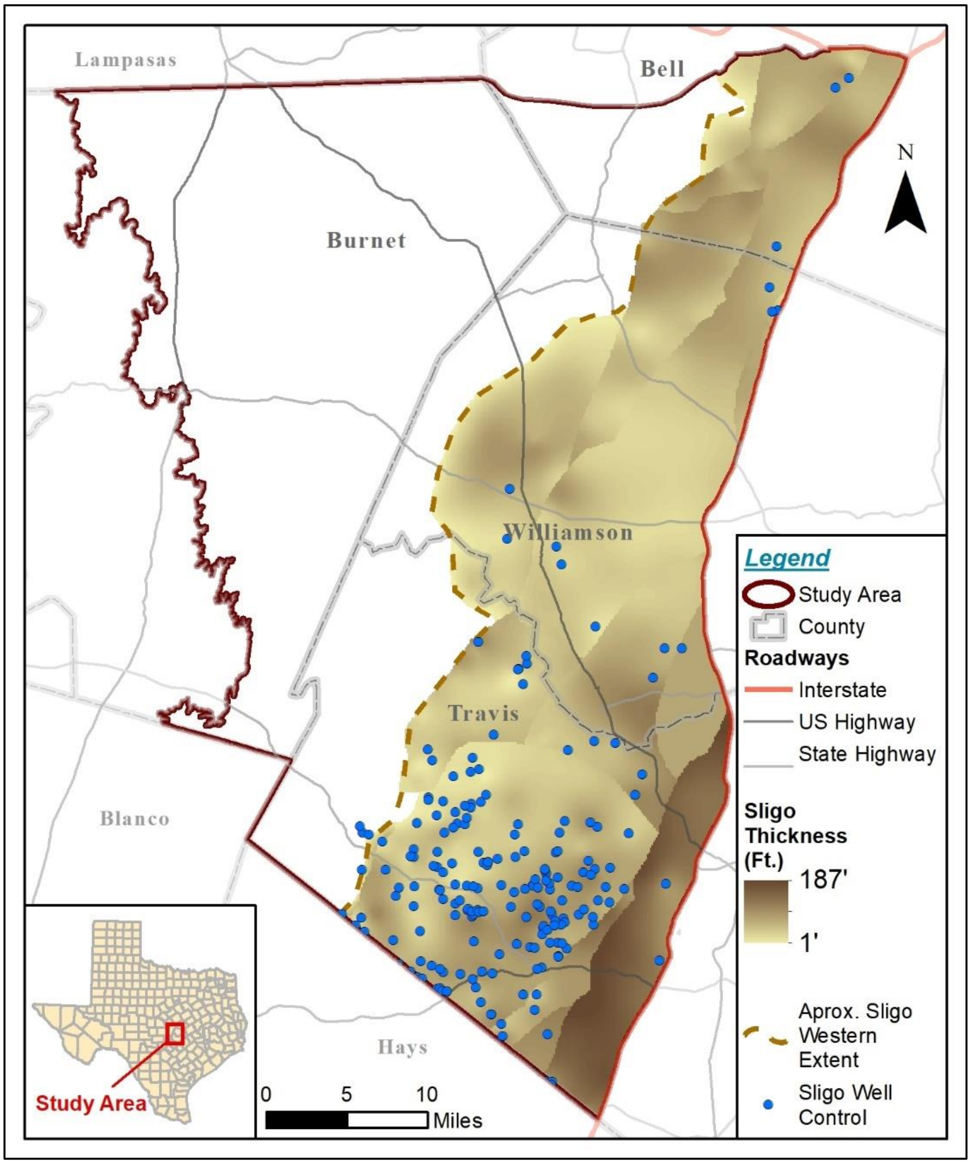


Figure 36 – Sligo Thickness (Leapfrog Model Export).

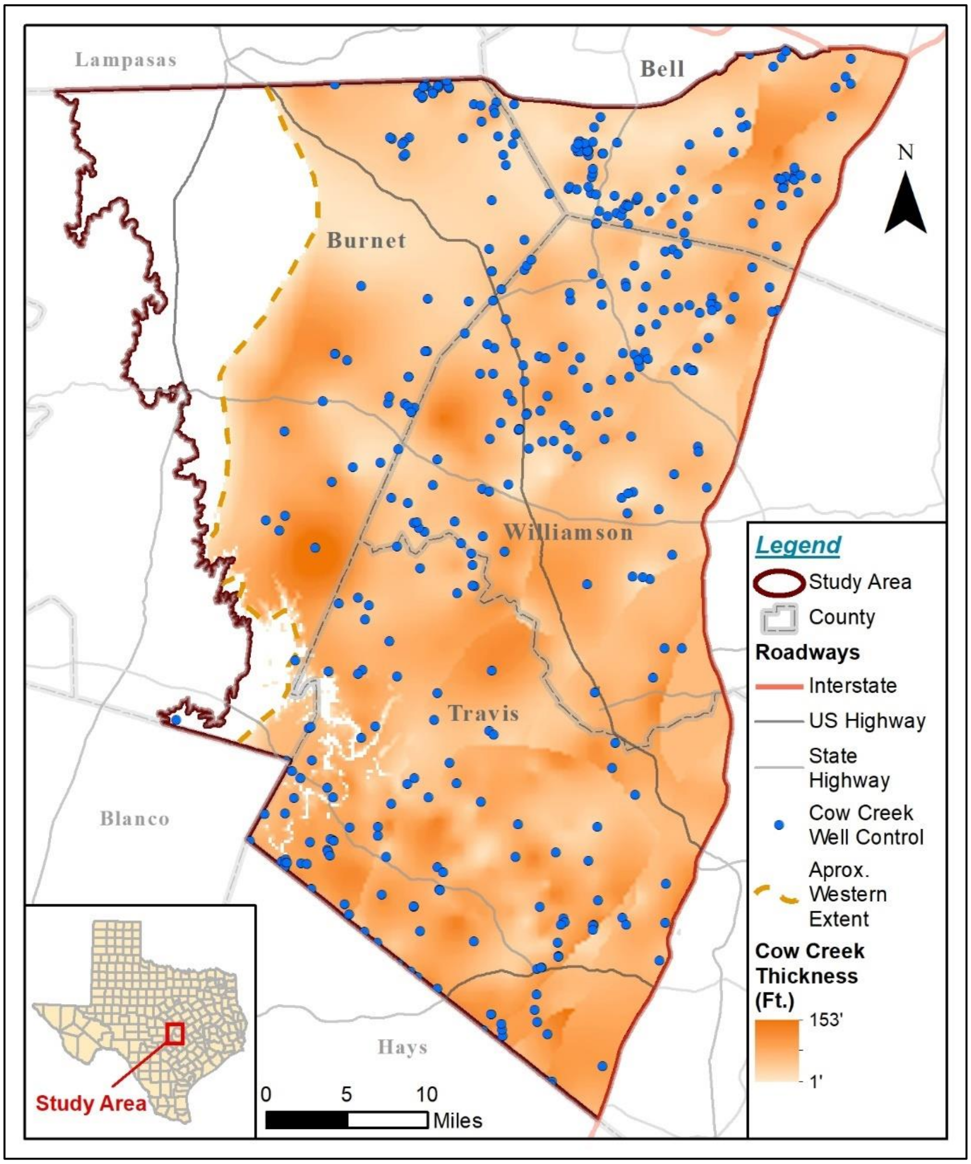


Figure 37 – Cow Creek Thickness (Leapfrog Model Export).

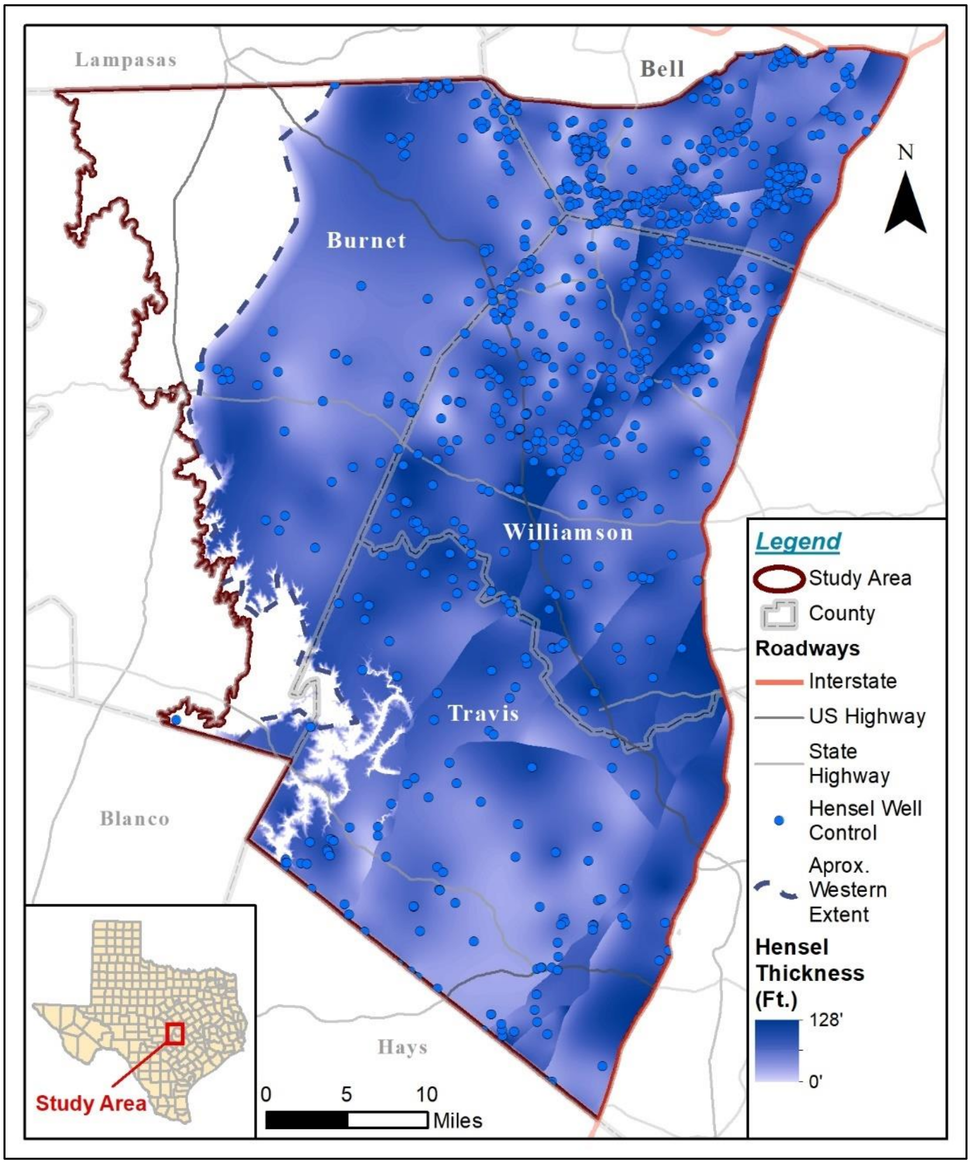


Figure 38 – Hensel Thickness (Leapfrog Model Export).

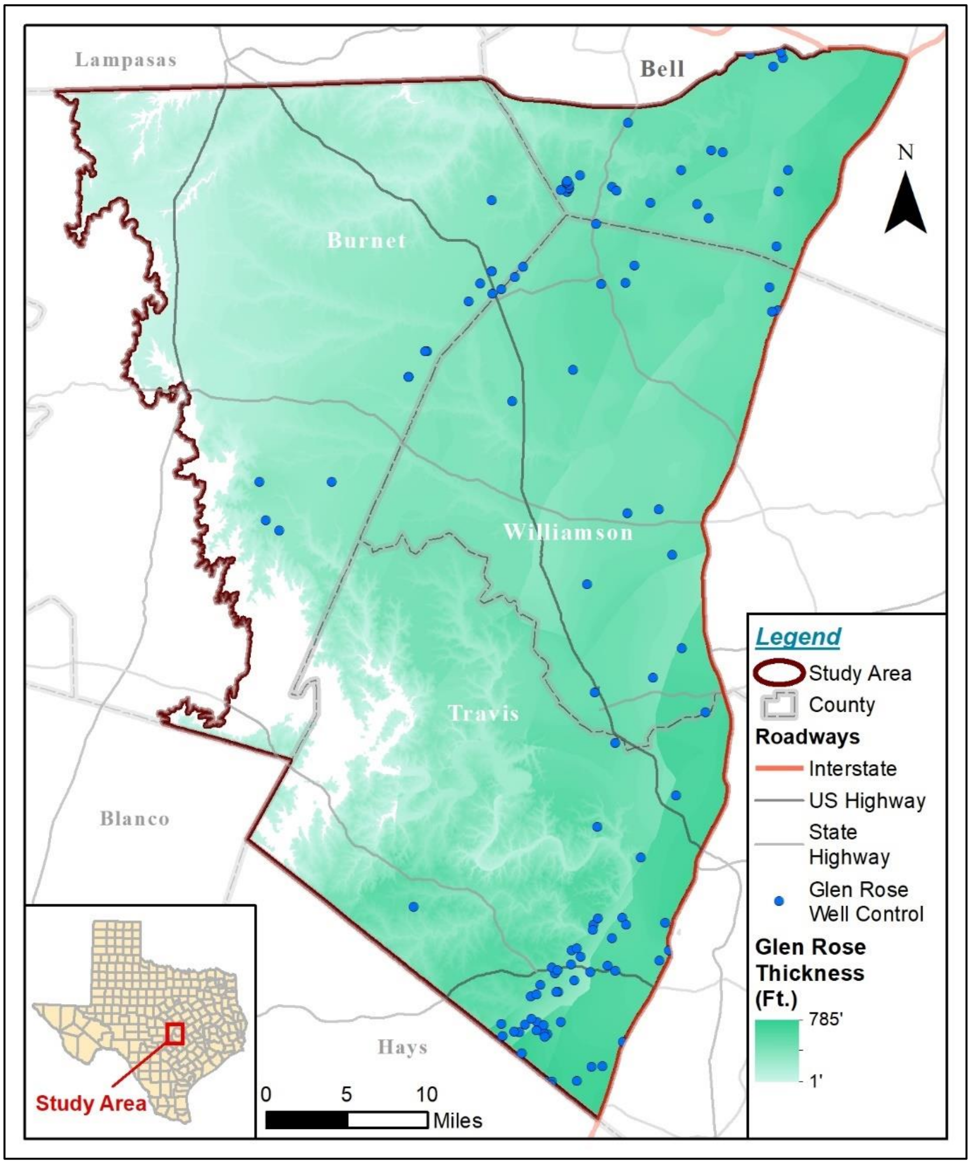


Figure 39 – Glen Rose Thickness (Leapfrog Model Export).

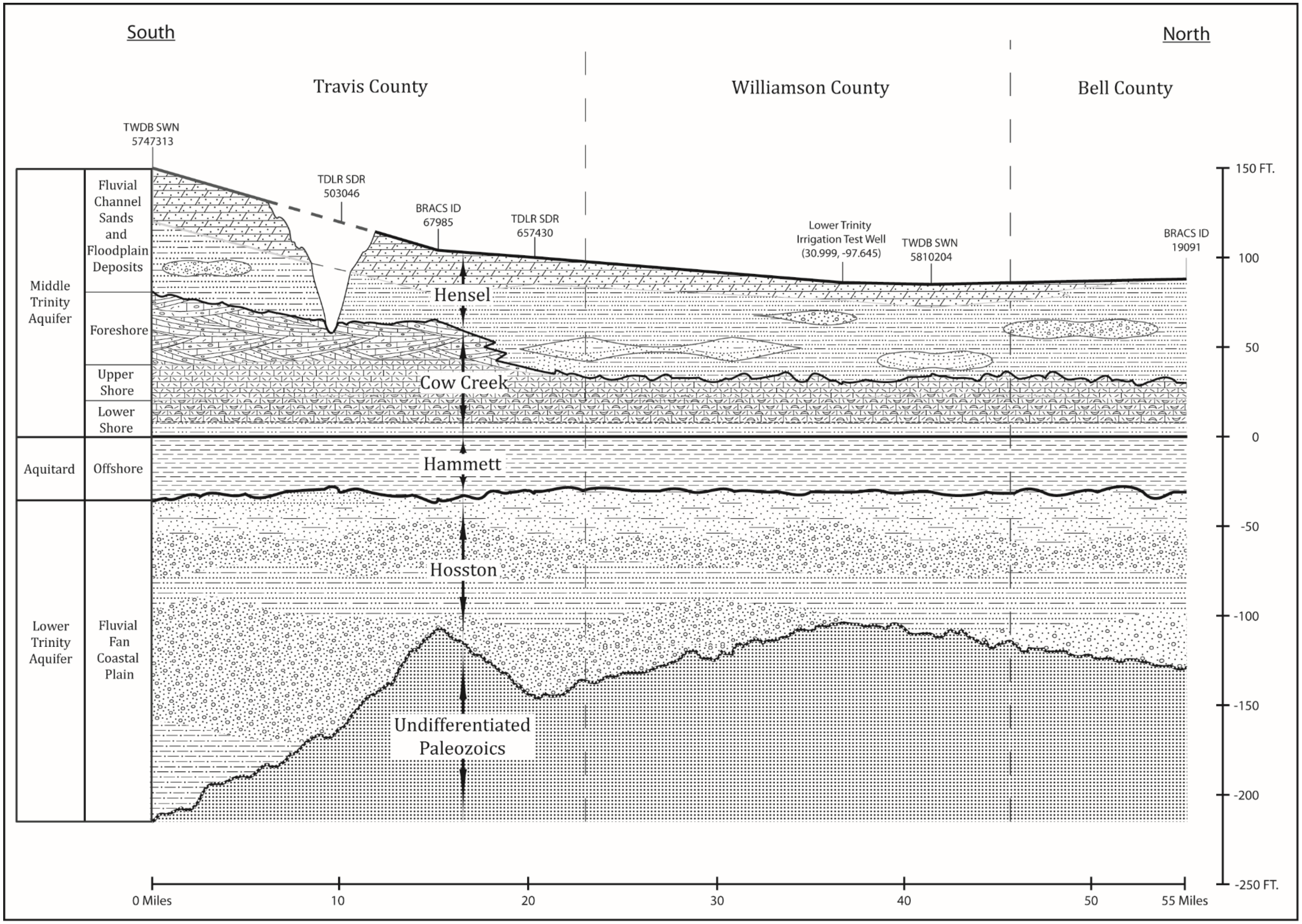


Figure 40 - Stratigraphic section of the Middle and Lower Trinity Aquifer flattened on the Hammett (datum) along cross section line D-D'.

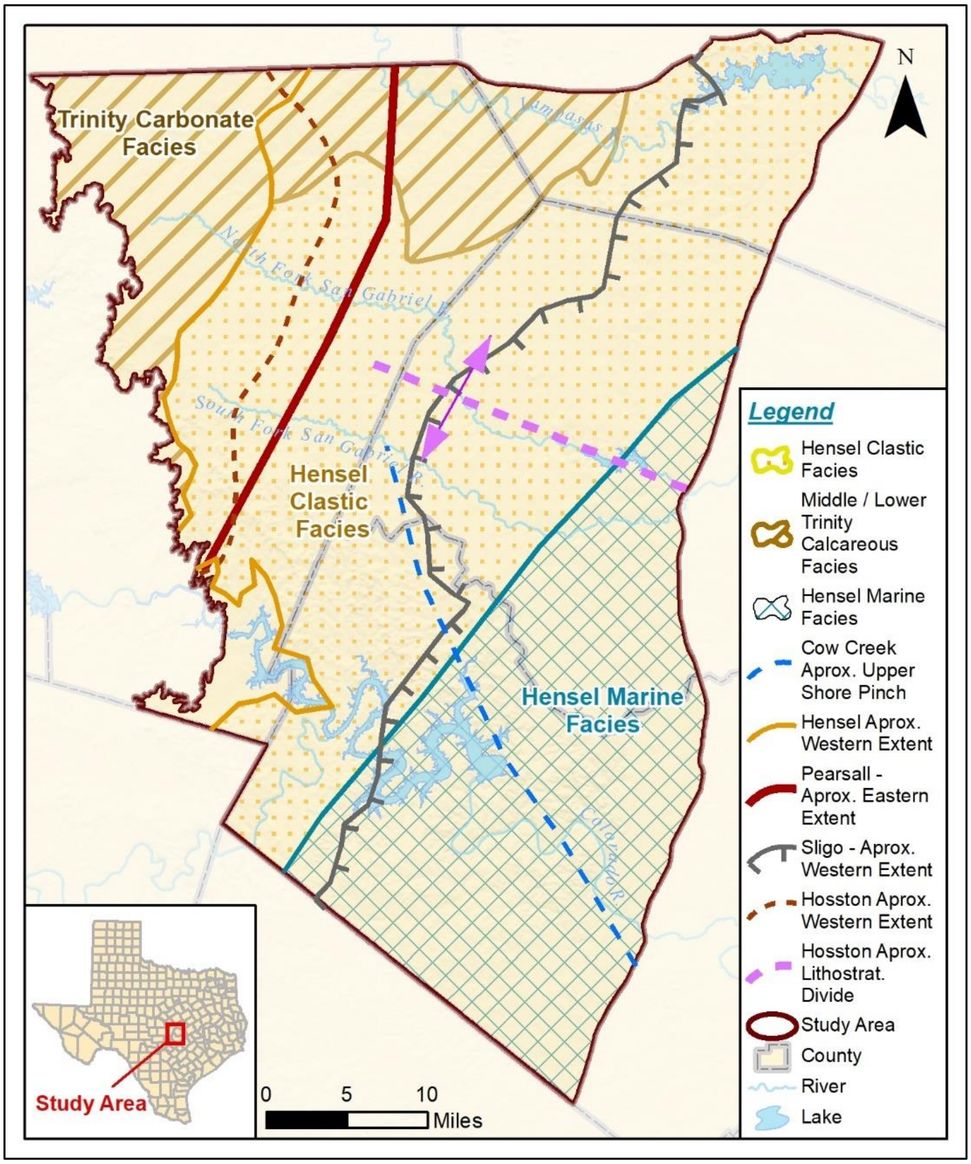


Figure 41 – Paleogeologic Model of the Middle and Lower Trinity Aquifer.

SECTION 4: DISCUSSION

The work presented herein includes a summation of findings from numerous authors and integrates these results with a detailed hydrostratigraphic model. From this analysis, new observations were made that will ultimately aid in a better understanding of the Trinity Aquifer within central Texas. These results are significant because changing stratigraphic environments within an aquifer system may correlate to variations in aquifer properties, water chemistry, well yields, and regional trends. When well-understood, these stratigraphic changes can also inform aquifer hydraulics where data is limited or can offer model constraints.

The early Cretaceous depositional environments of the Trinity Aquifer appear to be strongly correlated with the undifferentiated Paleozoic paleogeography. The direct relationship of the Hosston formation with this unit has been previously documented as a control on formation thickness (Boone, 1968). From this analysis, we see thicker sections of the Hosston within the eastern portion of the study area and in southern Travis County. Also identified is that the Lampasas Arch is located directly north of an area within Burnet County where Hensel and Hosston deposition is absent. This same general area also corresponds to the calcareous facies of the Middle and Lower Trinity Aquifer as first reported by Klemt et al. (1975). It is possible that the Lampasas Arch, similar to the Llano uplift, served as a local promontory feature within early Cretaceous time, restricting the movement and deposition of clastic sediments in this area. A regional divide within Hosston depositional systems is also hypothesized to exist within central Williamson County. Hosston formation lithologies north and south of this divide appear significantly different, possibly alluding to separate sediment sources.

Significant observations on the Middle Trinity Hensel and Cow Creek area are also presented within this report. The upper and near shore Cow Creek pinch-out is mappable along the northern edge of the San Marcos Arch (Hunt, 2024). This pinch-out is observable within geophysical logs and drill cuttings across Bell, Burnet and Williamson counties. In addition, we present clastic and marine facies of the Hensel formation mapped for the first time in northern Travis and Williamson counties. These observations help to better explain why the Cow Creek is a prolific karstic aquifer within Travis and Hays counties, while in Bell County it is often considered irrelevant. Instead, the primary source of Middle Trinity groundwater is the Hensel unit above, whereas within portions of Travis County the Hensel marine facies provides relatively undesirable groundwater. We also identified across various datasets a “green shale” that appears near the top of the Hensel clastic facies. This green shale may serve as a regional marker bed for the upper Hensel sand layer within the study area. This research also includes revised extents for the Sligo and Pearsall formations.

For local policy and groundwater management decisions, the hydrogeologically distinct areas identified within this report may provide the early framework for defining groundwater management zones and management strategies. With continued evaluations of these reported stratigraphic changes, the impact of these systems on aquifer mechanics can be better understood. This work and the interpretations presented within this report can be advanced further with additional well-specific data points in the form of rock core, drill cuttings and geophysical logs. As new data is collected, these observations can and should be refined. Although this analysis included the development of a detailed hydrostratigraphic model, there is still much to be learned from this initial dataset.

With this new data, considerations should also be given to update regional models with this new discernment of the Trinity Aquifer. For example, in the current GAMs, the vertical and lateral variations within the Hensel and Cow Creek are not well defined in Travis County. Although this type of discernment may not be appropriate for regional models, it is an important consideration for any future local groundwater modeling efforts.

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Appendix A –

Hydrostratigraphic Well Control Dataset

(Delivered as an electronic attachment.)

Appendix B –

LPGCD 3D Hydrogeologic Model Leapfrog Viewer

(Delivered as an electronic attachment.)

Appendix C –

LPGCD Hydrogeologic Model Project Geodatabase

(Delivered as an electronic attachment.)