

Geologic and Hydrostratigraphic Map of the Anhalt, Fischer, and Spring Branch 7.5-Minute Quadrangles, Blanco, Comal, and Kendall Counties, Texas



Scientific Investigations Map 3333

Cover: *Left*, Unidentified coral mold from an outcrop of the lower Glen Rose Limestone (lower 50 ft). Photograph taken September 3, 2014, by Allan Clark. *Top right*, Sauropod tracks in the Blanco River channel approximately 2.9 miles west of the town of Blanco near the stratotype location for the *Corbula* marker bed. Photograph taken August 19, 2014, by Allan Clark. *Bottom right*, Unidentified species of fossil coral from an outcrop of the lower Glen Rose Limestone (lower 50 ft). Photograph taken January 27, 2014, by Allan Clark.

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By Allan K. Clark and Robert R. Morris

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**U.S. Department of the Interior
U.S. Geological Survey**

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Conversion Factors and Datum

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (cm)
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi ²)	2.590	square kilometer (km ²)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) and the World Geodetic System of 1984 (WGS 84).

Geologic and Hydrostratigraphic Map of the Anhalt, Fischer, and Spring Branch 7.5-Minute Quadrangles, Blanco, Comal, and Kendall Counties, Texas

By Allan K. Clark and Robert R. Morris

Abstract

This report describes the geology and hydrostratigraphy of the Edwards and Trinity Groups in the Anhalt, Fischer, and Spring Branch 7.5-minute quadrangles, Blanco, Comal, and Kendall Counties, Texas. The hydrostratigraphy was defined based on variations in the amount and type of porosity of each lithostratigraphic unit, which varies depending on the unit's original depositional environment, lithology, structural history, and diagenesis.

Rocks exposed in the study area are of the Lower Cretaceous Trinity Group and lower part of the Kainer Formation of the Lower Cretaceous Edwards Group. The mapped outcrops in the study area are the Pearsall Formation and Glen Rose Limestone of the Trinity Group. The Pearsall Formation consists of, in ascending order: the Hammett Shale, Cow Creek Limestone, and Hensell Sand Member. The Glen Rose Limestone is composed of the informal lower and upper members. In the study area the Edwards Group consists only of the informal basal nodular member of the Kainer Formation. The faulting and fracturing in the study area are part of the Miocene-age Balcones fault zone, an extensional system of faults that generally trends southwest to northeast in south-central Texas. An igneous dike, containing aphanitic texture, cuts through part of the Anhalt quadrangle near the confluence of Honey Creek and the Guadalupe River. The dike penetrates the Cow Creek Limestone Member and the lower part of the Hensell Sand Member outcropping at three locations.

The hydrostratigraphic units of the Edwards and Trinity aquifers have been mapped and described herein using a classification system developed by Choquette and Pray (1970), which is based on porosity types being fabric or not-fabric selective. The naming of hydrostratigraphic units is also based on preexisting names and topographic or historical features that occur in outcrop. The only hydrostratigraphic unit of the Edwards aquifer present in the study area is VIII hydrostratigraphic unit. The mapped hydrostratigraphic units of the upper Trinity aquifer are, from top to bottom: the cavernous, Camp Bullis, upper evaporite, fossiliferous, and lower evaporite and they are interval equivalent to the upper member of the Glen

Rose Limestone. The middle Trinity aquifer (interval equivalent to the lower member of the Glen Rose Limestone) contains, from top to bottom: the Bulverde, Little Blanco, Twin Sisters, Doeppenschmidt, Rust, and Honey Creek hydrostratigraphic units. The lower part of the middle Trinity aquifer is formed by the Hensell, Cow Creek, and Hammett hydrostratigraphic units which are interval equivalent to the Hensell Sand Member, the Cow Creek Limestone, and the Hammett Shale Member, respectively, of the Pearsall Formation.

Introduction

This study area is the Anhalt, Fischer, and Spring Branch 7.5-minute U.S. Geological Survey (USGS) quadrangles located in Blanco, Comal, and Kendall Counties, Texas (fig. 1), covering an area of approximately 194 square miles (mi²). The area consists of outcrops of the upper Lower Cretaceous Edwards Group and the Lower Cretaceous Trinity Group (U.S. Geological Survey, 2014). The only remaining outcrops of the Edwards Group are of the basal nodular member of the Kainer Formation which caps two hills. The Trinity Group outcrops are composed of faulted and fractured soluble rock units of the Hammett Shale (Lozo and Stricklin, 1956), Cow Creek Limestone (Barnes, 1976), and Hensell Sand Members of the Pearsall Formation (Barnes, 1976), and the informal lower and upper members of the Glen Rose Limestone (Lozo and Stricklin, 1956). These rocks compose the entire Trinity aquifer, which is subdivided into the upper, middle, and lower Trinity aquifers (Ashworth, 1983).

The upper Trinity aquifer is contained in the upper member of the Glen Rose Limestone (Ashworth, 1983). The middle Trinity aquifer is contained within the lower member of the Glen Rose Limestone, and the Cow Creek Limestone and Hensell Sand Members of the Pearsall Formation (Ashworth, 1983). The Hammett Shale Member is a confining unit between the lower and middle Trinity aquifers (Ashworth, 1983). The lower Trinity aquifer is contained in the Hosston and Sligo Formations (Ashworth, 1983) which are not present in surface outcrops in the study area.

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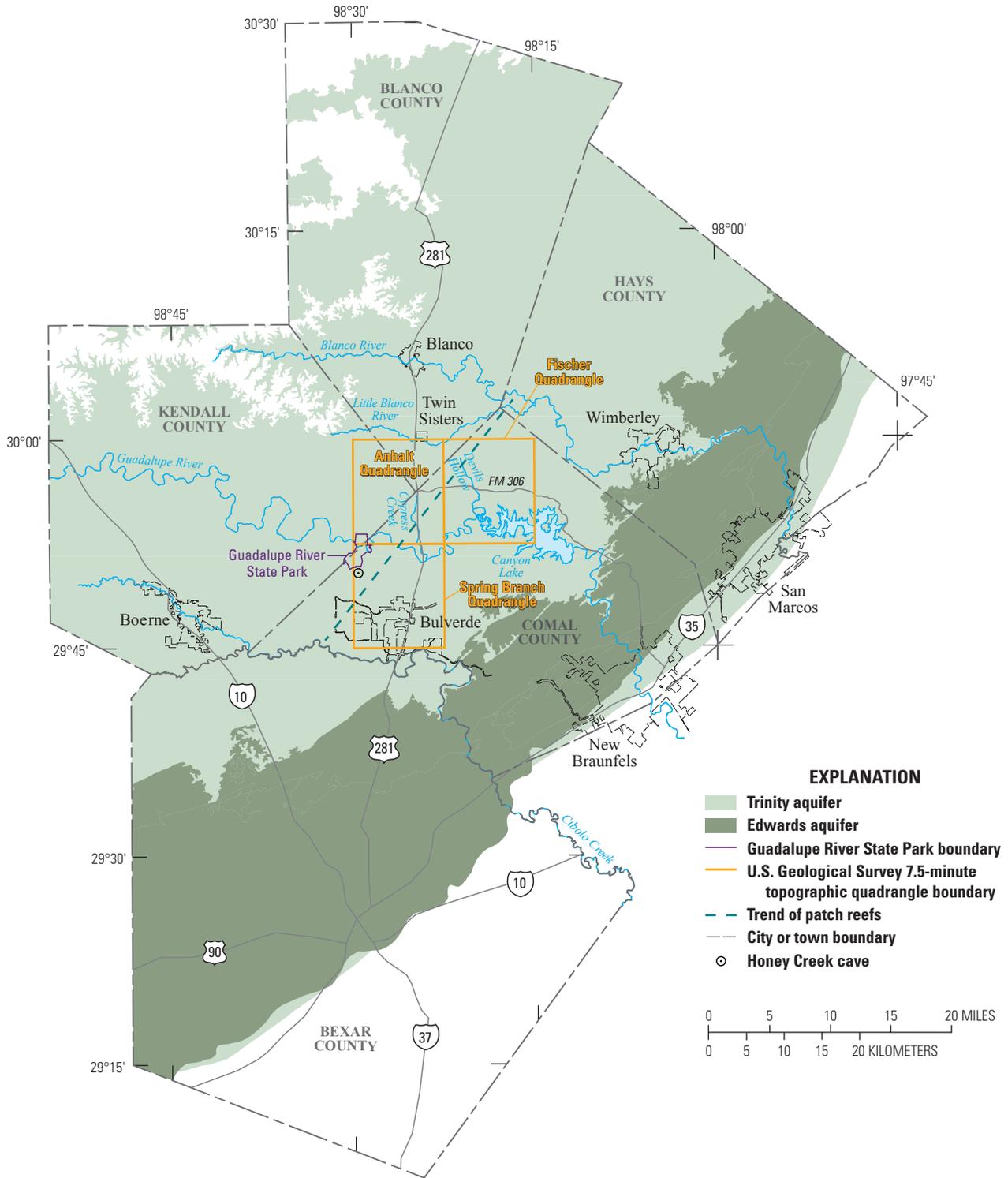


Figure 1. Location of the study area.

Although the Trinity aquifer is classified as a major aquifer by the State of Texas, transmissivities and water yields can be comparatively lower than other aquifers in the area (Maclay, 1995; Mace and others, 2000) resulting in other available sources of water being used. Population growth and increased drought conditions have combined to renew interest in the Trinity aquifer and concerns about groundwater availability (Mace and others, 2000).

The dissolution of the carbonate rocks composing the Edwards and Trinity aquifers results in distinctive landforms rich in both springs and karst features such as caves, sinkholes, and other visible areas of solution-enlarged porosity. Porosity developed in carbonate rocks can have appreciable effect on the hydrogeologic characteristics of the formations and can create focused points or areas of recharge (Hanson and Small, 1995; U.S. Geological Survey, 2011). The same porosity that can focus recharge can also result in an aquifer that is susceptible to contamination because storm-water runoff is quickly transferred to the subsurface (Ryan and Meiman, 1996). The hydrostratigraphy was defined based on variations in the amount and type of porosity in the lithologic units, which were defined by the original depositional environment, lithology, structural history, and diagenesis. Detailed hydrostratigraphic mapping of the area can help water managers determine the effects of future development of the groundwater resources and aid in planning the response to various water issues.

Purpose and Scope

This report presents the detailed 1:24,000-scale hydrostratigraphic map, and proposed names and descriptions of the hydrostratigraphic units in the study area. The hydrostratigraphy was defined based on variations in the amount and type of porosity of each lithostratigraphic unit, which varies depending on the unit's original depositional environment, lithology, structural history and diagenesis. This study focuses on the outcrops of the Trinity and part of the Edwards aquifers within the Anhalt, Fischer, and Spring Branch 7.5-minute quadrangles.

The hydrostratigraphic mapping can aid water managers in determining the effects of drought and increasing development of groundwater resources in the study area. This mapping might also help in the placement of recharge structures, areas for aquifer storage and recovery projects, and determining the likely pathways of contamination.

Methods of Investigation

Geologic maps, nearby geophysical logs, and previous reports were compiled to assist in field mapping (Whitney, 1952; Lozo and Stricklin, 1956; Stricklin and others, 1971; Rose, 1972; Stricklin and Smith, 1973; Amsbury, 1974; Barnes, 1974, 1976; Perkins, 1974; Collins, 1992a,b,c; Barker and Ardis, 1996; Mancini and Scott, 2006; Wierman and others, 2010; Clark and others, 2014). Geophysical logs near the

study area in Blanco and Hays Counties (fig. 1) were correlated with geophysical logs where the hydrostratigraphic units were first identified, in northern Bexar County (fig. 1). Field mapping of the hydrostratigraphic units was accomplished on an Apple iPad2 containing geospatially registered 7.5-minute USGS topographic maps and utilizing their integrated global positioning system (GPS). The field data were transferred to esri ArcMap (esri, 2014), quality checked and then used to produce the study area's hydrostratigraphic map.

Lithologic and hydrostratigraphic descriptions are from field observations and previous investigations. Lithologic descriptions (table 1) are based on Dunham's (1962) carbonate rock classification system, which concentrates on the rock identification of carbonate fabrics. Porosity type is identified as fabric selective or not-fabric selective (table 1) under the sedimentary carbonate classification system of Choquette and Pray (1970). The assigned hydrostratigraphic unit informal names are based on previously defined names or topographic or historical features in the study area. Formal lithostratigraphic units and geologic names were verified using the USGS Geologic Names Lexicon (U.S. Geological Survey, 2014).

Faults identified in the field were based on observed and inferred stratigraphic offsets. Strike and dip of faults and fractures were also noted. Bedding attitudes of fractures and faults were obtained using a handheld compass and (or) the iPad2 compass application call GeoId (Apple, Inc., 2013). The GeoId data were compared on a daily basis with the handheld compass to cross verify the data. Strikes of fractures and faults were input into Grapher (Golden Software, Inc.), graphing software, to produce a rose diagram showing direction and abundance of the various features.

Geologic Framework

The Trinity Group rocks were deposited during the Early Cretaceous (table 1) on a large shallow marine carbonate platform. The Trinity Group was deposited by three transgressive clastic-carbonate "couplets" on the platform (Lozo and Stricklin, 1956; Stricklin and others, 1971). The three transgressive "couplets" are: (1) the Hosston and Sligo Formations (Imlay, 1940); (2) the Hammett Shale Member (Lozo and Stricklin, 1956) and the Cow Creek Limestone Member (Hill, 1901) of the Pearsall Formation (Imlay, 1940); and (3) the Hensell Sand Member (Hill, 1901) of the Pearsall Formation and the Glen Rose Limestone (Hill, 1891; table 1). These units contain shale, mudstone to grainstone, boundstone, sandstone, and argillaceous limestone. The overlying Edwards Group (Hill, 1891) within the study area was deposited in an open marine setting to supratidal flats (Rose, 1972; Maclay and Small, 1986) and the basal nodular member (informal) of the Edwards Group was deposited in a subtidal environment (Maclay and Small, 1986) during the beginning of a marine transgressive cycle.

Stratigraphy

Trinity Group

In the subsurface, the Trinity Group overlies Pennsylvanian shale (Imlay, 1940) in the study area. The Group contains shale, mudstone to grainstone, boundstone, sandstone, and argillaceous limestone. The thickness of Trinity Group is approximately 525–540 ft in the study area.

Pearsall Formation

Stratigraphically, the lowermost mapped unit within the study area is the Hammett Shale Member of the Pearsall Formation (table 1). It is approximately 50 ft thick based on data from nearby wells. The contact between the Hammett Member and the overlying Cow Creek Limestone Member of the Pearsall (table 1) is conformable (Wierman and others, 2010). Although not visible in outcrop because of alluvium, soils, and surface waters the Hammett is interpreted as being at the surface of the topographically deeper sections of the study area. The interpretation of the Hammett Shale Member being at the surface is based on thickness of the overlying units and from field observations in topographic, vegetative, and hydrologic changes in the landscape. The Hammett is a burrowed mixture of clay, terrigenous silt, carbonate mud, dolomite, and carbonate particles (Amsbury, 1974). The lower 15 ft of the Hammett contains siltstone and dolomite. The upper 35 ft is primarily claystone with sandstone lenses overlain by fossiliferous dolomitic limestone (Lozo and Stricklin, 1956; Wierman and others, 2010).

The Cow Creek Limestone Member (fig. 2) is approximately 72 ft. thick based on both nearby well data and field observations. The upper contact of the Cow Creek Member with the Hensell Sand Member of the Pearsall is unconformable (Wierman and others, 2010). Wierman and others (2010)



Figure 2. Outcrop of the Cow Creek Limestone Member along the left bank of the Guadalupe River in Guadalupe River State Park, Comal County, Texas. Photograph taken September 3, 2011, by Robert Morris.



Figure 3. Unidentified coral mold from an outcrop of the lower Glen Rose Limestone (lower 50 ft). The outcrop is located in a road cut several hundred feet west of the junction of Farm to Market 306 and Devils Hollow, Comal County, Texas. Index finger used for scale. Photograph taken September 3, 2014, by Allan Clark.



Figure 4. Unidentified species of fossil coral from an outcrop of the lower Glen Rose Limestone (lower 50 ft). The outcrop is located at the confluence of Cypress Creek and Guadalupe River, Comal County, Texas. Photograph taken on January 27, 2014, by Allan Clark.

subdivided the Cow Creek lithostratigraphically into two informal units (table 1), a lower dolomitic unit and an upper grainstone unit.

The lower 14 ft of the Cow Creek Member is composed of dolomitic oyster mudstone to wackestone grading to a dolomitic oyster wackestone to packstone (Wierman and others, 2010). The upper 58 ft of the Cow Creek is brown to white, very fine-grained to fine-grained carbonate sand (grainstone) with localized cross-bedding (Wierman and others, 2010).

The Hensell Sand Member (table 1) of the Pearsall Formation is approximately 40 ft thick in the study area and conformably underlies the lower member of the Glen Rose Limestone (figs. 3 and 4). The bottom part of the Hensell Sand Member (table 1) is a reddish claystone and siltstone that contains terrigenous sand, oysters, pelecypods, and fossil fragments. Oysters commonly have beekite structures on the surface of the shell. Beekite is a chalcedony pseudomorph

occurring as small rings on the surface of shells (Gary and others, 1977). The upper part of the Hensell (table 1) is nodular, fine-grained sandstone that contains quartz and feldspar grains, fossil fragments, fish teeth, and pelecypods with beekite structures and quartz geodes. The Hensell Member commonly forms slopes, often with thicker soils and lush grasses, between the resistive Cow Creek Member and the overlying Glen Rose Limestone. The quartz geodes, some of which are more than a foot in diameter, increase in abundance and size near the small igneous dike mapped in the northwestern part of the Anhalt quadrangle.

Glen Rose Limestone

The Glen Rose Limestone consists of alternating beds of yellowish-tan, medium-bedded limestone and argillaceous limestone with minor evaporite layers. It is composed of lower and upper members (informal classification), separated by a regionally extensive marker bed, composed of the small fossil identified as *Corbula* sp. (Whitney, 1952). The *Corbula* bed marks the boundary between the lower and upper members of the Glen Rose Limestone (table 1).

Lower Member

The lower member (informal) of the Glen Rose Limestone (table 1) is 225–240 ft thick within the study area. The lower part contains 45–60 ft of very thick and resistive beds of wackestone to grainstone and boundstone (table 1). This lower part commonly contains shell fragments, pectens, *Miliolid* sp., *Orbitolina texana*, *Trigonia* sp., *Turritella* sp., *Toucasia* sp., *Caprinid* sp. and various corals (fig. 3, fig. 4) and oysters.

Above these resistive beds is approximately 50 ft of alternating beds of argillaceous wackestone to packstone and mudstone to grainstone, *miliolid* grainstone, and nodular, bioturbated wackestone (table 1). This 50 ft unit is generally obscured by soil and vegetation on slopes and has well developed stair-step topography. Although the section is heavily covered, ledges often contain *miliolid* grainstone, grainstone, nodular bioturbated wackestone, and monoplurids. The lower part of this section is dolomitic. Throughout the 50 ft thick unit, pectens, oysters, pelecypods, *Nerinia* sp., *Orbitolina texana*, *Tylostoma* sp., and monoplurids can be found.

This 50 ft section is overlain by a 40 ft section of thicker and more resistive mudstones to grainstone, with some boundstone (table 1). The resistive limestone sections are separated by argillaceous wackestone to packstone. Fossil assemblages are similar to the underlying 50 ft unit but include *Caprinid* sp.

Overlying the 40 ft section is a 30 ft section of thick argillaceous wackestone, interspersed shale, thin shale beds and occasional thin wackestone beds (table 1). This section often contains abundant *Orbitolina texana* with occasional pelecypods and gastropods.

Above the 30 ft argillaceous wackestone interval is 30 ft of mudstones to wackestone with beds of argillaceous wackestone (table 1). This 30 ft section also contains areas with

Caprinid patch reefs that appear to run in a trend from the Narrows on the Blanco River to the Camp Bullis area in north Bexar County. This section of the lower member of the Glen Rose Limestone often has very good stair-step topography and contains *Orbitolina texana* sp., *Monoplurids* sp., *Caprinid* sp., pecten, pelecypods, and gastropods.

Overlying this 30 ft section is another 30 ft unit of wackestone to grainstone with occasional *Monoplurids* sp. and *Toucasia* sp. It also contains argillaceous wackestone, shales, and evaporite beds (table 1). The wackestone to grainstone grades upward into an 8- to 10-ft-thick bioturbated, nodular, fossiliferous wackestone named the salenia bed by Francis L. Whitney (1952). Common fossils in the salenia bed are *Salenia texana* sp., *Hemiaster* sp., *Orbitolina texana* sp., *Nerinia* sp, pecten, gastropods, and pelecypods. The salenia bed is overlain by a 1 ft thick shale bed. The regionally extensive *Corbula* bed (fig. 5) overlies the shale bed.

Upper Member

The *Corbula* bed marks the boundary between the lower and upper members of the Glen Rose Limestone (table 1). According to Lozo and Stricklin (1956) the *Corbula* bed is at the top of the lower member of the Glen Rose Limestone. This report considers the *Corbula* marker bed to be at the base of the upper member of the Glen Rose Limestone because three *Corbula* beds have been found in the study area. The marker bed is the lowest of three *Corbula* beds; the remaining two beds generally lay 2.5 and 5 ft above the marker *Corbula* bed. The stratotype location of the *Corbula* marker bed (Scott and others, 2007) is near the town of Blanco on the Blanco River (fig. 1). At the stratotype location sauropod tracks (fig. 6), ripple marks and burrows can be found within the lower member of the Glen Rose Limestone. The *Corbula* marker bed, which is a grainstone, averages six inches thick and often contains ripple marks. The overlying *Corbula* beds are thin, often less than an inch thick, and usually contain more muds.



Figure 5. The marker bed of *Corbula* sp. in an outcrop 2.06 miles west of the Blanco River and 0.35 miles east of the Comal-Hays County line. Tape increments in tenths of a foot. Photograph taken April 17, 2013, by Robert Morris.



Figure 6. Sauropod tracks in the Blanco River channel approximately 2.9 miles west of the town of Blanco near the stratotype location for the *Corbula* marker bed. Photograph taken August 19, 2014, by Allan Clark.

The 10 ft thick unit of dissolved evaporites which overlie the *Corbula* bed is highly altered crystalline limestone produced from alteration of the original rock matrix. The evaporite bed also contains chalky mudstone, breccia, and boxwork voids where the evaporites have been dissolved.

In the study area, a 120 ft thick unit (table 1) overlies the lower evaporite unit. The 120 ft thick unit is composed of alternating wackestone, packstone, clay, and mudstone. Overlying the lower evaporite unit is a thinly laminated silty mudstone that can be easily recognized by its “platy” character in outcrop (Clark and others, 2009). Commonly abundant are the fossils: *Orbitolina minutia*, *Porocystis globularis*, *Tapes decepta*, *Protocardia texana*, *Turritella* sp., *Hemiaster* sp., *Neithea* sp., gastropods and mollusks.

The upper evaporite unit (table 1; fig. 7) is approximately 10 ft thick and is similar to the lower evaporite layer. It is formed from dissolved evaporites and is a highly altered crystalline limestone and chalky mudstone, breccia that commonly contains boxwork voids where the evaporites have been dissolved.

Overlying the upper evaporite unit is 160–320 ft of alternating beds of limestone and argillaceous limestone; limestone is primarily wackestone; some limestone is packstone to grainstone. The argillaceous limestone is not well cemented and contains varying grain sizes (table 1). A disconformity at the top of the upper member of the Glen Rose Limestone resulted in erosion and (or) non-deposition and resulting in a loss of up to 90 ft thickness in the northern part of the study area.

This eroded part, where it exists, is composed of alternating and interfingering beds of limestone and argillaceous limestone, evaporites, mudstone to grainstone, primarily wackestone, highly burrowed. The argillaceous limestones are generally not well cemented and has varying grain sizes.

Edwards Group

The Edwards Group overlies the Trinity Group; mudstone, wackestone, packstone, grainstone, boundstone, dolomitic limestone, argillaceous limestone, evaporites, shale, and chert. Most of these rocks have been removed by erosion. Thickness of remaining Edwards Group is 60 ft. Only basal nodular member of Kainer Formation is present in the study area.

Kainer Formation

The Kainer Formation makes up the lower part of the Edwards Group (table 1). The unit at the base of the Kainer Formation is a shaly, nodular limestone; burrowed mudstone to miliolid grainstone. The basal nodular unit is approximately 60 ft thick in the study area; it can be identified in the field by nodular gray mudstone containing black rotund bodies (commonly called “brb’s”) and the occurrence of miliolids, gastropods, and the fossil oyster *Protocardia texana* (Stein and Ozuna, 1995; Clark, 2003).

Structural Features

Faulting (fig. 8) and fracturing in the study area are part of the Miocene-age Balcones fault zone. This fault zone is probably an extension of the Ouachita structural belt which underlies most of central Texas (Caran and others, 1982). The Balcones fault zone is an extensional system of faults that generally trend southwest to northeast in south-central Texas. The faults have normal throw, are *en echelon*, and are downthrown to the southeast. Variation in strikes and dips of the faults in the outcrop is a result of stress-strain relations of the different lithologies of the rocks (Trudgill, 2002; Ferrill and others, 2003; Clark and others, 2014).



Figure 7. Boxwork porosity in the upper evaporite unit, approximately 120 ft above the *Corbula* bed. 0.8 mile south of the Blanco River and 3.22 miles west of Highway 281. Photograph taken September 11, 2014, by Robert Morris.



Figure 8. Fault juxtaposing the lower 50 ft of the lower Glen Rose Limestone against the middle part of the lower Glen Rose Limestone off Farm to Market Road 306 west of Devils Hollow. Fault displacement is estimated to be 140 ft, down to the south. Photograph taken August 15, 2014, by Allan Clark.

A rose diagram (fig. 9) of fractures shows that the primary trend orientation is northeast to southwest and averages approximately 50 degrees which is consistent with trend of the Balcones fault zone in the area. The conjugant fractures trend perpendicular to the Balcones fault zone at approximately 118 degrees. Dips on the fractures vary between 45 and 90 degrees with most dips between 88 and 90 degrees. Dips of the fractures and faults vary based on the variation in rock lithologies.

The igneous dike is of Early Cretaceous age or younger and cuts through the northwestern part of the Anhalt quadrangle near the confluence of Honey Creek and the Guadalupe River. The dike penetrates the Cow Creek Member and the lower part of the Hensell Member. The best exposure is in the Cow Creek Member along Honey Creek, approximately 300 ft upstream from the confluence of the creek with the Guadalupe River. At this location, the dike is columnar jointed and appears to be dipping slightly to the north. The actual dip of the dike cannot be determined because weathering resulted in a transitional contact with the Cow Creek and the Hensell Members.

Hydrostratigraphy

Hydrostratigraphic units were mapped using the porosity-based classification system developed by Choquette and Pray (1970). According to Choquette and Pray, porosity that develops as a result of textural and structural features of the rock is classified as “fabric selective.” If there is no relation between the porosity and textural and structural features, the porosity is classified as “not-fabric selective.” To characterize the hydrostratigraphic units shown on the map, only primary porosity types were used. The primary fabric selective porosity types identified in the study area are interparticle moldic, burrowed, and bedding plane porosity. The primary not-fabric selective porosity types are fracture, breccia, channel, vug, or cave porosity.

Maclay and Small (1976) originally proposed mapping the Edwards aquifer outcrops using hydrostratigraphic units (HSU) for the Edwards aquifer. Maclay and Small (1976) separated the Edwards aquifer into eight hydrostratigraphic subdivisions (I through VIII). In the study area, only VIII HSU, the basal nodular member remains that caps several hills.

The Trinity aquifer is subdivided into upper, middle, and lower segments (Ashworth, 1983). Clark (2003, 2005) subdivided the upper member of the Glen Rose Limestone in parts of northern Bexar County (fig 1.) into five informal HSUs (designated A through E) to better describe the unit’s hydrologic properties. Clark and others (2009) mapped northern Bexar County and renamed the HSUs (top to bottom) as: cavernous, Camp Bullis, upper evaporite, fossiliferous, and lower evaporite. Blome and Clark (2014), Clark and others (2014), and Pantea and others (2014) subdivided the lower member of the Glen Rose Limestone into six informal HSUs (designated A through F). For this report the units identified in lower member of the Glen Rose have been renamed (top to bottom) as: Bulverde (A), Little Blanco (B), Twin Sisters (C), Doeppenschmidt (D), Rust (E), and Honey Creek (F).

The informal HSUs have been mapped (sheet 1) using porosity types identified in the field during the course of the study, coupled with data from previous studies (Wierman and others, 2010; Blome and Clark, 2014; Clark and others, 2014; Pantea and others, 2014), and from geophysical data from wells in nearby Blanco County (fig. 1) obtained from the Blanco-Pedernales Ground Water Conservation District. From field observations the argillaceous limestones (marls) and shales have little porosity and low permeability; however, field observations suggest that the argillaceous limestone and evaporite units might store groundwater in both the upper and middle Trinity aquifers and that the limestone units drain the storage areas via fractures and conduits.

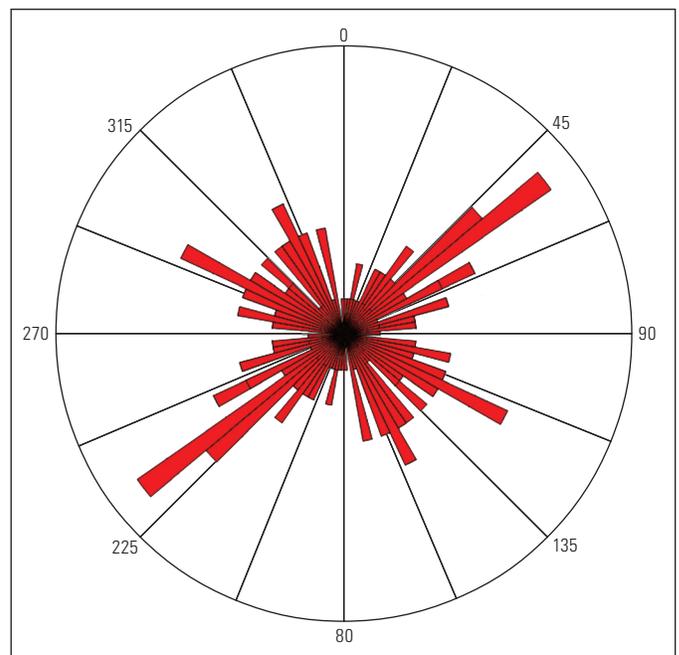


Figure 9. Rose diagram of plot of fault and fracture trends.

Hydrostratigraphy of Edwards Aquifer

VIII Hydrostratigraphic Unit

VIII HSU is the only part of the Edwards aquifer remaining in the study area and is found capping two hills (table 1, sheet 1) with an approximate thickness of 60 ft. VIII HSU contains fabric selective bedding plane and not-fabric selective fracture and minor cave porosity. It contains minor lateral cavern development at the surface and is regionally considered a confining unit to the Edwards aquifer, but locally is water bearing where porosity has been enhanced (Clark and others, 2009). VIII HSU interval is in the basal nodular member of the Kainer Formation.

Hydrostratigraphy of Upper Trinity Aquifer

Cavernous Hydrostratigraphic Unit

The cavernous HSU is absent in the northern part of the study area and up to 90 ft thick in the south (table 1, sheet 1). Changes in deposition at the contact between the Edwards and Trinity aquifers have caused variation in thickness. It contains fabric-selective interparticle, moldic, moldic (boxwork), burrow, bedding plane, vug, fracture channel and breccia, and cave porosity. Not-fabric selective porosity in fracture, channel, vug, and cave porosity. This unit has an abundance of caves (Clark, 2005), where present.

Camp Bullis Hydrostratigraphic Unit

The Camp Bullis HSU is [approximately] 160 ft thick in the study area (table 1, sheet 1). It is similar in lithology to the cavernous HSU to the south but with less karst development because of less porosity and permeability (Clark and others, 2009). Fabric selective bedding plane and burrow porosity, and not-fabric selective fracture porosity are the primary types identified in the field, although some cave development has been observed, probably caused by the intersection of fractures with bedding planes. Most of the Camp Bullis HSU's fractures seen have little solution enlargement and as a whole it is a confining unit except where caves are present (Clark, 2005).

Upper Evaporite Hydrostratigraphic Unit

The upper evaporite HSU is 10 ft thick and contains fabric selective interparticle, moldic (box work), and breccia porosity (table 1, plate 1). The unit intercepts the downward percolation of groundwater and diverts it laterally. Member tends to channel water laterally to discharge at springs and seeps (Clark, 2005; Clark and others, 2009).

Fossiliferous Hydrostratigraphic Unit

The fossiliferous HSU is 120 ft thick in the study area (table 1, sheet 1). The fossiliferous unit generally contains little fabric selective porosity but does contain some not-fabric selective fracture and cave porosity (Clark, 2005). Fracture and cave porosity is limited to the thicker limestones near the top of the unit in the southern part of the study area (Clark, 2005).

Lower Evaporite Hydrostratigraphic Unit

The lower evaporite HSU is 10 ft thick and contains the same fabric selective porosity and water-bearing characteristics as the upper evaporite unit. The lower evaporite HSU contains fabric selective interparticle, moldic (boxwork) porosity, and fabric selective breccia porosity as a result of collapse (table 1, plate 1). The unit intercepts the downward percolation of groundwater, diverts water laterally along the contact with the underlying shale bed(s) at the top of the Bulverde HSU discharging as springs and seeps (Clark, 2005; Clark and others, 2009).

Hydrostratigraphy of the Middle Trinity Aquifer

The middle Trinity aquifer encompasses, from top to bottom, the lower member of the Glen Rose Limestone and the Hensell Sand Member and the Cow Creek Limestone Member of the Pearsall Formation (Ashworth, 1983). Thickness of the middle Trinity aquifer is approximately 360 ft in the study area. In the northern Bexar County area, the lower member of the Glen Rose Limestone was divided into six informal hydrostratigraphic units, which are from top to bottom: A through F (Blome and Clark, 2014; Pantea and others, 2014). Based on later investigations, Clark and others (2014) renamed the three lowest HSUs the Doeppenschmidt (D), Rust (E), and Honey Creek (F). Additional investigations produced for this report resulted in the renaming of the upper three HSUs. The revised HSUs (with the equivalent lettered units of Blome and Clark, 2014, in parentheses) are, from top to bottom, the Bulverde (A), Little Blanco (B), Twin Sisters (C), Doeppenschmidt (D), Rust (E), Honey Creek (F), Hensell, Cow Creek, and Hammett. Field observations of the outcrops of the middle and upper Trinity aquifer imply that the argillaceous limestone units probably store water within the interparticle pores and the limestone beds probably control groundwater flow.

Bulverde Hydrostratigraphic Unit

The Bulverde HSU (Kgrb, formerly unit A) is the uppermost unit of the middle Trinity aquifer (table 1, sheet 1). The Bulverde HSU is approximately 30 ft thick and contains fabric selective bedding plane porosity, and moldic and breccia porosity where evaporites have been dissolved. It also contains not-fabric selective fracture porosity. The shale bed (fig. 10) at the top of the unit is a local barrier to downward migration of water and results in water moving laterally to discharge as



Figure 10. Moldic to channel porosity in the Honey Creek hydrostratigraphic unit, Comal County, Texas. Note handheld GPS for scale. Photograph taken September 12, 2014, by Robert Morris.

seeps and springs. The unit is interpreted as being a confining unit and is often used for constructing stock ponds. The unit was named for outcrops in the Bulverde, Texas area (fig. 1).

Little Blanco Hydrostratigraphic Unit

The Little Blanco HSU (Kgrlb; formerly unit B) is 30 ft thick in the study area and contains fabric selective moldic and bedding plane porosity, and not-fabric selective fracture porosity (table 1, plate 1). Patch reefs contain fabric selective moldic porosity. The Little Blanco HSU functions as an aquifer and was named for exposures along the Little Blanco River in northern Comal County (fig. 1).

Twin Sisters Hydrostratigraphic Unit

The Twin Sisters HSU (Kgts; formerly unit C) is 30 ft thick and contains fabric selective interparticle porosity (table 1, plate 1). In the study area the Twin Sisters HSU functions as a semi-confining unit in the shale beds. This unit appears to move water laterally resulting in water discharges from seeps and springs along hillsides providing water to numerous stock ponds. The unit was named for exposures near the Twin Sisters community west of Canyon Lake (fig. 1).

Doepenschmidt Hydrostratigraphic Unit

The Doepenschmidt HSU (Kgrd; formerly unit D) is 40 ft thick and contains fabric selective interparticle, moldic, burrowed, and bedding plane porosity (table 1, plate 1). In addition, the unit contains not-fabric selective fracture and cave porosity. There are seeps and springs near the contact with the underlying Rust HSU. The Doepenschmidt HSU functions as an aquifer with in the thicker beds of limestone. The Doepenschmidt unit was named after the Doepenschmidt homestead (Clark and others, 2014; fig. 1).

Rust Hydrostratigraphic Unit

The Rust HSU (Kgrr; formerly unit E) is 50 ft thick and contains fabric selective interparticle porosity and not-fabric selective fracture and cave porosity (table 1, plate 1). Fracture porosity is not well developed but several of the thicker limestone beds have fractures with solution enlargement. The unit contains cave porosity primarily near faults (pl. 1) and probably as a result of roof collapse of caves in the underlying Honey Creek HSU. This HSU appears to function as a barrier to subsurface flow, because springs and seeps flow from near its contact with the Doepenschmidt HSU. The Rust unit was named for the Rust homestead (Clark and others; 2014; fig. 1).

Honey Creek Hydrostratigraphic Unit

The Honey Creek HSU (Kgrhc; formerly unit F) is 45–60 ft thick and is the lowest HSU in the lower member of the Glen Rose Limestone (table 1, sheet 1; Clark and others, 2014). The Honey Creek HSU contains fabric selective interparticle, moldic (fig. 10), burrow, and bedding plane porosity. It also contains not-fabric selective fracture, channel, and cave porosity. This HSU functions as an aquifer and exhibits well-developed porosity and permeability (Clark and others, 2014). The Honey Creek cave system is the longest explored cave system in Texas at over 20 mi (Texas Speleological Survey, 2012), and discharges water into Honey Creek. The unit was named for Honey Creek Cave (Clark and others, 2014).

Hensell Hydrostratigraphic Unit

The Hensell HSU (Kheh) is 40 ft thick and contains not-fabric selective cave porosity (table 1, plate 1; Clark and others, 2014). The unit also contains fabric selective interparticle and moldic porosity in its upper part. The lower part of the Hensell HSU contains fabric selective moldic and shelter porosity and not-fabric selective cave porosity. The cave porosity is likely associated with roof collapse of cave(s) in the underlying Cow Creek unit. The Hensell HSU functions as an aquifer in the study area. The Hensell unit was named for the Hensell Sand Member (Clark and others, 2014).

Cow Creek Hydrostratigraphic Unit

The Cow Creek HSU (Kcccc) is 72 ft thick and contains fabric selective interparticle, moldic, burrow, and bedding plane porosity; and not-fabric selective fracture, vug, channel, and cave porosity (table 1, sheet 1; Clark and others, 2014). This HSU functions as an aquifer and is the primary interval targeted for water-well drilling in the area. The Cow Creek unit was named for the Cow Creek Limestone Member (Clark and others, 2014).

Hammett Hydrostratigraphic Unit

The Hammett HSU (Khah) is 50 ft thick and not exposed in the study area; however, based on stratigraphic thicknesses of the overlying units, it is shown on the map where it is inferred to underlie areas along the Guadalupe River and beneath Canyon Lake (table 1, sheet 1). The interval functions as a confining unit, based on field observations and reported data (Ashworth, 1983; Weirman and others, 2010; Clark and others, 2014), restricting the downward migration of groundwater resulting in the formation of springs near the base of the Cow Creek HSU unit. The Hammett unit was named for the Hammett Shale Member (Clark and others, 2014).

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Summary

The Anhalt, Fischer, and Spring Branch 7.5-minute quadrangles are located in Blanco, Comal, and Kendall Counties, Texas (fig. 1), and cover approximately 194 mi². The rocks originated as marine and terrigenous sediments deposited during the late Early Cretaceous, and form the upper Trinity and lower Edwards Groups.

This report presents a detailed 1:24,000-scale hydrostratigraphic map, and proposes names and descriptions of the informal hydrostratigraphic units in the study area. The hydrostratigraphy was based on the amount and type of porosity of the stratigraphic units. The hydrostratigraphic units were determined by mapping the stratigraphic units and applying the porosity characteristics of Choquette and Pray (1970). Previously assigned and newly proposed hydrostratigraphic unit names were based on already defined names or on topographic or local historical features.

The Trinity Group rocks were deposited during the Early Cretaceous (table 1) on a large shallow marine carbonate platform during three transgressive clastic-carbonate “couplets”: (1) the Hosston and Sligo Formations (which do not occur in the map area), (2) the Hammett Shale and Cow Creek Limestone Members of the Pearsall Formation, and (3) the Hensell Sand Member of the Pearsall Formation, and the Glen Rose Limestone. These units contain shale, mudstone to

grainstone, boundstone, sandstone, and argillaceous limestone. Rocks of the overlying Edwards Group were deposited during the late Early Cretaceous in an open marine to supratidal environment. The basal nodular member of the Kainer Formation at the base of the Edwards Group was deposited in a sub-tidal environment at the beginning of a marine transgressive cycle. The basal nodular member is a shaley, nodular limestone with burrowed mudstone to wackestone. The remaining part of the Edwards Group is missing because of erosion.

The Balcones fault zone is an extensional system of faults that generally trend 50 degrees, southwest to northeast, in south-central Texas. The faults have normal throw, are *en echelon*, and are downthrown to the southeast. The conjugant fractures trend perpendicular to the Balcones fault zone at approximately 118 degrees. An igneous dike of Early Cretaceous age or younger cuts through the northwestern part of the Anhalt quadrangle near the confluence of Honey Creek and the Guadalupe River. The dike penetrates the Cow Creek Limestone and the lower part of the Hensell Sand Members.

Maclay and Small (1976) proposed mapping the Edwards aquifer outcrops using eight hydrostratigraphic subdivisions, I through VIII. Ashworth (1983) subdivided the rocks of the Trinity aquifer into upper, middle, and lower segments. Clark (2003, 2005) mapped and subdivided the rocks of the upper Trinity aquifer in northern Bexar County into five informal HSUs designated A through E. Clark and others (2009) expanded the mapping in northern Bexar County and renamed the HSUs, from top to bottom: Cavernous, Camp Bullis, upper evaporite, fossiliferous, and lower evaporite. Blome and Clark (2014) divided rocks of the middle Trinity aquifer into nine hydrostratigraphic units to better describe the unit's hydrologic properties. For this report, the HSUs of the middle Trinity aquifer have been mapped and renamed, top to bottom: Bulverde, Little Blanco, Twin Sisters, Doeppenschmidt, Rust, Honey Creek, Hensell, Cow Creek, and Hammett.

The informal HSUs have been mapped using porosity types identified in the field during the course of the study, coupled with data from previous studies and from geophysical data from wells in nearby Blanco County. The hydrostratigraphic units of the Edwards and Trinity aquifers have been mapped and described herein using a classification system developed by Choquette and Pray (1970), which is based on porosity types being fabric or not-fabric selective. From field observations, the argillaceous limestones (marls) and shales have little porosity and low permeability; however, field observations suggest that the argillaceous limestone and evaporite units might store groundwater in both the upper and middle Trinity aquifers and that the limestone units drain the storage areas via fractures and conduits.

The hydrostratigraphic mapping can aid water managers in determining the effects of drought and increasing development of groundwater resources in the study area. The lower part of the Trinity aquifer (Hosston and Sligo Formations) do not occur in the study area. This mapping might also help in the placement of recharge structures, areas for aquifer storage and recovery projects, and determining the likely pathways of contamination.

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