Prepared in cooperation with the Edwards Aquifer Authority

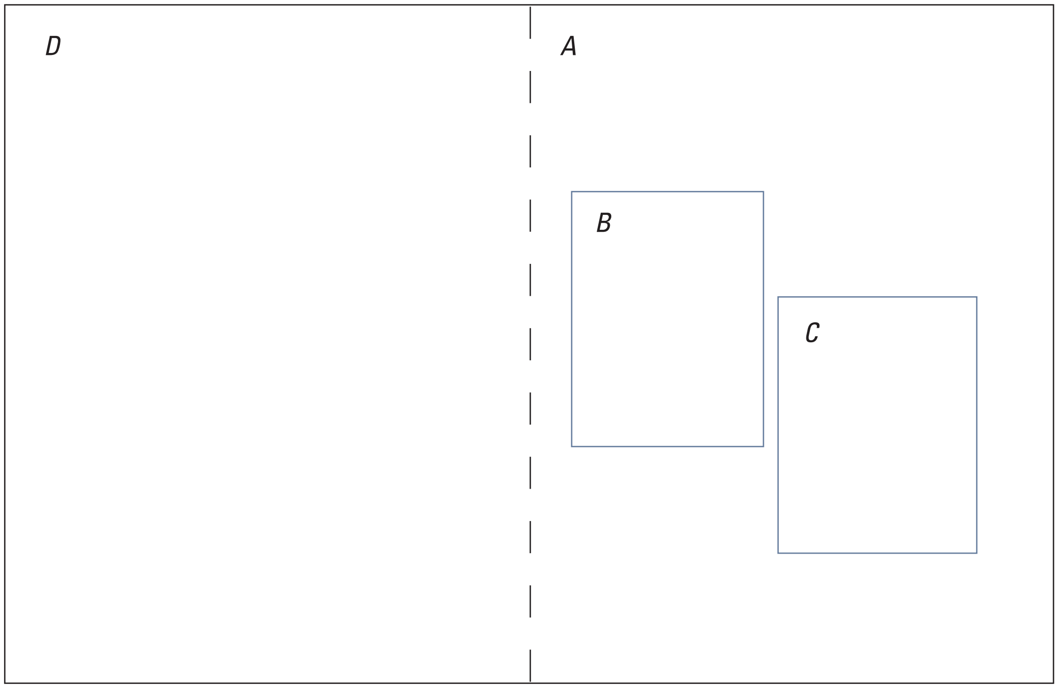
Geologic Framework and Hydrostratigraphy of the Edwards and Trinity Aquifers Within Northern Medina County, Texas

Pamphlet to accompany

Scientific Investigations Map 3526

Supersedes USGS Scientific Investigations Map 3461

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



Cover.
A, Photograph showing west-oriented view of fog in the Medina River Valley, on the Medina River downstream from Medina Lake Dam, northern Medina County, Texas (photograph by Allan K. Clark, U.S. Geological Survey, October 21, 2019).
B, Photograph showing cave in the western bank of the Medina River downstream from Medina Lake Dam, northern Medina County, Texas. The cave is in the upper member of the Glen Rose Limestone, cavernous hydrostratigraphic unit (photograph by Allan K. Clark, U.S. Geological Survey, October 21, 2019).
C, Photograph showing Allan K. Clark examining rock fragment of the Devils River Limestone and also showing a boulder of the Devils River Limestone and bluebonnets in the study area, northern Medina County, Texas (photograph by Allan K. Clark, U.S. Geological Survey, June 17, 2019).
D, Photograph showing bluebonnets, boulders and cobbles of the Devils River Limestone with scale and rock hammer, northern Medina County, Texas (photograph by Allan K. Clark, U.S. Geological Survey, June 17, 2019).

Geologic Framework and Hydrostratigraphy of the Edwards and Trinity Aquifers Within Northern Medina County, Texas

By Allan K. Clark, Robert R. Morris, and Alexis P. Lamberts

Prepared in cooperation with the Edwards Aquifer Authority

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U.S. Department of the Interior
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[On sheet]

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

Datum

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).

Geologic Framework and Hydrostratigraphy of the Edwards and Trinity Aquifers Within Northern Medina County, Texas

By Allan K. Clark, Robert R. Morris, and Alexis P. Lamberts

Abstract

During 2023–24, the U.S. Geological Survey, in cooperation with the Edwards Aquifer Authority, revised a previous publication of the geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers that was completed during 2018–20 within northern Medina County, Texas. The purpose of this report is to present the updated geologic framework and hydrostratigraphy of the rocks containing the Edwards and Trinity aquifers in northern Medina County from field observations of the surficial expressions of the rocks. The report includes a detailed 1:24,000-scale hydrostratigraphic map with names and descriptions of the geologic and hydrostratigraphic units (HSUs) in the study area. This study includes updates to the geology of the Kainer Formation (or its stratigraphic equivalent, the Fort Terrett Formation) with the addition of a burrowed unit between the basal nodular and dolomitic members. The hydrostratigraphy was also updated with the addition of HSU IIA for the upper part of the Devils River Limestone and the Seco Pass HSU for the burrowed member of the Kainer (or Fort Terrett) Formation.

The Cretaceous age rocks (listed in ascending order) in the study area are part of the Trinity Group, Edwards Group and stratigraphically equivalent Devils River Limestone, Washita Group, Eagle Ford Group, Austin Group, and Taylor Group, with isolated areas where Late Cretaceous age igneous rocks have intruded. The groups and formations are composed primarily of relatively thick layers of clays, shales, and limestone. The igneous rocks are coarse-grained ultramafic in composition.

Hydrostratigraphically, the rocks exposed in the study area (listed in descending order from land surface) are igneous, the upper confining unit to the Edwards aquifer, the Edwards aquifer, the upper zone of the Trinity aquifer, and the upper part of the middle zone of the Trinity aquifer. The karstic carbonate Edwards and Trinity aquifers developed because of their original depositional history, primary and secondary porosity, diagenesis, fracturing, and faulting. These factors have resulted in development of modified porosity, permeability, and transmissivity within and between the aquifers.

Introduction

The karstic Edwards and Trinity aquifers (fig. 1) are classified as major sources of water in south-central Texas by the Texas Water Development Board (George and others, 2011). The geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers largely control groundwater flow paths and storage in northern Medina County (Kuniansky and Ardis, 2004). Detailed maps and descriptions of the geologic framework and hydrostratigraphy are needed by water managers to effectively manage available groundwater resources in south-central Texas. Hence, an initial characterization completed during 2018–20 (Clark and others, 2020) was updated during 2023–24 by the U.S. Geological Survey (USGS), in cooperation with the Edwards Aquifer Authority, to better document the geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within northern Medina County, Tex.

The surficial rock exposures in northern Medina County are mostly of sedimentary origin with isolated igneous intrusions associated with mantle upwelling. Field observations of surficial rocks were used to identify the upper confining unit to the Edwards aquifer and to identify the rocks that contain the Edwards aquifer and the upper and middle zones of the Trinity aquifer. The thicknesses of the mapped lithostratigraphic units and hydrostratigraphic units (HSUs) were also estimated from field observations. Descriptions of the geologic framework and HSUs in this report were modified from those in Stein and Ozuna (1995), Small and Clark (2000), Clark (2003), Clark and others (2009), Blome and Clark (2014), and Clark and others (2016, 2023).

Description of Study Area

The study area (fig. 1) is the northern 442 square miles of Medina County. The rocks exposed within the study area are outcrops of the Trinity, Edwards, Washita, Eagle Ford, Austin, and Taylor Groups, with isolated pockets of igneous rocks (Barker and Ardis, 1996) (fig. 2). The rocks are primarily sedimentary carbonates that formed during the Cretaceous age (Barker and Ardis, 1996). Faulting in the study area occurred during the late Oligocene to early Miocene (Weeks, 1945b) and resulted in an extensional fault system known as the Balcones fault zone (Hill, 1900). The Balcones fault zone generally trends southwest to northeast in south-central Texas (Maclay and Small, 1986). The faults are vertical to near vertical, en echelon, and mostly downthrown to the southeast (Hill, 1900; Maclay and Small, 1986). Karst features in the study area include sinkholes, caves, and other solution-enlarged conduit features that facilitate rapid infiltration of surface waters to the subsurface (Veni, 1988; Lindgren and others, 2011).

Purpose and Scope

The purpose of this report is to describe the geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within northern Medina County, Tex. (fig. 1). A geologic map of the surficial extent of the rocks that contain the Edwards and Trinity aquifers (fig. 3) was created from field observations. Identification of the various HSUs with observed porosity is helpful in identifying areas of groundwater recharge, discharge, and groundwater flow paths within and between the aquifers and HSUs. The scope of the report is the geologic framework and hydrostratigraphy of the outcrops of the Edwards and Trinity aquifers within northern Medina County (fig. 1). The report includes descriptions of the geology and hydrostratigraphy, as well as a detailed map of the hydrostratigraphy. In addition to the rocks that contain the Edwards and Trinity aquifers, parts of the adjacent upper confining unit to the Edwards aquifer and igneous rocks are described. Compared to the level of detail available in existing geologic maps, the geologic map in this report was prepared at a scale of 1:24,000 to aid water managers as they work to anticipate and mitigate issues related to changing land use and increasing groundwater demands.

Methods of Investigation

Geological data and information from previous reports (Barnes, 1974; Small and Clark, 2000; Clark, 2003, 2004; Clark and others, 2009; Blome and Clark, 2014; Clark and others, 2016, 2023) were reviewed to assist in field mapping. Geologic framework and hydrostratigraphic mapping was completed on public and private land in northern Medina County; newly gained access to areas that previously could not be assessed led to this updated report. Hence, the previously published descriptions of the geologic framework and hydrostratigraphic map were updated on the basis of new field observations. Field-mapping techniques were consistent with those used in other studies (Clark, 2003; Clark and Morris, 2015; Clark and others, 2016, 2018, 2023) and were guided by using Global Positioning System (GPS) units, digital maps, and geologic mapping applications installed on a tablet computer. Field observations were recorded onsite by using a tablet computer loaded with geospatially registered 7.5-minute USGS topographic maps. Locations of visible and interpreted geologic contacts, faults and fractures, marker units, and other areas of interest were recorded by using an integrated fourth or fifth generation long-term evolution (LTE) assisted GPS receiver on the tablet computer. In areas without cellular service, positions were determined by using a hand-held compass and triangulation techniques. The data obtained by using the tablet computer compass application were independently cross verified on a regular basis with data obtained by using a handheld compass. The field data were imported into a geographic information system (GIS) by using ArcMap versions 10.6.1 or 10.8.1 (Esri, 2020). Some data were transferred manually from the tablet computer directly into ArcMap. All transferred data were quality checked by comparison with original draft data and then used to examine the geologic framework and develop the hydrostratigraphic map of the study area.

Various published sources were consulted for geologic names, lithologic descriptions, HSU names, and porosity information. Formal geologic names are consistent with those in the U.S. Geological Survey National Geologic Map Database (U.S. Geological Survey, 2023). Informal geologic member names are consistent with previous publications (Rose, 1972; Maclay and Small, 1976; Collins, 1999; Clark and others, 2009; Blome and Clark, 2014; Clark and others, 2016, 2020, 2023). Lithologic descriptions follow the classification system of Dunham (1962) and Wright (1992). The HSU names and porosity types are consistent with those used in previous publications (Rose, 1972; Maclay and Small, 1976; Clark and others, 2009; Blome and Clark, 2014; Clark and others, 2016, 2023) (fig. 2). Porosity descriptions are based on the sedimentary carbonate classification system of Choquette and Pray (1970). Porosity varies in each lithostratigraphic unit and is dependent on the unit's original depositional environment, lithology, structural history, and diagenesis (fig. 2).

The descriptions of the geologic framework and hydrostratigraphy in this report were adapted for the study area from Rose (1972), Maclay and Small (1976), and Clark and others (2016, 2023). Descriptions of clastic rocks were done under the classification scale of Wentworth (1922).

The thicknesses of the mapped members (formal and informal) and HSUs were estimated from field observations. Thickness variations are caused by variations in local depositional and erosional conditions. Digital data that define the geographical extent of the surficial HSUs and faulting within the study area and associated metadata are available for download in a companion data release (Lamberts and others, 2024).

Geologic Framework

The Cretaceous age rocks (listed in ascending order here and throughout the remainder of the report) in the study area are part of the Trinity Group (Hill, 1888; Ross, 1943; Clark and others, 2009; Blome and Clark, 2014), Edwards Group

(Hill and Vaughan, 1898; Rose, 1972; Maclay and Small, 1976) and the equivalent Devils River Limestone (Udden, 1907), Washita Group (Adkins, 1932), Eagle Ford Group (Hill, 1887; Wilmarth, 1938), Austin Group (Shumard, 1860; Adkins, 1932), Taylor Group (Hill, 1892; Stenzel, 1938), and igneous intrusive rocks (Liddle, 1918).

The groups and formations are composed primarily of relatively thick layers of clays, shales, and limestones. The limestones are composed of mudstone through grainstone, framestone and boundstone, dolomite, and argillaceous and evaporitic rocks (Clark and others, 2016) (fig. 2). Sporadic igneous intrusions (Liddle, 1918) are present throughout the study area. The igneous rocks are coarse-grained ultramafic in composition (Miggins and others, 2004).

Trinity Group

The Early Cretaceous to late Early Cretaceous age Trinity Group was deposited as sediments on a large, shallow marine carbonate platform (the Comanche shelf, fig. 1) as clastic-carbonate “couplets” during marine transgressional events. During each transgressional event, sea levels of interior seaways rose relative to land surface and then retreated (Lozo and Stricklin, 1956; Stricklin and others, 1971). Each of the transgressional events resulted in deposition of sediments that formed several formations of the Trinity Group, including the Glen Rose Limestone, the only formation of the Trinity Group described in this report (underlying the Glen Rose Limestone are additional formations that do not crop out in the study area and are not discussed). The Glen Rose Limestone is commonly divided into a lower member and an upper member. The thickness of the lower member of the Glen Rose Limestone is between 170 and 300 feet (ft) (Blome and Clark, 2014; Clark and others, 2016, 2023) (fig. 2), thinning from the east to the west. The upper member of the Glen Rose Limestone is between 328 and 440 ft thick. Descriptions of the formal and informal members are described, and their associated lithologies are shown (fig. 2).

Edwards Group and Devils River Limestone

Field observations during this study were based on better access to private land compared to the access available in previous mapping efforts. During this study, field observations indicated that the Kainer Formation (or its stratigraphic equivalent, the Fort Terrett Formation) and the lower part of the Person Formation extend farther into the northwestern part of Medina County than previously observed (Small and Clark, 2000). In a previous study, outcrops of the various members that form the Kainer Formation were found in northern Uvalde County at Garner State Park (fig. 1), which is west of the northern extent of the Kainer Formation described in Small and Clark (2000).

Rocks of the late Early Cretaceous age Edwards Group were deposited on the Comanche shelf and San Marcos Arch (fig. 1) in the northwestern and eastern parts of the study area, and the late Early Cretaceous age Devils River Limestone of the Devils River trend (fig. 1) (Moore, 2010) was deposited in the western part of the study area, which fringes the Maverick Basin (fig. 1). In the study area, the Edwards Group (fig. 2) is composed of the Kainer Formation (or its stratigraphic equivalent, the Fort Terrett Formation) and the Person Formation (Rose, 1972) (fig. 2) in the San Marcos Arch (fig. 1). The Fort Terrett Formation is laterally and stratigraphically equivalent to the Kainer Formation (Rose, 1972) and is present in the northwestern part of the study area in the Comanche shelf (fig. 1), whereas the Kainer and Person Formations are present in the central and eastern parts. The Devils River Limestone is stratigraphically equivalent to the Edwards Group (fig. 2) and fringes the Maverick Basin (fig. 1).

The Kainer Formation (or its stratigraphic equivalent, the Fort Terrett Formation) and Person Formation are primarily composed of mudstone to grainstone, shales, and chert (Rose, 1972) (fig. 2). These sediments were deposited in coastal environments ranging from open shelves to supratidal flats (Rose, 1972; Maclay and Small, 1986) during two separate marine transgressions. The 240–390 ft thick Kainer (or Fort Terrett) Formation is composed of the informal and formal (bottom to top) basal nodular (Kkbn), burrowed (Kkb), dolomitic (Kkd), Kirschberg Evaporite (Kkke), and grainstone (Kkg) members (Rose, 1972; Maclay and Small, 1976). The overlying Person Formation (fig. 2) was deposited during a subsequent marine transgression (Rose, 1972). The 170–204 ft thick Person Formation is composed of the informal regional dense (Kprd), leached and collapsed (undivided, Kplc), and cyclic and marine (undivided, Kpcm) members (Rose, 1972; Maclay and Small, 1976). Descriptions of each of the geologic units and their associated lithology are shown (fig. 2) and discussed in further detail in Clark and others (2016, 2018, 2023).

In the northern part of the study area, the Fort Terrett Formation (fig. 2) of the Comanche shelf (fig. 1) is composed of mudstone to grainstone, crystalline limestone, dolomite, shaly limestone, and chert in the form of beds and large nodules. Based on field observations, the Fort Terret Formation is found as caps on hills and because of erosion is only 200 ft thick or less. The Fort Terrett Formation was deposited in a low wave energy, shallow marine environment (Rose, 1972). Only the informal basal nodular, burrowed, and dolomitic members (fig. 2) and the formal Kirschberg Evaporite Member (fig. 2) of the Fort Terrett Formation are exposed in the study area (fig. 3).

The Devils River Limestone (fig. 2) of the Devils River trend (fig. 1) is composed of mudstone to grainstone, framestone to boundstone, mudstone, shaly limestone, and chert in the form of beds and large nodules. The lower part of the Devils River Limestone was deposited in shallow water, intertidal to supratidal environments around the subsiding Maverick Basin west of the study area (Lozo and Smith, 1964;

Rose, 1972) (fig. 1). As subsidence in the Maverick Basin continued, the upper part of the Devils River Limestone was deposited as a carbonate bank composed of rudist patch reefs and biostromes (Rose, 1972; Clark and Small, 1997) (fig. 4).

The lower part of the Devils River Limestone is laterally equivalent to the Kainer Formation (fig. 2). Therefore, the traditional arbitrary boundary depicted in previous publications as the transition from the Edwards Group to the Devils River trend is obsolete. For this report, the Devils River Limestone was informally divided into lower and upper parts. The lower part of the Devils River Limestone contains the same informal and formal geologic units that form the Kainer Formation to the east—that is, in ascending order, the basal nodular (Kdrvlbn), burrowed (Kdrvlb), dolomitic (Kdrvld), Kirschberg Evaporite (Kdrvlke), and grainstone (Kdrvlg) members (Maclay and Small, 1976). The lower part of the Devils River Limestone is between 240 and 390 ft thick in the study area. Like the Person Formation to the east, the regional dense (Kdrvurd) member is the basal unit of the upper part of the Devils River Limestone and is 20–24 ft thick; the remainder of the upper part of the Devils River (Kdrvu) Limestone in the study area consists of mudstone to grainstone, framestone, boundstone, and chert in the form of beds and large nodules and is between 150 and 250 ft thick. The upper part of the Devils River Limestone thickens to the west off the San Marcos Platform facies and into the Devils River trend. The regional dense member, within the upper part of the Devils River Limestone, contains an oolitic limestone in the upper part. Ooliths are small spheres that form as calcium carbonate is deposited on the surfaces of sand grains that are rolled (by wave action) around on a shallow sea floor. Overviews of the geologic units and their associated lithologies within the Edwards Group and Devils River Limestone are provided (fig. 2). More detailed descriptions of the Edwards Group are available in Clark and others (2016, 2023).

Washita, Eagle Ford, Austin, and Taylor Groups

Following the deposition of the Edwards Group (or Devils River Limestone), tectonic uplift, subaerial exposure, and erosion occurred in the area that is now south-central Texas (Rose, 1972). This area was then resubmerged during the late Early Cretaceous by another marine transgression that resulted in the deposition of shale, mudstone, and wackestone that formed the 2–20 ft thick Georgetown (Kg) Formation (Vaughan, 1900a) of the Washita Group (fig. 2). Much of the Georgetown Formation was subsequently removed during a period of marine regression (Rose, 1972).

The Del Rio (Kdr) Clay of the Washita Group (figs. 2 and 5) is 50–60 ft thick in the study area, contains clay and packstone, and was deposited in an open-shelf environment over the Georgetown Formation. The Del Rio Clay was deposited during a marine transgression during the early Late Cretaceous when the Stuart City Reef trend (fig. 1) was breached (Fisher and Rodda, 1969; Rose, 1972, p. 17). Continued deposition of sediments in shallow subtidal to intertidal zones resulted in the mudstone and wackestone that formed the 40–50 ft thick Buda (Kb) Limestone (Grunig and others, 1977) of the Washita Group (fig. 2).

The Late Cretaceous age Eagle Ford (Kef) Group (fig. 2) is 20–40 ft thick in the study area and was deposited as sandy shale and argillaceous limestone in a lagoonal to open-shelf marine environment (Grunig and others, 1977). As the marine transgression continued in the Late Cretaceous, an open, shallow shelf developed, and sediments were deposited far from shore, resulting in the mudstones and wackestones that form the 130–160 ft thick Austin (Ka) Group (fig. 2) (Grunig and others, 1977).

The uppermost stratigraphic unit exposed in the study area is the 230–540 ft thick Late Cretaceous age Pecan Gap (Kpg) Chalk of the Taylor Group (fig. 2). The Pecan Gap Chalk is composed of argillaceous limestone and calcareous clay and was deposited in an open marine environment (Ellisor and Teagle, 1934).

Overviews of the geologic units and their associated lithology for the Washita, Eagle Ford, Austin, and Taylor Groups are provided (fig. 2). More detailed descriptions of the Washita, Eagle Ford, Austin, and Taylor Groups are available in Clark and others (2016, 2023).

Igneous Intrusive Rocks

Two surficially exposed intrusive igneous bodies (Kig) (figs. 2 and 3) were identified in Medina County on the basis of information obtained from field mapping and previous reports (Liddle, 1918; Holt, 1956). Liddle (1918, p. 109) identified an igneous dike described as follows: “On Cow Creek one mile from its junction with the middle Verde Creek * * * a dike which has a northeast-southwest surface strike * * *” is an “impervious igneous mass ascending along a fault plane * * *.”

The second igneous body (figs. 3 and 6) is along County Road 241, approximately 4 miles from the intersection of County Road 241 and State Highway 173. Holt (1956, p. 52) described this second igneous body as “a small plug of olivine basalt * * *. This plug is about 300 feet in diameter at the surface and is surrounded by the Edwards limestone. The limestone near the contact has been altered to a varicolored marble containing veins of serpentine.”

Smith and others (2008) indicated that there were a few additional igneous bodies within the study area, although most are probably buried. The igneous rocks are Late Cretaceous age and are hypabyssal, composed of coarse-grained ultramafic material (Miggins and others, 2004). For a more detailed description of the composition and age dates of the igneous bodies, refer to Miggins and others (2004) and Smith and others (2008).

Structure

The principal structural feature in northern Medina County is the Balcones fault zone (fig. 1), which is the result of late Oligocene and early Miocene extensional faulting (Weeks, 1945a, b; Galloway and others, 2000; Rose, 2016, 2017) and fracturing resulting from the eastern part of the Edwards Plateau uplift (Rose, 2017). In the Balcones fault zone, most of the faults in the study area are high-angle to vertical, en echelon, normal faults that are predominantly downthrown to the southeast (George, 1952) (fig. 7).

The Balcones fault zone is considered dormant (Ewing, 2005b), and its location may be a result of a reactivation of older, deeper faulting associated with the Ouachita structural belt (Ewing, 2005a) (fig. 1). As is typical with extensional fault zones, the Balcones fault zone includes horst and graben structures (Pantea and others, 2014). The faulting has resulted in juxtaposition of stratigraphically older rocks against younger rocks of varying lithologies. A noteworthy fault within the study area is the Haby Crossing Fault (fig. 3), which from field observations has a displacement of 650 ft or more. The amount of displacement results in most of the Edwards Group being offset and leaving only the very basal part of the group being juxtaposed against the Pecan Gap Chalk near the Diversion Lake Dam (fig. 3).

The authors have observed that because of the faulting and subsequent development of large relay ramps (Hovorka and others, 1996) in the study area the rocks become progressively younger from northwest to southeast and from northeast to southwest. Relay ramps are common in an extensional fault system (Ferrill and Morris, 2008). Ramp structures can be relatively small features that extend less than a few yards to large features that extend tens of miles. Relay ramps form in extensional fault systems to accommodate stress relief and an increase in deformation of the rock fabric (Clark and Journey, 2006). Ramp structures link the footwall of a fault segment with the hanging wall of an overlapping fault segment (Collins, 1995; Clark and Journey, 2006; Hunt and others, 2015). As extension occurs, the increased strain on the rock fabric causes faulting that results in the formation of relay ramps with rotation and internal fracturing occurring along the ramps (Trudgill, 2002; Ferrill and Morris, 2008). Continued extension results in the formation of cross faults within the relay ramp structure (Trudgill, 2002). Some examples of reports documenting relay ramp structures within the Balcones fault zone include Collins (1995), Clark and Journey (2006), Clark and others (2013), and Hunt and others (2015).

Hydrostratigraphy

Hydrostratigraphically, the rocks exposed in the study area (listed in descending order from land surface as they appear in a stratigraphic column) are isolated outcrops of igneous rocks, the upper confining unit to the Edwards aquifer, outcrops of the rocks that contain the Edwards aquifer, outcrops of the rocks that contain the upper zone of the Trinity aquifer, and outcrops of the rocks that contain the upper part of the middle zone of the Trinity aquifer. Descriptions of the HSUs, thicknesses, hydrologic function, porosity types, and field identification are provided (fig. 2) and are described further in Clark and others (2016, 2018, 2023). Identification of the various HSUs and their observed porosity types may be helpful in identifying areas of recharge and discharge and groundwater flow paths within and between the aquifers and HSUs. Streamflow losses may correspond to specific HSUs that contain porosity, such as interconnected moldic porosity or caves, and areas of solution-enhanced fractures or faults. Areas with little or no streamflow losses indicate that the underlying HSUs have less porosity. Springs and seeps are often associated with a more porous HSU containing water that overlies a less porous HSU.

Igneous Intrusive Rocks

Igneous rocks may form barriers to groundwater flow because porosity within the nearby limestone units is filled by low porosity secondary minerals, such as serpentine (Liddle, 1918; Holt, 1956; Miggins and others, 2004), which forms by contact metamorphism of the limestone units (Liddle, 1918; Holt, 1956) and by the igneous material itself (Miggins and others, 2004). Liddle (1918, p. 110) noted, “a spring rises to the surface from the fault at the north side of the dike and flows into Cow Creek. The dike, in intruding the [Glen Rose Limestone], has cut through a water-bearing horizon, and since the igneous rock is practically impervious, it [the dike] has afforded an impediment to the water which, under hydrostatic pressure, rises to the surface. A shaft has been sunk [on the south side of the dike] some 90 feet in the [Glen Rose Limestone] at the contact between the limestone and the dike.” From Liddle’s description, the igneous material is impervious, resulting in a spring on the north side of the dike; the impervious nature of the igneous material is supported by the fact that the 90-ft shaft dug south of the dike contained no water. The spring identified by Liddle (1918) was not observed by the authors of this report, which could be because groundwater levels have declined since the spring was originally identified by Liddle. According to Maclay (1995), the igneous rocks in Uvalde County may influence major Edwards aquifer groundwater flow paths. From field observations in the study area and descriptions in previous reports (Liddle, 1918; Holt, 1956; Maclay, 1995; Miggins and others, 2004), igneous intrusions do not likely play an appreciable role in modifying groundwater flow paths in northern Medina County.

Upper Confining Unit to the Edwards Aquifer

The rocks that form the upper confining unit to the Edwards aquifer are (from top to bottom) the Taylor, Austin, Eagle Ford, and Washita Groups (Maclay and Small, 1976;

Small and Clark, 2000; Clark and others, 2016, 2023) (fig. 2). These groups are generally collectively categorized as a confining unit to the Edwards aquifer and are not separated into discrete HSUs. Except for the Austin Group (Petitt and George, 1956) and parts of the Georgetown Formation of the Washita Group (Stein and Ozuna, 1995), the rocks that form the upper confining unit to the Edwards aquifer do not supply appreciable amounts of water to wells in the study area. Therefore, the hydrologic characteristics of only the Austin Group and the Georgetown Formation of the Washita Group are described in this report.

The Austin Group is hydrologically connected to the underlying Edwards aquifer (Groschen, 1996; Banta and Clark, 2012) and in some places the Trinity aquifer (Clark and others, 2016, 2023) depending on the amount of displacement along faults. The Austin Group supplies water to several springs in Uvalde, Medina, and Bexar Counties, as well as to some domestic and irrigation wells (Holt, 1959; Garza, 1962; Arnow, 1963; Banta and Clark, 2012). The most prolific wells and springs within the Austin Group likely tap water that moves up faults and fractures under artesian conditions from the underlying Edwards aquifer (Livingston and others, 1936; Veni, 1988; Banta and Clark, 2012).

The Georgetown Formation of the Washita Group was first placed within the group of rocks that contain the Edwards aquifer by Arnow (1959) because it is the formation targeted by drillers for setting well casing prior to drilling into the Edwards aquifer. Maclay and Small (1976) thus assigned the Georgetown Formation as HSU I of the Edwards aquifer; however, hydrologically it appears to function as a confining unit (George, 1952; Maclay and Small, 1976; Hanson and Small, 1995). George (1952), Land and Dorsey (1988), Blome and others (2005), and Clark and others (2006) considered this unit as part of the upper confining unit to the Edwards aquifer. Stein and Ozuna (1995) stated that the Georgetown Formation is not known to produce water. During field-mapping work, field observations indicated that earthen, unlined stock tanks are commonly built directly on the outcrop of the Georgetown Formation, which is consistent with the premise that hydrologically it functions as a confining unit.

Edwards and Trinity Aquifers

In the study area, the Edwards aquifer is contained in the rocks composing the Edwards Group and the Devils River Limestone, and the Trinity aquifer is contained in the rocks of the Trinity Group. The karstic carbonate Edwards and Trinity aquifers developed because of their original depositional history, primary and secondary porosity, diagenesis, fracturing, and faulting. These factors have resulted in development of modified porosity, permeability, and transmissivity within and between the aquifers. Most of the permeability within the Edwards and Trinity aquifers is associated with enhanced secondary porosity that is developed along bedding planes, fractures, and caves (Maclay and Small, 1983; Veni, 1987, 1988, 1994; Johnson and others, 2002; Ferrill and others, 2003; Gary and others, 2011). The Edwards and Trinity aquifers have traditionally been considered separate aquifers because of differences in permeability (Hammond, 1984; Kuniansky and Ardis, 2004); however, other assessments have shown that the Edwards aquifer and the upper part of the upper zone of the Trinity aquifer might function as a single aquifer (Johnson and others, 2002; Clark, 2003; Clark and others, 2009; Hunt and others, 2016). Barker and Ardis (1996) stated that recharge to the Edwards aquifer from the underlying Trinity aquifer is from diffuse upward leakage. Hydrologic connection between the Trinity and Edwards aquifers also occurs by lateral groundwater movement across faults. Hydrologic connection where faulting has occurred has resulted in water-bearing units of the aquifers and HSUs within the aquifers being in direct lateral contact with one another (Clark and Journey, 2006; Clark and others, 2006; Johnson and others, 2010). Detailed descriptions of the HSUs, thicknesses, hydrologic function, porosity types, and field identification are provided (fig. 2).

Edwards Aquifer

In the study area, the Edwards aquifer is contained in the following formations: the Georgetown Formation of the Washita Group and either the Person and Kainer (or Fort Terrett) Formations of the Edwards Group or the equivalent Devils River Limestone (fig. 2). The parts of the Edwards aquifer contained in the Georgetown Formation of the Washita Group and in the Person and Kainer (or Fort Terrett) Formations of the Edwards Group were subdivided informally into HSUs I–VII (Maclay and Small, 1976), Seco Pass (Clark and others, 2023), and VIII (Maclay and Small, 1976) (fig. 2). The uppermost subdivision of the Edwards aquifer is the Georgetown Formation of the Washita Group, which Maclay and Small (1976) designated as HSU I. Maclay and Small (1976) noted that HSU I of the Edwards aquifer was typically the unit where drillers would set casing before drilling through to the water-bearing units in the underlying Edwards aquifer. The Person Formation was designated as follows: HSU II for the informal cyclic and marine members (undivided), HSU III for the informal leached and collapsed members (undivided), and HSU IV for the informal regional dense member (Maclay and Small, 1976). The Kainer (or Fort Terrett) Formation was divided into the following: HSU V for the informal grainstone member (Maclay and Small, 1976), HSU VI for the informal Kirschberg evaporite member (formal member of the Fort Terrett Formation of the Edwards Group) (Maclay and Small, 1976), HSU VII for the informal dolomitic member (Maclay and Small, 1976), Seco Pass for the informal burrowed member (Rose, 1972; Clark and others, 2023), and HSU VIII for the informal basal nodular member (Maclay and Small, 1976).

The part of the Edwards aquifer within the Devils River trend has been mapped as undivided in previous reports. According to Clark and Small (1997), the Devils River trend, which is in the Devils River Limestone, is one of the most porous and permeable units in the Edwards aquifer.

Working within the informal hydrostratigraphic framework established by Maclay and Small (1976), the authors of this report identified the upper part of the Devils River Limestone as HSU IIA and HSU IV (fig. 2). HSU IIA is undivided and is laterally transitional from HSUs II and III of the upper part of the Person Formation (figs. 2 and 8). HSU IV of the Devils River Limestone is laterally equivalent to HSU IV of the Person Formation (fig. 2). The lower part of the Devils River Limestone has similar hydrologic characteristics to the lower part of the Edwards aquifer of the Edwards Group and has been designated as HSUs V, VI, VII, Seco Pass, and VIII (fig. 2) on the basis of laterally equivalent stratigraphy.

Trinity Aquifer

Ashworth (1983) subdivided the Trinity aquifer into upper, middle, and lower zones. In the study area only the upper zone and the upper part of the middle zone of the Trinity aquifer are exposed at the land surface (figs. 2 and 3). The middle and lower parts of the middle zone of the Trinity aquifer are not exposed at the land surface and therefore not represented or mapped on figure 2 or figure 3. The upper zone of the Trinity aquifer yields water from the upper member of the Glen Rose Limestone. The part of the middle zone of the Trinity aquifer present in the study area yields water from the lower member of the Glen Rose Limestone.

From field observations, the authors of this report suggest that beds of argillaceous limestone in the upper and middle zones of the Trinity aquifer slow the movement of groundwater, likely because of the heterogeneous grain sizes that form the beds. The argillaceous beds likely function as zones of groundwater retention, with water stored in the argillaceous beds being slowly released into fractures in adjacent limestone beds, bedding planes, and caves. The groundwater would then slowly make its way to larger conduits that either discharge in springs or wells or migrate into the juxtaposed and adjacent Edwards aquifer. In addition, the argillaceous beds may retain substantial quantities of water in the vadose zone.

The upper zone of the Trinity aquifer was provisionally subdivided into five HSUs by Clark (2003) and was later informally named by Clark and others (2009). The five informal HSUs composing the upper zone of the Trinity aquifer are (top to bottom) as follows: cavernous (figs. 9, 10, and 11), Camp Bullis, upper evaporite, fossiliferous (upper and lower), and lower evaporite. Descriptions of these HSUs are provided (fig. 2).

The middle zone of the Trinity aquifer was informally subdivided into eight HSUs by Blome and Clark (2014) and Clark and others (2014). In the study area, the five HSUs exposed at the land surface are (top to bottom) the Bulverde, Little Blanco, Twin Sisters, Doeppenschmidt, and Rust. From field observations, the hydrostratigraphic characteristics of the exposed HSUs in northern Medina County have similar characteristics to those in Bexar and Comal Counties (Clark and others, 2016, 2023).

Structure

Groundwater recharge and flow paths in the study area are affected not only by the hydrostratigraphic characteristics of the individual HSUs but also by faults, fractures, and geologic structure. Citing in part the work of Clark and others (2016, p. 13), “faulting and the resulting structures * * * common in fault zones like the Balcones fault zone may increase the potential of controlling or altering local groundwater flow (Pantea and others, 2014) by juxtaposing permeable and less permeable lithologies against one another. * * * Faulting produced highly fractured areas that have allowed for rapid infiltration of water and subsequently formed solutionally enhanced fractures, bedding planes, channels, and caves that are highly permeable and transmissive. The juxtaposition resulting from faulting has resulted in areas of interconnectedness between the Edwards and Trinity aquifers and the various HSUs that form the aquifers.” An example of the effect of faulting on groundwater flow paths is reported by Saribudak and Hawkins (2019, p. 164); they describe the Haby Crossing Fault as a “lateral barrier to groundwater flow between the Edwards aquifer recharge zone [Edwards aquifer on fig. 1] and the confined portion of the Edwards aquifer.”

Summary

The karstic Edwards and Trinity aquifers are classified as major sources of water in south-central Texas by the Texas Water Development Board. During 2023–24, the U.S. Geological Survey, in cooperation with the Edwards Aquifer Authority, revised a previous publication of the geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers that was completed during 2018–20 within northern Medina County, Tex. The purpose of this report is to present the updated geologic framework and hydrostratigraphy of the rocks containing the Edwards and Trinity aquifers in northern Medina County from field observations of the surficial expressions of the rocks. The thicknesses of the mapped members (formal and informal) and informal hydrostratigraphic units (HSUs) were estimated from field observations of the surficial expressions of the rocks. A detailed 1:24,000-scale hydrostratigraphic map of the surficial extent of the rocks that contain the Edwards and Trinity aquifers was created (on the basis of the field observations) and can be used to help assess possible areas of groundwater recharge and discharge in addition to groundwater flow paths. This study includes updates to the geology of the Kainer Formation (or its stratigraphic equivalent, the Fort Terrett Formation) with the addition of a burrowed unit between the basal nodular and dolomitic members. In addition, the hydrostratigraphy was updated with the addition of HSU IIA for the upper part of the Devils River Limestone and the Seco Pass HSU for the burrowed member of the Kainer (or Fort Terrett) Formation.

The Cretaceous age rocks (listed in ascending order) in the study area are part of the Trinity Group, Edwards Group and stratigraphically equivalent Devils River Limestone, Washita Group, Eagle Ford Group, Austin Group, and Taylor Group, with isolated areas where Late Cretaceous age igneous rocks have intruded. The groups and formations are composed primarily of relatively thick layers of clays, shales, and limestone. The limestones are composed of mudstone through grainstone, framestone and boundstone, dolomite, and argillaceous and evaporitic rocks. The igneous rocks are coarse-grained ultramafic in composition.

The principal structural feature in northern Medina County is the Balcones fault zone, which is the result of late Oligocene and early Miocene extensional faulting and fracturing resulting from the eastern part of the Edwards Plateau uplift. In the Balcones fault zone, most of the faults in the study area are high-angle to vertical, en echelon, normal faults that are predominantly downthrown to the southeast.

Hydrostratigraphically, the rocks exposed in the study area (listed in descending order from land surface) are igneous, the upper confining unit to the Edwards aquifer, the Edwards aquifer, the upper zone of the Trinity aquifer, and the upper part of the middle zone of the Trinity aquifer. Descriptions of the HSUs, thicknesses, hydrologic function, porosity types, and field identification are provided. Identification of the various HSUs and their observed porosity types may be helpful in identifying areas of recharge and discharge and also groundwater flow paths within and between the aquifers and HSUs. Streamflow losses may correspond to specific HSUs that contain porosity, such as interconnected moldic porosity or caves, and areas of solution-enhanced fractures or faults. Areas with little or no streamflow losses indicate that the underlying HSUs have less porosity. Springs and seeps are often associated with a more porous HSU containing water that overlies a less porous HSU.

Igneous rocks may form barriers to groundwater flow because porosity within the nearby limestone units is filled by low porosity secondary minerals, such as serpentine, which is caused by contact metamorphism of the limestone units and by the igneous material itself. From field observations in the study area and data from previous reports, it is unlikely that igneous intrusions play an appreciable role in modifying groundwater flow paths in northern Medina County.

The rocks that form the upper confining unit to the Edwards aquifer are (from top to bottom) the Taylor, Austin, Eagle Ford, and Washita Groups. Except for the Austin Group and parts of the Georgetown Formation of the Washita Group, the rocks that form the upper confining unit to the Edwards aquifer do not supply appreciable amounts of water to wells in the study area. The Austin Group is hydrologically connected to the underlying Edwards aquifer and in some places the Trinity aquifer, depending on the amount of displacement along faults. The Georgetown Formation of the Washita Group has been extensively described in the literature both as part of the Edwards aquifer and as part of the upper confining unit to the Edwards aquifer. This traditional manner of describing the Georgetown Formation of the Washita Group as both a confining unit and part of the Edwards aquifer is continued in this report. During field-mapping work, field observations indicated that earthen, unlined stock tanks are commonly built directly on the outcrop of the Georgetown Formation, which is consistent with the premise that the unit is generally confining.

In the study area, the Edwards aquifer is contained in the rocks composing the Edwards Group and the Devils River Limestone, and the Trinity aquifer is contained in the rocks of the Trinity Group. The karstic carbonate Edwards and Trinity aquifers developed because of their original depositional history, primary and secondary porosity, diagenesis, fracturing, and faulting. These factors have resulted in development of modified porosity, permeability, and transmissivity within and between the aquifers. The parts of the Edwards aquifer contained in the Georgetown Formation of the Washita Group and in the Person and Kainer (or Fort Terrett) Formations of the Edwards Group were subdivided informally into HSUs I–VII, Seco Pass, and VIII. The authors of this report identified the upper part of the Devils River Limestone as HSU IIA and HSU IV. HSU IIA is undivided and is laterally transitional from HSUs II and III of the upper part of the Person Formation. HSU IV of the Devils River Limestone is laterally equivalent to HSU IV of the Person Formation. The lower part of the Devils River Limestone has similar hydrologic characteristics to the lower part of the Edwards aquifer of the Edwards Group and has been designated as HSUs V, VI, VII, Seco Pass, and VIII on the basis of laterally equivalent stratigraphy.

Previous research subdivided the Trinity aquifer into upper, middle, and lower zones. In the study area only the upper zone and the upper part of the middle zone of the Trinity aquifer are exposed at the land surface. From field observations, the authors suggest that beds of argillaceous limestone in the upper and middle zones of the Trinity aquifer slow the movement of groundwater, probably because of the varying grain sizes that form the beds. The argillaceous beds likely function as zones of groundwater retention, with water stored in the argillaceous beds being slowly released into fractures in adjacent limestone beds, bedding planes, and caves. The groundwater would then slowly make its way to larger conduits that either discharge in springs or wells or migrate into the juxtaposed and adjacent Edwards aquifer. In addition, the argillaceous beds may retain substantial quantities of water in the vadose zone.

The five informal HSUs composing the upper zone of the Trinity aquifer are as follows (top to bottom): cavernous, Camp Bullis, upper evaporite, fossiliferous, and lower evaporite. The five HSUs of the middle zone of the Trinity aquifer exposed at the land surface are (top to bottom) the Bulverde, Little Blanco, Twin Sisters, Doeppenschmidt, and Rust.

Groundwater recharge and flow paths in the study area are affected not only by the hydrostratigraphic characteristics of the individual HSUs but also by faults, fractures, and geologic structure. Faulting and the resulting structures common in fault zones may increase the potential of controlling or altering local groundwater flow by juxtaposing permeable and less permeable lithologies against one another.

References Cited

Adkins, W.C., 1932, The Mesozoic system in Texas, *in* Sellards, E.H., Adkins, W.C., and Plummer, F.B., eds., The geology of Texas: Austin, Tex., University of Texas, Publication 3252, p. 329–518, accessed January 20, 2023, at https://store.beg.utexas.edu/ut-bulletins/3371-bl3232.html.

Arnow, T., 1959, Ground-water geology of Bexar County, Texas: Texas Board of Water Engineers Bulletin 5911, 62 p., accessed December 8, 2022, at https://www.twdb.texas.gov/publications/reports/bulletins/doc/Bull.htm/B5911.asp.

Arnow, T., 1963, Ground-water geology of Bexar County, Texas: U.S. Geological Survey Water-Supply Paper 1588, 36 p., 12 pls., accessed August 1, 2023, at https://doi.org/10.3133/wsp1588.

Ashworth, J.B., 1983, Ground-water availability of the Lower Cretaceous formations in the Hill Country of south-central Texas: Texas Department of Water Resources Report 273, 172 p., accessed December 6, 2022, at https://www.twdb.texas.gov/publications/reports/numbered_reports/doc/R273/Rpt273.pdf.

Banta, J.R., and Clark, A.K., 2012, Groundwater levels and water-quality observations pertaining to the Austin Group, Bexar County, Texas, 2009–11: U.S. Geological Survey Scientific Investigations Report 2012–5278, 18 p., 2 apps., accessed August 1, 2023, at https://doi.org/10.3133/sir20125278.

Barker, R.A., and Ardis, A.F., 1996, Hydrogeological framework of the Edwards-Trinity aquifer system, west-central Texas: U.S. Geological Survey Professional Paper 1421–B, 61 p., accessed December 6, 2022, at https://doi.org/10.3133/pp1421B.

Barnes, V.E., 1974, Geologic atlas of Texas, San Antonio sheet: Austin, University of Texas, Bureau of Economic Geology, scale 1:250,000, accessed December 12, 2022, at https://store.beg.utexas.edu/geologic-atlas-of-texas/2106-ga0029.html.

Blome, C.D., and Clark, A.K., 2014, Key subsurface data help to refine Trinity aquifer hydrostratigraphic units, south-central Texas: U.S. Geological Survey Data Series 768, 1 sheet, accessed December 12, 2022, at https://doi.org/10.3133/ds768.

Blome, C.D., Faith, J.R., Pedraza, D.E., Ozuna, G.B., Cole, J.C., Clark, A.K., Small, T.A., and Morris, R.R., comps., 2005, Geologic map of the Edwards aquifer recharge zone, south-central Texas: U.S. Geological Survey Scientific Investigations Map 2873, 1 sheet, scale 1:200,000, accessed October 26, 2023, at https://doi.org/10.3133/sim2873.

Choquette, P.W., and Pray, L.C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: American Association of Petroleum Geologists Bulletin, v. 54, no. 2, p. 207–250, accessed December 6, 2022, at https://archives.datapages.com/data/bulletns/1968-70/data/pg/0054/0002/0200/0207.htm.

Clark, A.K., 2003, Geologic framework and hydrogeologic features of the Glen Rose Limestone, Camp Bullis Training Site, Bexar County, Texas: U.S. Geological Survey Water-Resources Investigations Report 03–4081, 9 p., 1 pl., scale 1:24,000, accessed December 12, 2022, at https://doi.org/10.3133/wri034081.

Clark, A.K., 2004, Geologic framework and hydrogeologic characteristics of the Glen Rose Limestone, Camp Stanley Storage Activity, Bexar County, Texas: U.S. Geological Survey Scientific Investigations Map 2831, 1 sheet, scale 1:24,000, accessed May 6, 2022, at https://doi.org/10.3133/sim2831.

Clark, A.K., Blome, C.D., and Morris, R.R., 2014, Geology and hydrostratigraphy of Guadalupe River State Park and Honey Creek State Natural Area, Kendall and Comal Counties, Texas: U.S. Geological Survey Scientific Investigations Map 3303, 1 sheet, scale 1:24,000, 8-p. pamphlet, accessed December 12, 2022, at https://doi.org/10.3133/sim3303.

Clark, A.K., Faith, J.R., Blome, C.D., and Pedraza, D.E., 2006, Geologic map of the Edwards aquifer in northern Medina and northeastern Uvalde Counties, south-central Texas: U.S. Geological Survey Open-File Report 2006–1372, 23 p., 1 pl., accessed October 26, 2023, at https://doi.org/10.3133/ofr20061372.

Clark, A.K., Golab, J.A., and Morris, R.R., 2016, Geologic and hydrostratigraphic map of the Blanco, Payton, and Rough Hollow 7.5-minute quadrangles, Blanco, Comal, Hays, and Kendall Counties, Texas: U.S. Geological Survey Scientific Investigations Map 3363, 1 sheet, scale 1:24,000, 21-p. pamphlet, accessed December 6, 2022, at https://doi.org/10.3133/sim3363.

Clark, A.K., Golab, J.A., Morris, R.R., and Pedraza, D.E., 2023, Geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within northern Bexar and Comal Counties, Texas: U.S. Geological Survey Scientific Investigations Map 3510, 1 sheet, scale 1:24,000, 24-p. pamphlet, accessed December 11, 2023, at https://doi.org/10.3133/sim3510.

Clark, A.K., and Journey, C.A., 2006, Flow paths in the Edwards aquifer, northern Medina and northeastern Uvalde Counties, Texas, based on hydrologic identification and geochemical characterization and simulation: U.S. Geological Survey Scientific Investigations Report 2006–5200, 48 p., accessed December 12, 2022, at https://doi.org/10.3133/sir20065200.

Clark, A.K., and Morris, R.R., 2015, Geologic and hydrostratigraphic map of the Anhalt, Fischer, and Spring Branch 7.5-minute quadrangles, Blanco, Comal, and Kendall Counties, Texas: U.S. Geological Survey Scientific Investigations Map 3333, 1 sheet, scale 1:50,000, 13-p. pamphlet, accessed August 1, 2023, at https://doi.org/10.3133/sim3333.

Clark, A.K., Morris, R.R., and Lamberts, A.P., 2024, Geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within parts of Bandera and Kendall Counties, Texas: U.S. Geological Survey Scientific Investigations Map 3518, 1 sheet, scale 1:24,000, 11-p. pamphlet, accessed July 18, 2024, at https://doi.org/10.3133/sim3518.

Clark, A.K., Morris, R.R., and Pedraza, D.E., 2020, Geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within northern Medina County, Texas: U.S. Geological Survey Scientific Investigations Map 3461, 1 sheet, scale 1:24,000, 13-p. pamphlet, accessed July 31, 2023, at https://doi.org/10.3133/sim3461.

Clark, A.K., Pedraza, D.E., and Morris, R.R., 2013, Geologic framework, structure, and hydrogeologic characteristics of the Knippa Gap area in eastern Uvalde and western Medina Counties, Texas: U.S. Geological Survey Scientific Investigations Report 2013–5149, 35 p., 1 pl., accessed August 1, 2023, at https://doi.org/10.3133/sir20135149.

Clark, A.K., Pedraza, D.E., and Morris, R.R., 2018, Geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within Hays County, Texas: U.S. Geological Survey Scientific Investigations Map 3418, 1 sheet, scale 1:24,000, 11-p. pamphlet, accessed January 20, 2023, at https://doi.org/10.3133/sim3418.

Clark, A.K., and Small, T.A., 1997, Geologic framework of the Edwards aquifer and upper confining unit, and hydrogeologic characteristics of the Edwards aquifer, south-central Uvalde County, Texas: U.S. Geological Survey Water-Resources Investigations Report 97–4094, 11 p., 1 pl., scale 1:24,000, accessed January 20, 2023, at https://doi.org/10.3133/wri974094.

Clark, A.R., Blome, C.D., and Faith, J.R., 2009, Map showing the geology and hydrostratigraphy of the Edwards aquifer catchment area, northern Bexar County, south-central Texas: U.S. Geological Survey Open-File Report 2009–1008, 24 p., 1 pl., scale 1:50,000, accessed December 12, 2022, at https://doi.org/10.3133/ofr20091008.

Collins, E.W., 1995, Structural framework of the Edwards aquifer, Balcones fault zone, central Texas: Transactions—Gulf Coast Association of Geological Societies, v. 45, p. 135–142, accessed August 1, 2023, at https://archives.datapages.com/data/gcags/data/045/045001/0135.htm.

Collins, E.W., 1999, Geologic map of the Comanche Waterhole quadrangle, Texas: Austin, University of Texas, Bureau of Economic Geology, Open-File Map STATEMAP Study Area 4, 1 sheet, scale 1:24,000, accessed November 13, 2023, at https://ngmdb.usgs.gov/Prodesc/proddesc_70128.htm.

Douglass, R.C., 1960, The foraminiferal genus *Orbitolina* in North America: U.S. Geological Survey Professional Paper 333, 52 p., 14 pls., accessed July 25, 2018, at https://doi.org/10.3133/pp333.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, *in* Classification of Carbonate Rocks Symposium: American Association of Petroleum Geologists Memoir 1, p. 108–121, accessed December 8, 2022, at https://pubs.geoscienceworld.org/books/book/1475/chapter-abstract/107178011/Classification-of-Carbonate-Rocks-According-to?redirectedFrom=PDF.

Ellisor, A.C., and Teagle, J., 1934, Correlation of Pecan Gap Chalk in Texas: American Association of Petroleum Geologists, v. 18, no. 11, p. 1506–1536, accessed January 20, 2023, at https://doi.org/10.1306/3D932C86-16B1-11D7-8645000102C1865D.

Esri, 2020, ArcGIS Desktop—Release 10.8.1: Redlands, Calif., Esri, accessed January 20, 2023, at https://desktop.arcgis.com/en/arcmap/index.html.

Ewing, T.E., 2005a, Phanerozoic development of the Llano Uplift: South Texas Geological Society Bulletin, v. 45, no. 9, p. 15–25, accessed January 18, 2023, at https://www.academia.edu/71239211/Phanerozoic_Development_of_the_Llano_Uplift.

Ewing, T.E., 2005b, Structural mapping of the Edwards aquifer in eastern and central Uvalde County, Texas, using seismic, well and outcrop data—Public report on Uvalde County mapping: San Antonio, Tex., Frontera Exploration Consultants, 21 p., accessed August 1, 2023, at https://www.edwardsaquifer.org/wp-content/uploads/2019/05/2005_Ewing_2005StructuralMappingKnippaReport.pdf.

Ferrill, D.A., and Morris, A.P., 2008, Fault zone deformation controlled by carbonate mechanical stratigraphy, Balcones fault system, Texas: AAPG Bulletin, v. 92, no. 3, p. 359–380, accessed January 20, 2023, at https://doi.org/10.1306/10290707066.

Ferrill, D.A., Sims, D.W., Morris, A.P., Waiting, D.J., and Franklin, N.M., 2003, Structural controls on the Edwards aquifer/Trinity aquifer interface in the Camp Bullis quadrangle, Texas: Edwards Aquifer Authority and U.S. Army Corps of Engineers, prepared by Southwest Research Institute, San Antonio, Tex., [variously paged], accessed January 20, 2023, at https://www.edwardsaquifer.org/science_docs/structural-controls-on-the-edwards-aquifer-trinity-aquifer-interface-in-the-camp-bullis-quadrangle-texas/.

Fisher, W.L., and Rodda, P.U., 1969, Edwards Formation (Lower Cretaceous), Texas—Dolomitization in a carbonate platform system: American Association of Petroleum Geologists Bulletin, v. 53, no. 1, p. 55–72, accessed January 20, 2023, at https://doi.org/10.1306/5D25C593-16C1-11D7-8645000102C1865D.

Galloway, W.E., Ganey-Curry, P.F., Li, X., and Buffler, R.T., 2000, Cenozoic depositional history of the Gulf of Mexico Basin: American Association of Petroleum Geologists Bulletin, v. 84, p. 1743–1774, accessed January 20, 2023, at https://doi.org/10.1306/8626C37F-173B-11D7-8645000102C1865D.

Gary, M., Veni, G., Shade, B., and Gary, R., 2011, Spatial and temporal recharge variability related to groundwater interconnection of the Edwards and Trinity aquifers, Camp Bullis, Bexar and Comal Counties, Texas, p. 6–10 *in* Interconnection of the Trinity (Glen Rose) and Edwards aquifers along the Balcones fault zone and related topics—Karst Conservation Initiative Meeting, Austin, Tex., February 17, 2011, [Proceedings]: University of South Florida, 48 p., accessed December 8, 2022, at https://digitalcommons.usf.edu/cgi/viewcontent.cgi?article=1070&context=kip_talks.

Garza, S., 1962, Recharge, discharge, and changes in groundwater storage in the Edwards and associated limestones, San Antonio area, Texas—A progress report of studies, 1955–59: Texas Water Development Board Bulletin 6201, 42 p., accessed August 1, 2023, at http://www.twdb.texas.gov/publications/reports/bulletins/doc/B6201.pdf.

George, P.G., Mace, R.E., and Petrossian, R., 2011, Aquifers of Texas: Texas Water Development Board Report 380, 172 p., accessed August 1, 2023, at https://www.twdb.texas.gov/publications/reports/numbered_reports/doc/R380_AquifersofTexas.pdf?d=23236.398949342703.

George, W.O., 1952, Geology and ground-water resources of Comal County, Texas, *with sections on* Surface-water runoff by Breeding, S.D., and Chemical character of the water by Hastings, W.W.: U.S. Geological Survey Water Supply Paper 1138, 126 p., 3 pls., accessed December 12, 2022, at https://doi.org/10.3133/wsp1138.

Groschen, G.E., 1996, Hydrogeologic factors that affect the flow path of water in selected zones of the Edwards aquifer, San Antonio region, Texas: U.S. Geological Survey Water-Resources Investigations Report 96–4046, 73 p., accessed August 1, 2023, at https://doi.org/10.3133/wri964046.

Grunig, D., Young, K., Jordan, M.A., and Parker, D.L., 1977, Guidebook to the geology of Travis County: Austin, Tex., University of Texas, 143 p., accessed August 1, 2023, at https://repositories.lib.utexas.edu/bitstream/handle/2152/63760/Guidebook%20to%20the%20Geology%20of%20Travis%20County.pdf?sequence=2.

Hammond, W.W., Jr., 1984, Hydrogeology of the lower Glen Rose aquifer, south-central Texas: Austin, Tex., University of Texas, Ph.D. dissertation, 245 p.

Hanson, J.A., and Small, T.A., 1995, Geologic framework and hydrogeologic characteristics of the Edwards aquifer outcrop, Hays County, Texas: U.S. Geological Survey Water-Resources Investigations Report 95–4265, 10 p., accessed October 26, 2023, at https://doi.org/10.3133/wri954265.

Hazzard, R.T., 1939, Notes on the Comanche and pre-Comanche(?) Mesozoic formations of the Arkansas-Louisiana-Texas area and a suggested correlation with northern Mexico: Shreveport Geological Society, Guidebook no. 14, June 2–4, 1939, p. 155–189, accessed August 1, 2023, at https://ngmdb.usgs.gov/Prodesc/proddesc_101753.htm.

Hill, R.T., 1887, The topography and geology of the Cross Timbers and surrounding regions in northern Texas: American Journal of Science, 3d ser., v. 33, no. 196, p. 291–303, accessed September 6, 2024, at https://doi.org/10.2475/ajs.s3-33.196.291.

Hill, R.T., 1888, The Trinity formation of Arkansas, Indian Territory, and Texas: Science, v. 11, p. 21, accessed January 18, 2023, at https://www.science.org/doi/10.1126/science.ns-11.258.21.a.

Hill, R.T., 1891, The Comanche Series of the Texas-Arkansas region: Geological Society of America Bulletin, v. 2, no. 1, p. 503–528, accessed January 20, 2023, at https://pubs.geoscienceworld.org/gsa/gsabulletin/article-standard/2/1/503/2595/The-Comanche-Series-of-the-Texas-Arkansas-Region.

Hill, R.T., 1892, Geologic evolution of the non-mountainous topography of the Texas region—An introduction to the study of the Great Plains: The American Geologist, v. 10, no. 2, p. 105–115, accessed January 20, 2023, at https://books.google.com/books?id=5n62JqqoSSMC&pg=PA105&source=gbs_toc_r&cad=3#v=onepage&q&f=false.

Hill, R.T., 1900, Physical geography of the Texas region: U.S. Geological Survey Topographic Atlas of the United States, folio 3, accessed December 8, 2022, at https://repositories.lib.utexas.edu/handle/2152/78006.

Hill, R.T., and Vaughan, T.W., 1898, Geology of the Edwards Plateau and Rio Plain adjacent to Austin and San Antonio, Texas, with reference to the occurrence of underground waters, *in* Walcott, C.D., Eighteenth annual report of the United States Geological Survey to the Secretary of the Interior, 1896–1897—Part II—Papers chiefly of a theoretical nature: U.S. Geological Survey Annual Report 18, p. 193–321, accessed December 12, 2022, at https://doi.org/10.3133/ar18.

Holt, C.L.R., Jr., 1956, Geology and ground-water resources of Medina County, Texas: Texas Board of Water Engineers, Bulletin 5601, 220 p., accessed August 1, 2023, at https://www.twdb.texas.gov/publications/reports/bulletins/doc/bull.htm/B5601.asp.

Holt, C.L.R., Jr., 1959, Geology and ground-water resources of Medina County, Texas: U.S. Geological Survey Water-Supply Paper 1422, 220 p., accessed August 1, 2023, at https://doi.org/10.3133/wsp1422.

Hovorka, S.D., Dutton, A.R., Ruppel, S.C., and Yeh, J.S., 1996, Edwards aquifer ground-water resources—Geologic controls on porosity development in platform carbonates, south Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations no. 238, 75 p., accessed December 7, 2022, at https://store.beg.utexas.edu/reports-of-investigations/1201-ri0238.html.

Hunt, B.B., Andrews, A.G., and Smith, B.A., 2016, Hydraulic conductivity testing in the Edwards and Trinity aquifers using multiport monitor well systems, Hays County, central Texas: Barton Springs/Edwards Aquifer Conservation District, Report of Investigations 2016–0831, 39 p., accessed August 1, 2023, at https://www.researchgate.net/publication/308452367_Hydraulic_Conductivity_Testing_in_the_Edwards_and_Trinity_Aquifers_Using_Multiport_Monitor_Well_Systems_Hays_County_Central_Texas.

Hunt, B.B., Smith, B.A., Andrews, A., Wierman, D.A., Broun, A.S., and Gary, M.O., 2015, Relay ramp structures and their influence on groundwater flow in the Edwards and Trinity aquifers, Hays and Travis Counties, central Texas: National Cave and Karst Institute, Symposium 4, 14th Sinkhole Conference, 12 p., accessed August 1, 2023, at https://www.researchgate.net/publication/281558159_Relay_Ramp_Structures_and_Their_Influence_on_Groundwater_Flow_in_the_Edwards_and_Trinity_Aquifers_Hays_and_Travis_Counties_Central_Texas.

Inden, R.F., 1974, Lithofacies and depositional model for a Trinity Cretaceous sequence, central Texas, *in* Perkins, B.F., and Amsbury, D.L., eds., Aspects of Trinity geology: Geoscience and Man, v. 8, p. 37–52, accessed January 20, 2023, at https://catalog.princeton.edu/catalog/9916194553506421.

Johnson, S., Esquilin, R., Mahula, D., Thompson, E., Mireles, J., Gloyd, R., Sterzenback, J., Hoyt, J., and Schindel, G., 2002, Hydrogeologic data report for 2001: Edwards Aquifer Authority, 134 p., accessed January 20, 2023, at https://www.edwardsaquifer.org/science_docs/edwards-aquifer-authority-hydrogeologic-report-for-2001/.

Johnson, S., Schindel, G., and Veni, G., 2010, Tracing groundwater flowpaths in the Edwards aquifer recharge zone, Panther Springs Creek Basin, northern Bexar County, Texas: Edwards Aquifer Authority Report 10–01, May 2010, 112 p., accessed December 12, 2022, at https://www.edwardsaquifer.org/wp-content/uploads/2019/02/2010_Johnson-etal_PantherSpringsFlowpaths.pdf.

Kuniansky, E.L., and Ardis, A.F., 2004, Hydrogeology and ground-water flow in the Edwards-Trinity aquifer system, west-central Texas—Regional aquifer-system analysis—Edwards-Trinity: U.S. Geological Survey Professional Paper 1421–C, 78 p., accessed December 12, 2022, at https://doi.org/10.3133/pp1421C.

Lamberts, A.P., Clark, A.K., and Morris, R.R., 2024, Geospatial dataset for the geologic framework and hydrostratigraphy of the Edwards and Trinity aquifers within northern Medina County, Texas, at 1:24,000: U.S. Geological Survey data release, https://doi.org/10.5066/P9G6G8GT.

Land, L.F., and Dorsey, M.E., 1988, Reassessment of the Georgetown Limestone as a hydrogeologic unit of the Edwards aquifer, Georgetown area, Texas: U.S. Geological Survey Water-Resources Investigations Report 88–4090, 54 p., accessed October 26, 2023, at https://doi.org/10.3133/wri884190.

Liddle, R.A., 1918, The geology and mineral resources of Medina County: Austin, Tex., University of Texas, Bureau of Economic Geology and Technology, University of Texas Bulletin No. 1860, October 25, 1918, p. 106–111, accessed August 1, 2023, at https://books.google.com/books?id=kAhHAQAAMAAJ&pg=PA176&lpg=PA176&dq=austin+chalk+springs+medina+county+texas&source=bl&o.

Lindgren, R.J., Houston, N.A., Musgrove, M., Fahlquist, L.S., and Kauffman, L.J., 2011, Simulations of groundwater flow and particle-tracking analysis in the zone of contribution to a public-supply well in San Antonio, Texas: U.S. Geological Survey Scientific Investigations Report 2011–5149, 93 p., accessed December 12, 2022, at https://doi.org/10.3133/sir20115149.

Livingston, P., Sayre, A.N., and White, W.N., 1936, Water resources of the Edwards limestone in the San Antonio area, Texas: U.S. Geological Survey Water-Supply Paper 773–B, 113 p., accessed January 20, 2023, at https://doi.org/10.3133/wsp773B.

Lozo, F.E., and Smith, C.I., 1964, Revision of Comanche Cretaceous stratigraphic nomenclature, southern Edwards Plateau, southwest Texas: Transactions—Gulf Coast Association of Geological Societies, v. 14, p. 285–306, accessed January 20, 2023, at https://www.semanticscholar.org/paper/Revision-of-Comanche-Cretaceous-Stratigraphic-Texas-Lozo-Smith/062768955b40d4fb7e823f1b05bdeedabf3f7ad2.

Lozo, F.E., and Stricklin, F.L., Jr., 1956, Stratigraphic notes on the outcrop basal Cretaceous, central Texas: Transactions—Gulf Coast Association of Geological Societies, v. 6, p. 67–78, accessed December 4, 2022, at https://archives.datapages.com/data/gcags/data/006/006001/pdfs/0067.pdf.

Maclay, R.W., 1995, Geology and hydrology of the Edwards aquifer in the San Antonio area, Texas: U.S. Geological Survey Water-Resources Investigations Report 95–4186, 69 p., 12 sheets, accessed January 20, 2023, at https://doi.org/10.3133/wri954186.

Maclay, R.W., and Small, T.A., 1976, Progress report on geology of the Edwards aquifer, San Antonio area, Texas, and preliminary interpretation of borehole geophysical and laboratory data on carbonate rocks: U.S. Geological Survey Open-File Report 76–627, 65 p., accessed December 12, 2022, at https://doi.org/10.3133/ofr76627.

Maclay, R.W., and Small, T.A., 1983, Hydrostratigraphic subdivisions and fault barriers of the Edwards aquifer, south-central Texas: Journal of Hydrology, v. 61, nos. 1–3, p. 127–146, accessed December 4, 2022, at https://www.sciencedirect.com/science/article/pii/0022169483902391.

Maclay, R.W., and Small, T.A., 1986, Carbonate geology and hydrology of the Edwards aquifer in the San Antonio area, Texas: Texas Water Development Board Report 296, 90 p., accessed November 15, 2022, at https://www.twdb.texas.gov/publications/reports/numbered_reports/index.asp.

Miggins, D.P., Blome, C.D., and Smith, D.V., 2004, Preliminary $^{40}Ar/^{39}Ar$ geochronology of igneous intrusions from Uvalde County, Texas—Defining a more precise eruption history for the southern Balcones volcanic province: U.S. Geological Survey Open-File Report 2004–1031, 27 p., accessed October 27, 2023, at https://doi.org/10.3133/ofr20041031.

Moore, D.W., 2010, Geologic map of the Edwards aquifer and related rocks in northeastern Kinney and southernmost Edwards Counties, south-central Texas: U.S. Geological Survey Scientific Investigations Map 3105, 1 sheet, scale 1:50,000, 18-p. pamphlet, accessed November 13, 2023, at https://doi.org/10.3133/sim3105.

Pantea, M.P., Blome, C.D., and Clark, A.K., 2014, Three-dimensional model of the hydrostratigraphy and structure of the area in and around the U.S. Army–Camp Stanley Storage Activity Area, northern Bexar County, Texas: U.S. Geological Survey Scientific Investigations Report 2014–5074, 13 p., accessed May 6, 2022, at https://pubs.usgs.gov/sir/2014/5074/.

Perkins, B.F., 1974, Paleoecology of a rudist reef complex in the Comanche Cretaceous, Glen Rose Limestone, central Texas, *in* Perkins, B.F., ed., Aspects of Trinity division geology—A symposium: Baton Rouge, La., Louisiana State University, Geoscience and Man, v. 8, p. 131–173, accessed January 20, 2023, at https://catalog.princeton.edu/catalog/9916194553506421.

Petitt, B.M., Jr., and George, W.O., 1956, Ground-water resources of the San Antonio area, Texas—A progress report of current studies: Texas Board of Water Engineers Bulletin 5608, v. 1, 80 p., accessed August 1, 2023, at http://www.twdb.texas.gov/publications/reports/bulletins/doc/B5608_V1.pdf.

Roemer, F., 1852, Die Kreidebildungen von Texas und ihre organischen Einschlüsse [The Cretaceous formations of Texas and their organic inclusions]: Bonn, Germany, Adolph Marcus Publishing, 100 p., 11 pls., accessed January 20, 2023, at https://doi.org/10.5962/bhl.title.15015. [In German.]

Rose, P.R., 1972, Edwards Group, surface, and subsurface, central Texas: Austin, Tex., University of Texas, Bureau of Economic Geology Report of Investigations 74, 198 p., accessed December 8, 2022, at https://doi.org/10.23867/RI0074D.

Rose, P.R., 2016, Late Cretaceous and Tertiary burial history, central Texas: Gulf Coast Association of Geological Societies Journal, v. 5, p. 141–179, accessed December 12, 2022, at http://www.gcags.org/Journal/2016.GCAGS.Journal/2016.GCAGS.Journal.v5.09.p141-179.Rose.pdf.

Rose, P.R., 2017, Regional stratigraphy of the Edwards Group and associated formations of Texas (lower Cretaceous, Comanchean)—In defense of the classic view: Gulf Coast Association of Geological Societies Journal, v. 6, p. 111–134, accessed December 12, 2022, at http://www.gcags.org/Journal/2017.GCAGS.Journal/2017.GCAGS.Journal.v6.08.p111-134.Rose.pdf.

Ross, C.P., 1943, Geology and ore deposits of the Shafter mining district, Presidio County, Texas, chap. B *of* Contributions to economic geology, 1941–42: Washington, D.C., U.S. Government Printing Office, U.S. Geological Survey Bulletin 928, p. 45–125, accessed December 12, 2022, at https://doi.org/10.3133/b928B.

Saribudak, M., and Hawkins, A., 2019, Hydrogeophysical characterization of the Haby Crossing Fault, San Antonio, Texas, USA: Journal of Applied Geophysics, v. 162, p. 164–173, accessed August 1, 2023, at https://doi.org/10.1016/j.jappgeo.2019.01.009.

Shumard, B.F., 1860, Observations upon the Cretaceous strata of Texas: Academy of Science of St. Louis Transactions, v. 1, p. 583–590, accessed January 20, 2023, at https://ngmdb.usgs.gov/Prodesc/proddesc_87756.htm.

Small, T.A., and Clark, A.K., 2000, Geologic framework and hydrogeologic characteristics of the Edwards aquifer outcrop, Medina County, Texas: U.S. Geological Survey Water-Resources Investigations Report 2000–4195, 15 p., accessed December 12, 2022, at https://doi.org/10.3133/wri004195.

Smith, D.V., McDougal, R.R., Smith, B.D., and Blome, C.D., 2008, Distribution of igneous rocks in Medina and Uvalde Counties, Texas, as inferred from aeromagnetic data: U.S. Geological Survey Scientific Investigations Report 2007–5191, 12 p., 1 pl., scale 1:250,000, accessed August 1, 2023, at https://doi.org/10.3133/sir20075191.

Stein, W.G., and Ozuna, G.B., 1995, Geologic framework and hydrogeologic characteristics of the Edwards aquifer recharge zone, Bexar County, Texas: U.S. Geological Survey Water-Resources Investigations Report 95–4030, 8 p., accessed December 8, 2022, at https://doi.org/10.3133/wri954030.

Stenzel, H.B., 1938, The geology of Leon County, Texas: Austin, Tex., The University of Texas, Bureau of Economic Geology, no. 3818, 295 p., accessed January 20, 2023, at http://dx.doi.org/10.26153/tsw/7446.

Stricklin, F.L., Jr., Smith, C.I., and Lozo, F.E., 1971, Stratigraphy of Lower Cretaceous Trinity deposits of central Texas: Austin, Tex., University of Texas at Austin, Bureau of Economic Geology Report of Investigations 71, 63 p., accessed December 8, 2022, at https://store.beg.utexas.edu/reports-of-investigations/1819-ri0071.html.

Trudgill, B.D., 2002, Structural controls on drainage development in the Canyonlands grabens of southeast Utah, USA, *in* Underhill, J.R., and Trudgill, B.D., eds., The structure and stratigraphy of rift systems: American Association of Petroleum Geologists Bulletin Special Issue, v. 86, no. 6, p. 1095–1112, accessed December 6, 2022, at https://www.researchgate.net/publication/279604140_Structural_controls_on_drainage_development_in_the_Canyonlands_Grabens_of_Southeast_Utah.

Udden, J.A., 1907, Report on a geological survey of the lands belonging to the New York and Texas Land Company, Ltd., in the Upper Rio Grande embayment in Texas: Rock Island, Ill., Augustana Library Publications, no. 6, p. 51–107, accessed January 20, 2023, at https://babel.hathitrust.org/cgi/pt?id=uiug.30112027202057&view=1up&seq=8.

U.S. Geological Survey, 2023, National Geologic Map Database, Geolex search: U.S. Geological Survey online database, accessed October 26, 2023, at https://ngmdb.usgs.gov/Geolex/search.

Vaughan, T.W., 1900a, Uvalde folio, Texas: Washington, D.C., U.S. Geological Survey Geologic Atlas of the United States Folio GF–64, 7 p., 3 pls., accessed January 20, 2023, at https://hdl.handle.net/1969.1/2825.

Vaughan, T.W., 1900b, Reconnaissance in the Rio Grande coal fields of Texas: Washington, D.C., U.S. Geological Survey Bulletin 164, 95 p., 11 pls., accessed January 20, 2023, at https://doi.org/10.3133/b164.

Veni, G., 1987, Fracture permeability—Implications on cave and sinkhole development and their environmental assessments, *in* Beck, B.F., and Wilson, W.L., eds., Karst hydrogeology—Engineering and environmental applications: Boston, A.A. Balkema, p. 101–105, accessed January 18, 2023, at https://openlibrary.org/books/OL9108212M/Karst_hydrogeology_Engineering_and_environmental_applications.

Veni, G., 1988, The caves of Bexar County (2d ed.): Austin, Tex., Texas Memorial Museum, University of Texas at Austin, Speleological Monographs, v. 2, 300 p., accessed December 6, 2022, at https://www.texasspeleologicalsurvey.org/PDF/TNSC_Pubs/Veni-Bexar-PublicR.pdf.

Veni, G., 1994, Geomorphology, hydrology, geochemistry, and evolution of the karstic Lower Glen Rose aquifer, south-central Texas: Pennsylvania State University, Ph.D. dissertation, 712 p., accessed December 8, 2022, at https://www.texasspeleologicalsurvey.org/publications/TSS_Monographs.php.

Weeks, A.W., 1945a, Oakville, Cuero, and Goliad Formations of Texas Coastal Plain between Brazos River and Rio Grande: American Association of Petroleum Geologists Bulletin, v. 29, p. 1721–1732, accessed January 18, 2023, at https://pubs.geoscienceworld.org/aapgbull/article/29/12/1721/547006/Oakville-Cuero-and-Goliad-Formations-of-Texas.

Weeks, A.W., 1945b, Balcones, Luling, and Mexia fault zones in Texas: American Association of Petroleum Geologists Bulletin, v. 29, p. 1733–1737, accessed December 8, 2022, at https://pubs.geoscienceworld.org/aapgbull/article/29/12/1733/547004/Balcones-Luling-and-Mexia-Fault-Zones-in-Texas1.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, no. 5, p. 377–392, accessed September 6, 2024, at https://www.journals.uchicago.edu/doi/10.1086/622910.

Wilmarth, M.G., 1938, Lexicon of geologic names of the United States (including Alaska): U.S. Geological Survey Bulletin 896, pts. 1–2, 2,396 p., accessed January 20, 2023, at https://doi.org/10.3133/b896.

Wright, V.P., 1992, A revised classification of limestones: Sedimentary Geology, v. 76, nos. 3–4, p. 177–185, accessed August 1, 2023, at https://doi.org/10.1016/0037-0738(92)90082-3.

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