In cooperation with the Bexar-Medina-Atascosa Counties Water Control and Improvement District No. 1

Geologic Framework and Hydrogeologic Characteristics of the Outcrops of the Edwards and Trinity Aquifers, Medina Lake Area, Texas

Water-Resources Investigations Report 97–4290

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

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By Ted A. Small and Rebecca B. Lambert

U.S. GEOLOGICAL SURVEY

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Geologic Framework and Hydrogeologic Characteristics of the Outcrops of the Edwards and Trinity Aquifers, Medina Lake Area, Texas

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Abstract

The hydrogeologic subdivisions of the Edwards aquifer outcrop in the Medina Lake area in Medina and Bandera Counties generally are porous and permeable. The most porous and permeable appear to be hydrogeologic subdivision VI, the Kirschberg evaporite member of the Kainer Formation; and hydrogeologic subdivision III, the leached and collapsed members, undivided, of the Person Formation. The porosity of the rocks in the Edwards aquifer outcrop is related to depositional or diagenetic elements along specific stratigraphic horizons (fabric selective) and to dissolution and structural elements that can occur in any lithostratigraphic horizon (not fabric selective). Permeability depends on the physical properties of the rock such as size, shape, and distribution of pores.

The Edwards aquifer has relatively large porosity and permeability resulting, in part, from the development or redistribution of secondary porosity. Lithology, stratigraphy, diagenesis, and karstification account for the effective porosity and permeability in the Edwards aquifer outcrop. Karst features that can greatly enhance effective porosity and permeability in the Edwards aquifer outcrop include sinkholes, dolines, and caves.

Field observations in the Medina Lake area confirm the findings of previous investigators that Medina Lake mostly overlies rocks of the upper member of the Glen Rose Limestone. The channel downstream of Medina Dam to the upper end of Diversion Lake also overlies the upper member of the Glen Rose Limestone. Most of Diversion Lake overlies a thin section of the Edwards aquifer—hydrogeologic subdivision VIII (basal nodular member) and the basal part of hydrogeologic subdivision VII (dolomitic member). Hydrogeologic subdivisions VIII and VII might be hydraulically connected to Medina Lake at high lake stages.

The Trinity aquifer, which crops out in the northern part of the Medina Lake area and underlies the Edwards aquifer in the southern part, is much less permeable and productive than the Edwards aquifer. Where the Trinity aquifer underlies the Edwards, the Trinity acts as a lower confining unit on the Edwards.

INTRODUCTION

The Edwards aquifer in the Balcones fault zone is one of the most permeable and productive carbonate aquifers in the Nation. In addition to providing public water supply to more than 1 million people in south-central Texas, the Edwards aquifer provides large quantities of water to agriculture, industry, and major springs. The major springs support recreational activities and businesses, provide flow to downstream users, and provide habitat for several threatened or endangered species. The Edwards aquifer is extremely complex, with intensely faulted and fractured, karstic limestone outcrops that are recharged by local streams and precipitation.

The Trinity aquifer is much less permeable and productive than the Edwards aquifer. The mostly carbonate rocks of the Trinity aquifer supply water to scattered communities, ranches, and individuals throughout the primarily rural area north of the Balcones fault zone known locally as the Hill Country. The Trinity aquifer crops out in the northern part of the Medina Lake area and underlies the Edwards aquifer in the southern part of the Medina Lake area (pl. 1).

Medina and Diversion Lakes (fig. 1) are located on the Medina River in northeastern Medina and southeastern Bandera Counties. Medina Dam was constructed and completed in 1912 to create a reservoir to supplement existing irrigation supplies. The Medina River is impounded behind Medina Dam, and water from the dam is discharged through a canyon to a small impoundment (Diversion Lake), where part of the water then is diverted into the Medina irrigation canal (pl. 1).

Streams that originate from discharge of the Trinity aquifer in the topographically rugged Hill Country generally flow south, cross the Edwards aquifer outcrop (the recharge zone) in the Balcones fault zone (fig. 1), and lose much, if not all, of their flow to faults, fractures, sinkholes, and caves in the outcrop. After entering the aquifer, the water moves east through Medina County to points of discharge in Medina and Bexar Counties (mostly irrigation and municipal wells) and then northeast, parallel or almost parallel to the northeast-trending Balcones faults into Comal and Hays Counties, where it is discharged by wells and springs.

Recharge to the Edwards aquifer averaged 674,200 acre-feet (acre-ft) during 1934–95 (Brown and Patton, 1996). Recharge to the Edwards aquifer from the Medina Lake Basin ranged from 6,300 to 104,000 acre-ft, with an average of 61,300 acre-ft during 1934–95 (Brown and Patton, 1996). Seepage losses from Medina and Diversion Lakes are assumed to recharge the Edwards aquifer either directly, or indirectly through the Trinity aquifer.

The U.S. Geological Survey, in cooperation with the Bexar-Medina-Atascosa Counties Water Control and Improvement District No. 1, mapped the outcrops of the Edwards and Trinity aquifers and described their hydrogeologic characteristics (porosity and permeability) to document conditions pertinent to movement and contamination of ground water. This report describes the geologic framework and hydrogeologic characteristics of the outcrops of the Edwards and Trinity aquifers in the Medina Lake area in Medina and Bandera Counties. This information will help to provide a better understanding of the processes controlling the spatial distribution of recharge and the flow of water into the aquifers.

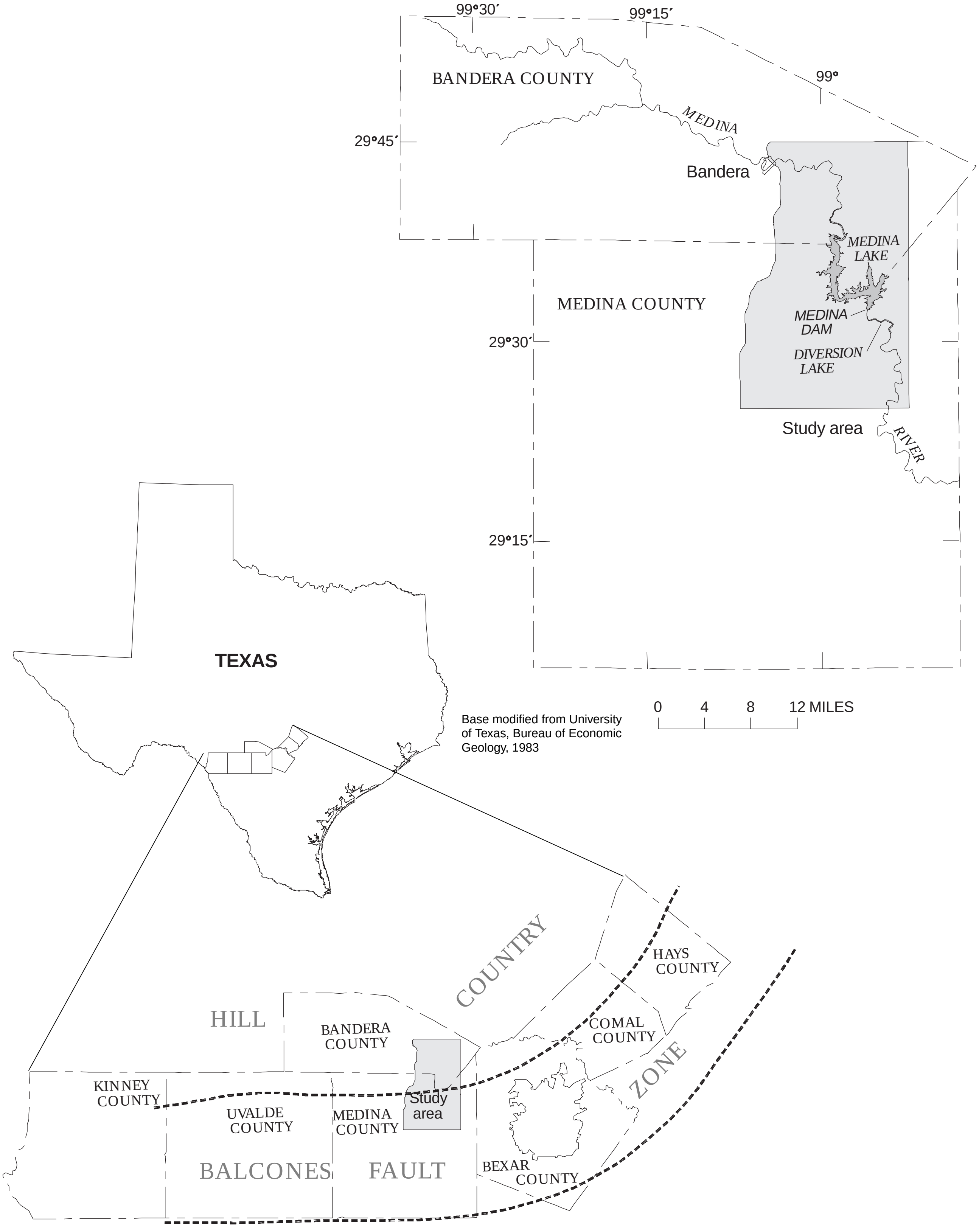
Methods of Investigation

The hydrogeologic subdivisions (table 1) of the Edwards aquifer modified from Maclay and Small (1976) and the stratigraphic nomenclature of Rose (1972) for the Edwards Group were used to map the Edwards aquifer outcrop in the Medina Lake area. The carbonate-rock classification system of Dunham (1962) was used for the lithologic descriptions. Distinct marker beds, such as the regional dense member of the Person Formation and the basal nodular member of the Kainer Formation (Edwards aquifer), the *Corbula martinae* bed at the top of the lower member of the Glen Rose Limestone (middle Trinity aquifer), and the evaporite beds in the upper member of the Glen Rose Limestone (upper Trinity aquifer), were used as stratigraphic identifiers where possible. The sedimentary carbonate classification system of Choquette and Pray (1970) was used to determine the porosity type. Member, hydrogeologic subdivision, and porosity/permeability type were determined at the outcrops (table 1). The hydrogeologic subdivisions of the outcrops of the Edwards and Trinity aquifers in the Medina Lake area are shown on plate 1.

Well logs and geologic map data were compiled and used in mapping the hydrogeologic subdivisions of the Edwards aquifer in the study area. The thicknesses of the hydrogeologic subdivisions that compose the Edwards aquifer were determined from well logs in and adjacent to the aquifer outcrop in Medina and Bandera Counties. The lower and upper members of the Lower Cretaceous Glen Rose Limestone that compose the outcrop of the Trinity aquifer were mapped adjacent to the Edwards aquifer outcrop. The Leona Formation, Uvalde Gravel, Escondido Formation, Anacacho Limestone, and Austin Group, undivided (the upper confining unit), are juxtaposed against the Edwards Group on the southeast side of the Haby Crossing fault (pl. 1), and were mapped along the southern boundary of the Edwards aquifer outcrop.

Caves and other karst features were located during mapping using information from Elliot and Veni (1994) and local property owners. Recent aerial photographs were used to locate rock exposures so that relatively fresh outcrop could be examined. Original land-surface topography of excavated quarries was interpolated from exposed outcrop and 7.5-minute topographic maps. Outcrops of the Edwards and Trinity aquifers also were interpolated throughout areas that are covered by a thin mantle of alluvial deposits.

Displacement on most faults in the study area often is difficult to determine. Fault traces commonly are obscured and difficult to identify in the field. Fault traces were postulated and estimated on the basis of abrupt lithologic or stratigraphic dissimilarities and at



Base modified from University of Texas, Bureau of Economic Geology, 1983

Figure 1. Location of the study area.

Table 1. Summary of the lithologic and hydrologic properties of the hydrogeologic subdivisions of the outcrops of the Edwards and Trinity aquifers, Medina Lake area, Texas

[Hydrogeologic subdivisions modified from Maclay and Small (1976); groups, formations, members, and thicknesses modified from Holt (1956), Stricklin and others (1971), Rose (1972), and Ashworth (1983); lithology modified from Dunham (1962); and porosity type modified from Choquette and Pray (1970). CU, confining unit; *, not exposed in the study area; AQ, aquifer]

Hydrogeologic subdivision			Group, formation, or member				Hydro-logic function	Thickness (feet)	Lithology	Field identification	Cavern development	Porosity/ permeability type
Upper Cretaceous	Upper confining unit		Leona Formation, Uvalde Gravel, Escondido Formation, Anacacho Limestone, and Austin Group, undivided				CU, except for Leona Formation and Uvalde Gravel	665–1,200	Argillaceous, light-gray to buff, fossiliferous limestone; chalky, marly, and hard limestone; clay, silt, and sandstone	Chert and limestone cobbles; clay, silt, sand, shale, and soft, marly limestone	Rare to none	Low to high porosity/low to high permeability
			Eagle Ford Group				CU	30–50	Brown, flaggy shale and argillaceous limestone	*	None	Low porosity/low permeability
			Buda Limestone				CU	40–50	Buff, light-gray, dense mudstone	*	None	Low porosity/low permeability
			Del Rio Clay				CU	40–50	Bluish-green to yellowish-brown clay	*	None	Low porosity/low permeability
Lower Cretaceous	I	Edwards aquifer	Georgetown Formation				Karst AQ; not karst CU	2–20	Reddish-brown, gray to light-tan, marly limestone	*	None	Low porosity/low permeability
	II		Devils River Formation	Edwards Group	Person Formation	Cyclic and marine members, undivided	AQ	0–10	Mudstone to packstone; *miliolid* grainstone; chert	*	Many subsurface; might be associated with earlier karst development	Laterally extensive; both fabric and not fabric/water-yielding
	III					Leached and collapsed members, undivided	AQ	70–90	Crystalline limestone; mudstone to grainstone; chert; collapsed breccia	Bioturbated iron-stained beds separated by massive limestone beds; stromatolitic limestone	Extensive lateral development; large rooms	Majority not fabric/one of the most porous and permeable
	IV					Regional dense member	CU	16–20	Dense, argillaceous mudstone	Wispy iron-oxide stains	Very few; only vertical fracture enlargement	Not fabric/low permeability; vertical barrier
	V				Kainer Formation	Grainstone member	AQ	50–60	*Miliolid* grainstone; mudstone to wackestone; chert	White crossbedded grainstone	Few caves	Not fabric/recrystallization reduces permeability
	VI					Kirschberg evaporite member	AQ	50–60	Highly altered crystalline limestone; chalky mudstone; chert	Boxwork voids, with neospar and travertine frame	Probably extensive cave development	Majority fabric/one of the most porous and permeable
	VII					Dolomitic member	AQ	110–140	Mudstone to grainstone; crystalline limestone; chert	Massively bedded, light gray; *Toucasia* abundant	Caves related to structure or bedding planes	Mostly not fabric; some bedding-plane fabric/water-yielding
	VIII					Basal nodular member	Karst AQ; not karst CU	50–60	Shaly, fossiliferous, nodular limestone; mudstone; *miliolid* grainstone	Massive, nodular, and mottled; abundant gastropods and *Exogyra texana*	Large lateral caves at surface; a few caves near Koenig Creek (see pl. 1)	Fabric; stratigraphically controlled/large conduit flow at surface; no permeability in subsurface
	Upper Trinity aquifer		Upper member of the Glen Rose Limestone				CU; evaporite beds AQ	350–500	Yellowish-tan, thinly bedded limestone and marl	Stair-step topography; alternating limestone and marl; *Orbitolina minuta*	Some surface cave development	Some water production at evaporite beds/relatively impermeable
	Middle Trinity aquifer		Lower member of the Glen Rose Limestone				AQ	300–320	Massive fossiliferous limestone; rudistid reefs and caves; few thin beds of marl and dolomitic limestone	Massive, reefal limestone; *Orbitolina texana* and *Corbula martinae*	Some cave development	Mostly fabric; small to moderate quantities of water from caves and reefs/low permeability

least one of the following: fault scarps, fault breccia, long linear travertine or sparry calcite deposits, or steeply dipping strata thought to represent fault-bend folds. Fault-bend folds are bedding deformations associated with fault-block movement (Suppe, 1985, p. 343). The strike of these features was measured with a compass to determine the orientation of the faults. The lengths of many of the faults were projected on the basis of lineaments visible on land surface or in aerial photographs. Faults were inferred based on the location of lineaments on photographs in areas where only slight stratigraphic dissimilarities were indicated, or where the faults extend beyond the mapped area.

Acknowledgments

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GEOLOGIC FRAMEWORK

General Features

Previous mapping done in the Medina Lake area identified the rock units to the group or formation levels only, separating the Edwards Group (Edwards aquifer) from the Glen Rose Limestone (Trinity aquifer). Sayre (1936) mapped the Edwards and Georgetown Limestones as a single unit. Sayre (1936) also mapped the Glen Rose Limestone in areas northwest and east of Medina Lake. William F. Guyton and Associates (1955) described the distribution of rocks of the Edwards and associated limestones (Edwards Group and Georgetown Formation), rocks older than the Edwards, and rocks younger than the Edwards but no additional detail of the stratigraphy or structure in the Medina Lake study area. Holt (1956) indicated that the distribution of the rocks, now known as the Edwards Group (Rose, 1972), is not as widespread as previously mapped. Core borings at Medina Dam showed that much of the channel of the spillway and the bed of the Medina River downstream from the dam are in the Glen Rose Limestone (U.S. Army Corps of Engineers, 1965). Rose (1972) indicated that the Glen Rose Limestone composes the greater part of the outcrop area and that the Edwards Group outcrops appear to be more discontinuous and dissected in the study area. Rocks of the Edwards Group form the caps and bluffs on the hills surrounding Medina and Diversion Lakes. Barnes and others (1992) showed that Medina Lake overlies the upper member of the Glen Rose Limestone and that the intervening canyon between the two dams, and Diversion Lake, overlie the upper member of the Glen Rose Limestone and the Edwards Limestone, undivided. Collins (1995) reported that (1) rocks beneath Medina Lake are mostly upper Glen Rose Limestone, (2) the floor of the canyon between Medina Dam and the upper end of Diversion Lake is upper Glen Rose Limestone, and (3) Diversion Lake is in the lower part of the Kainer Formation.

Holt (1956, p. 14) reported a regional dip of the rocks now known as the Edwards Group of about 15 to 20 feet per mile (ft/mi) to the southeast in Medina County. The approximate thicknesses of the rocks were reported by Rose (1972). The faults in northern Medina County are part of the Balcones fault zone (fig. 1). Although most of the faults in the area trend southwest to northeast, a few cross faults trend southeast to northwest. Generally, the faults are normal, with the downthrown blocks down to the southeast. Topographic relief is not visible at all of the faults, partly because the rocks on both sides of some faults have similar weathering characteristics, and possibly because the rate of movement is no faster than the rate of erosion.

Maclay and Small (1984, p. 33) define flow-barrier faults as faults that have vertical displacement greater than 50 percent of the total thickness of the aquifer, sufficient to juxtapose permeable layers against relatively less permeable layers. The thickness of the Edwards aquifer in Medina County is about 450 feet (ft). Therefore, faults in the study area with a vertical displacement of about 225 ft or greater were designated as flow-barrier faults. A series of faults extends from the southwestern part of the study area toward the northeast. Haby Crossing fault (pl. 1), with a vertical displacement of about 600 ft, probably is the only flow-barrier fault in the study area. Generalized hydrogeologic section *A–A′* (fig. 2) shows the relative positions of the rocks of the Edwards aquifer south of Medina Lake, and *B–B′* (fig. 3) shows that the Haby Crossing fault

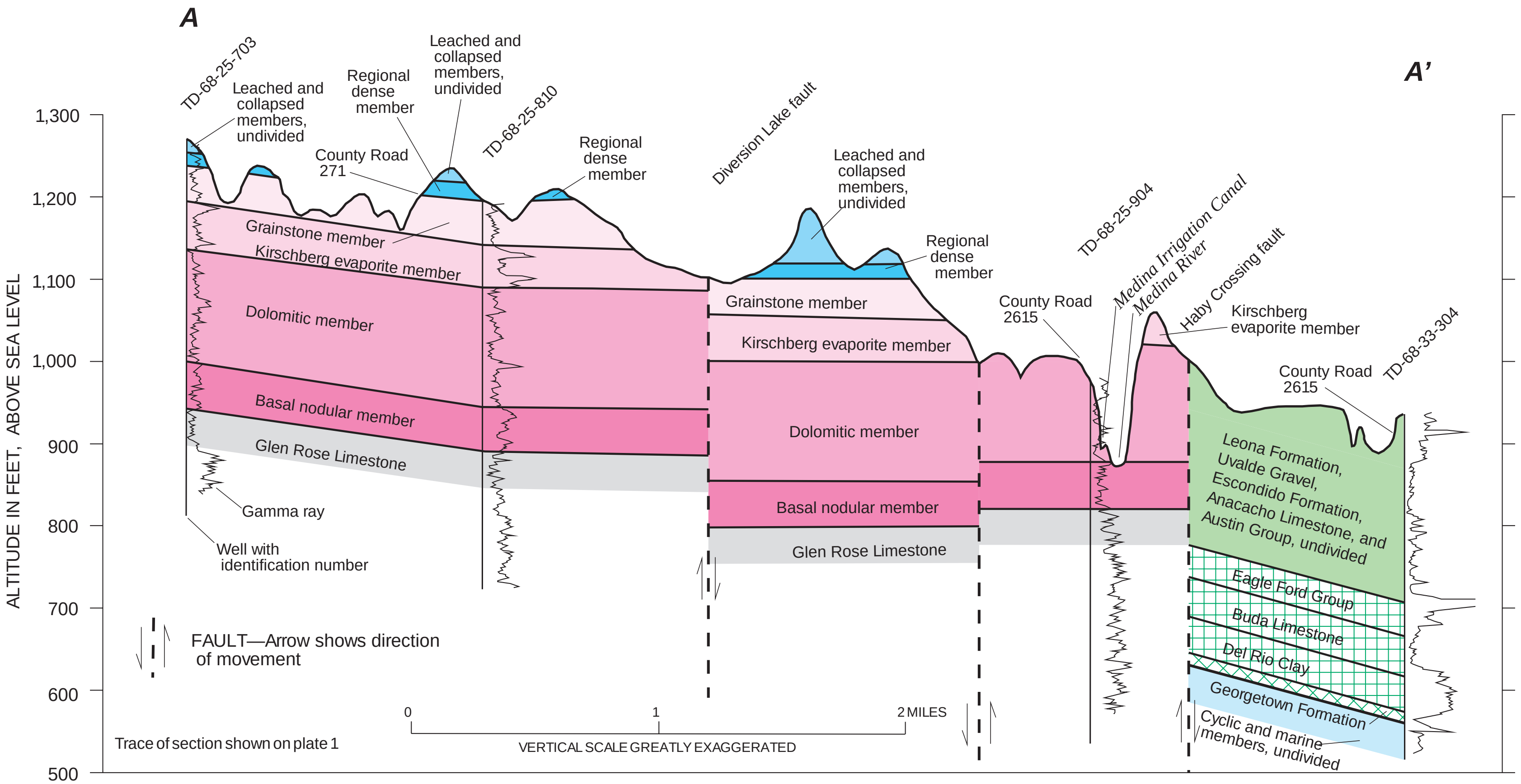

Figure 2. Generalized hydrogeologic section *A–A'* of the Edwards aquifer, Medina Lake area, Texas.

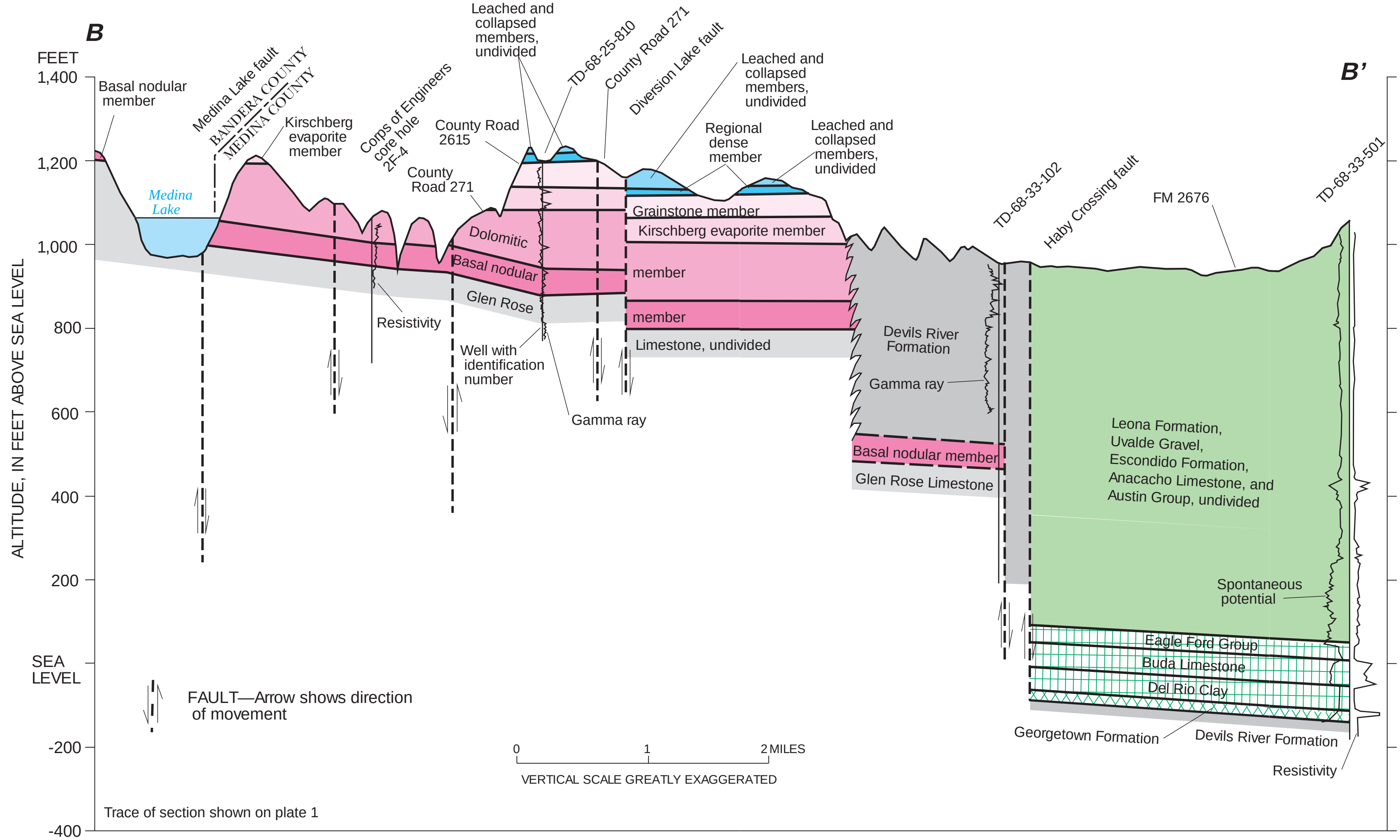

Figure 3. Generalized hydrogeologic section *B–B′* of the Edwards aquifer, Medina Lake area, Texas.

juxtaposes rocks of the Edwards aquifer against rocks of the upper confining unit.

Some of the faults in Medina and Bandera Counties are similar to those in Bexar County described by Arnow (1959, p. 20) and mark the trace of shatter zones, where the faults are not single, sharp breaks as shown by a single line placed on a map. Field observations of features associated with faults include linear sparry travertine (a clear to translucent secondarily precipitated calcite) deposits within many of the fault shatter zones, and caliche-like fault gouge, sometimes containing small boulders, as well as actual displacement of beds.

Stratigraphy

The Lower Cretaceous Glen Rose Limestone ranges in thickness from about 650 to 820 ft in the Medina Lake area in Medina and Bandera Counties (table 1). The Glen Rose Limestone is divided informally into lower and upper members (George, 1952). According to George (1952, p. 17), the division is made at the top of a well-known fossiliferous zone called *Salenia texana*, which is below the middle of the Glen Rose Limestone. About 2 ft above the *Salenia texana* zone is a thin, flaggy limestone bed containing large quantities of a distinctive, small clam, *Corbula martinae* (Whitney, 1952). Because the *Corbula martinae* bed was the easiest to identify, it was used to locate the top of the lower member of the Glen Rose Limestone.

The lower member of the Glen Rose Limestone is the uppermost unit of the middle Trinity aquifer. The lower member of the Glen Rose Limestone consists of thick-bedded, massive fossiliferous limestone, characterized in the study area by rudist patch reefs at the top (Petta, 1977) and a few thin beds of marl and dolomitic limestone (Stricklin and others, 1971). Some of the marl beds contain large quantities of the small foraminifer *Orbitolina texana*. Overlying the basal unit is a fossiliferous shale and nodular marl capped by the flaggy limestone bed containing *Corbula martinae*.

The upper member of the Glen Rose Limestone is the upper Trinity aquifer, which consists of yellowish-tan, thinly bedded limestone and marl. The upper member of the Glen Rose Limestone is identified by its characteristic stair-step topography caused by the differential weathering of the nonresistant marl and resistant limestone and dolomite beds (Stricklin and others, 1971, p. 23). Some of the marl beds contain large quantities of the small foraminifer *Orbitolina minuta* (Reeves, 1967). Evaporite beds are found near the middle and at the base of the upper member. At the outcrop, the evaporites have been leached by downward-percolating ground water, producing uneven settling of claystone beds formerly between or overlying the gypsum bed (Ashworth, 1983). Concurrent with the dissolution of evaporite is the development of collapse breccia zones of increased porosity and permeability, which is evident by the numerous sinkholes and caverns that are exposed along streambeds where the lower Glen Rose Limestone crops out (Reeves, 1967).

The Edwards Group (Rose, 1972) (table 1) is about 350 to 440 ft thick in Medina and Bandera Counties. The Walnut Clay, Comanche Peak Limestone, and Edwards Limestone of Holt (1956) are approximately equivalent to the Edwards Group of Rose (1972). Bedded or nodular chert characterize much of the formation. Holt (1956, p. 23) reported that the chert ranges in color from light gray to black and is not known to occur in any other formation in the area. This information is useful when mapping the outcrop of the Edwards Group. The rocks that compose the Edwards aquifer outcrop in the Medina Lake area mostly are flat-lying beds of light-gray to light-tan, locally nodular, cherty limestone (table 1).

The major formal lithostratigraphic units of the Edwards aquifer are the Kainer, Person, and Georgetown Formations (table 1). The Kainer and Person Formations of the Edwards Group were divided into seven informal members by Rose (1972). These members were modified by Maclay and Small (1976) into eight informal hydrogeologic subdivisions, which include the overlying Georgetown Formation. The Georgetown Formation is not known to yield water in the study area. However, because well drillers historically have considered the Georgetown Formation the top of the Edwards aquifer, the formation is included as part of the aquifer. Except for the Georgetown Formation, the strata that compose the Edwards aquifer were deposited in shallow to very shallow marine waters (Rose, 1972) and reflect depositional environments resulting from slight changes in water level, water chemistry, water temperature, and circulation. These factors caused subtle to not-so-subtle variations in the overall lithology of the various members and some variations within the individual members.

The Kainer Formation (Rose, 1972, p. 18) is about 260 to 320 ft thick in Medina and Bandera Counties. The lithology of the Kainer Formation consists of marine sediments of shaly, nodular, fossiliferous (mostly rudistids and oysters) limestones and mudstones of the basal nodular member that grade upward into intertidal and supratidal mudstones of the dolomitic member, and these grade into the supratidal, evaporitic crystalline limestones of the Kirschberg evaporite member. The formation terminates in the shallow marine *miliolid* grainstone of the grainstone member. The basal nodular member and the lower part of the dolomitic member of the Kainer Formation are distinctly burrowed. Major collapsed features noted elsewhere by Rose (1972) in the Kirschberg evaporite member were not evident in Medina and Bandera Counties. The lack of major collapsed features might indicate fewer massive gypsum deposits and more interbedded limestone that would have prevented major collapses after evaporite removal.

The Person Formation (Rose, 1972, p. 19) is about 86 to 120 ft thick in the study area in Medina County. The regional dense member at the base of the Person Formation is a dense, argillaceous mudstone, which is easily recognized in cores and usually recognizable on geophysical logs (Small, 1985). Deposition of the Person Formation above the regional dense member continued with the dolomitic biomicrite of the leached and collapsed members, undivided, which contain layers of collapsed breccia, burrowed mudstone, and crystalline limestone. The cyclic and marine members, undivided, consist of small upward-grading cycles of mudstone to packstone to *miliolid* grainstone that range from massive to thin beds that occasionally are crossbedded. Much of the cyclic and marine members, undivided, in Medina and Bandera Counties, which were not identified in the study area, might have been removed by erosion before the deposition of the Georgetown Formation. The top of the cyclic and marine members, undivided, is identified in the subsurface south of the Haby Crossing fault (fig. 2).

Complete sections of the Edwards Group are not well exposed in the Medina County part of the Medina Lake area because of faulting and erosion. However, partial sections of the Edwards Group rocks crop out in many places. The description of a generalized stratigraphic section composited from these partial sections is listed in table 2 (at end of report). The section was measured mostly on or near FM 1283 and along County Road 265 (pl. 1).

The Georgetown Formation, which overlies the Edwards Group, was deposited on the eroded surface of the Person Formation in deeper water than was characteristic for most of the Edwards Group deposition (Rose, 1972, p. 71). The Georgetown Formation is about 2 to 20 ft thick (Rose, 1972), but is not exposed in the study area. Elsewhere in Medina County, the Georgetown Formation generally consists of reddish-brown, gray to light-tan, marly limestone (table 1).

The Upper Cretaceous Del Rio Clay, Buda Limestone, Eagle Ford Group; and the Leona Formation, Uvalde Gravel, Escondido Formation, Anacacho Limestone, and Austin Group, undivided, compose the upper confining unit of the Edwards aquifer (table 1). The Del Rio Clay, Buda Limestone, and Eagle Ford Group are not exposed in the study area. The Leona Formation, Uvalde Gravel, Escondido Formation, Anacacho Limestone, and Austin Group, undivided, crop out in the study area south of the Haby Crossing fault (pl. 1). The Del Rio Clay is about 40 to 50 ft thick and consists of bluish-green to yellowish-brown clay (table 1). The Buda Limestone is about 40 to 50 ft thick and consists of buff, light-gray, dense mudstone. The Eagle Ford Group is about 30 to 50 ft thick and consists of brown, flaggy shale and argillaceous limestone. The Leona Formation, Uvalde Gravel, Escondido Formation, Anacacho Limestone, and Austin Group, undivided, is about 665 to 1,200 ft thick and consists of argillaceous, light-gray to buff, fossiliferous limestone; chalky, marly, and hard limestone; and clay, silt, and sandstone.

HYDROGEOLOGIC CHARACTERISTICS

General Features

The Edwards aquifer has relatively large porosity and permeability resulting, in part, from the development or redistribution of secondary porosity (Maclay and Small, 1976). Lithology, stratigraphy, diagenesis, and selective dissolution (karstification) account for the effective porosity and permeability in the Edwards aquifer outcrop. Karst features that can greatly enhance the effective porosity and permeability in the outcrop include sinkholes, dolines, and caves. The subtropical-subhumid climate (Larkin and Bomar, 1983) is not favorable for rapid karst development. The presence of caves in the Edwards Group limestone in Medina and Bandera Counties is random, and the morphology is controlled by the local stratigraphy.

The Trinity aquifer in south-central Texas generally is much less permeable than the Edwards aquifer in the Balcones fault zone, and the ability of the Trinity aquifer to yield and transmit water is only a small fraction of that of the Edwards aquifer (Barker and Ardis, 1996, p. B40; B47). Because the differences in water-yielding and transmitting characteristics between the two aquifers are so large, the Trinity aquifer, where it underlies the Edwards aquifer, often is considered a lower confining unit of the Edwards aquifer.

Porosity and Permeability

According to Choquette and Pray (1970, p. 212), porosity in sedimentary carbonates is either fabric selective or not fabric selective. Fabric selective porosity is related directly to the depositional or diagenetic fabric elements of a sediment and typically is controlled by lithostratigraphic horizon. Not fabric selective porosity is not related to depositional or diagenetic fabric elements of a sediment and can exist in any lithostratigraphic horizon. Effective, or drainable, porosity consists of pores that are well connected by sufficiently large openings, generally greater than 0.1 micrometer (µm) in diameter. In the Edwards aquifer, effective porosity is more closely associated with large permeability than with total porosity, which includes unconnected or dead-end pores (Maclay and Small, 1976).

Choquette and Pray (1970, p. 222) designated seven types of carbonate porosity that are "extremely common and volumetrically important." Five of these (interparticle, intraparticle, intercrystalline, moldic, and fenestral) generally are fabric selective, and two (fracture and vuggy) are not fabric selective. According to Choquette and Pray (1970, p. 223–224), breccia porosity, which is found in the Edwards aquifer outcrop, is a type of interparticle porosity and can be either fabric selective or not fabric selective. Other types of porosity in the Edwards aquifer outcrop are channel and cavern, both of which are not fabric selective; and burrow, which can be either fabric selective or not fabric selective.

According to Ford and Williams (1989, p. 130), permeability depends on the physical properties of the rock, particularly size, shape, and distribution of pores. Ford and Williams (1989, p. 150) further state that, "As a consequence of the effects of fissuring and differential solution, permeability may be greater in some directions than in others, as well as in certain preferred stratigraphic horizons." The type of porosity and permeability of the Trinity aquifer observed in the field, the eight hydrogeologic subdivisions of the Edwards aquifer, and the upper confining unit are discussed in ascending order.

The rocks of the lower member of the Glen Rose Limestone in the Medina Lake area appear to have relatively large porosity associated with rudist patch reefs and caves. This is evident in the patch reefs along Red Bluff Creek (pl. 1). Most of the porosity associated with the reefs is moldic; however, permeability is small unless the zone is fractured (Ashworth, 1983). The porosity associated with caves is not fabric selective. The rocks of the upper member of the Glen Rose Limestone are relatively impermeable and, where they underlie the Edwards aquifer, generally act as the lower confining unit of the Edwards aquifer.

Hydrogeologic subdivision VIII (basal nodular member) has negligible porosity and permeability in the subsurface and can be regarded as part of the lower confining unit (Maclay and Small, 1984). Locally, along the Medina Lake shoreline and in the spillway channel, this subdivision has secondary (mostly not fabric selective) porosity in the form of large undercut caves. The lateral cave development might result from dissolution associated with perching of infiltrating meteoric water on the underlying, relatively impermeable upper member of the Glen Rose Limestone (Kastning, 1986). The perching would allow time for dissolution to occur within this subdivision. Many seeps and springs discharge from the lower part of this hydrogeologic subdivision in Medina and Bandera Counties. The basal nodular member (and also hydrogeologic subdivision VII, the dolomitic member) might be hydraulically connected to Medina Lake at high lake stages.

Hydrogeologic subdivision VII (dolomitic member) generally is porous and relatively permeable. Locally, some of the evaporite beds within this subdivision are burrowed and dissolved to the extent of being honeycombed and, therefore, permeable. However, most of the burrowed beds, particularly those observed along the large roadcuts on FM 1283 east of Medina Lake (pl. 1), have little porosity or permeability. Many of the beds contain isolated molds, casts, and burrows with large secondary (fabric selective) porosity but little permeability because the openings rarely are connected. Generally, the permeable layers are restricted to solution-enlarged bedding planes. A small but relatively deep cave (unnamed) was located in this subdivision near Medina Lake (pl. 1).

Hydrogeologic subdivision VI (Kirschberg evaporite member) generally is considered to be one of the most porous and permeable subdivisions of the Kainer Formation. The porosity, mostly fabric selective, has been described as boxwork (Maclay and Small,

1976) because of the configuration of voids and the secondary neospar and travertine deposits. However, boxwork voids are not common in the study area. Layers of chalky and crystalline limestone are more common, and the chalky limestone appears to be porous.

Hydrogeologic subdivision V (grainstone member) is widely recrystallized. The recrystallization greatly reduces the effective porosity and permeability of this subdivision; however, this subdivision has local interparticle, intraparticle, and fracture porosity.

Hydrogeologic subdivision IV (regional dense member) probably is an effective vertical confining unit between the underlying Kainer Formation and the overlying members of the Person Formation. However, this subdivision is only about 16 to 20 ft thick in the study area; and caves, faults, and fractures (primarily not fabric selective porosity), and fracture-associated permeability might greatly reduce the effectiveness of the regional dense member to act as a confining unit in some areas.

Hydrogeologic subdivision III (leached and collapsed members, undivided) probably is the most porous and permeable subdivision within the Person Formation. This subdivision has predominantly not fabric selective porosity where evaporite minerals have been dissolved. However, breccia porosity resulting from evaporite dissolution can be either fabric selective or not fabric selective (Choquette and Pray, 1970). Cavern porosity and permeability associated with faulting and (or) evaporite dissolution also is common. At least two large caves, Boehme’s and Haby Bat (pl. 1), are in this subdivision. According to Elliott and Veni (1994, p. 231), Boehme’s Cave “* * * takes in a huge quantity of flood water.”

Hydrogeologic subdivision II (cyclic and marine members, undivided) has moldic and vuggy porosity and permeability associated with fossiliferous zones, and fracture porosity and permeability associated with faulting. This subdivision is not exposed in the study area.

Hydrogeologic subdivision I (Georgetown Formation) has negligible porosity and permeability. This subdivision also is not exposed in the study area.

The upper confining unit on the Edwards aquifer consists of the Del Rio Clay, Buda Limestone, Eagle Ford Group; and the Leona Formation, Uvalde Gravel, Escondido Formation, Anacacho Limestone, and Austin Group, undivided (Rose, 1972). These rocks collectively have negligible effective porosity and permeability. However, the Leona Formation and the Uvalde Gravel very locally can be highly permeable and considered aquifers. The Del Rio Clay, Buda Limestone, and Eagle Ford Group are not exposed in the study area.

SUMMARY

The Edwards aquifer in the Balcones fault zone, one of the most permeable and productive carbonate aquifers in the Nation, provides public water supply to more than 1 million people in south-central Texas. In addition, the Edwards aquifer provides large quantities of water to agriculture, industry, and major springs. The major springs support recreational activities and businesses, provide water to downstream users, and provide habitat for several threatened or endangered species. The Trinity aquifer, which crops out in the northern part of the Medina Lake area and underlies the Edwards aquifer in the southern part, is much less permeable and productive than the Edwards aquifer. Where the Trinity aquifer underlies the Edwards, the Trinity acts as a lower confining unit on the Edwards.

Streams that originate from discharge of the Trinity aquifer cross the Edwards aquifer outcrop (the recharge zone) in the Balcones fault zone and lose much, if not all, of their flow to faults, fractures, sinkholes, and caves in the outcrop. After entering the aquifer, the water moves east through Medina County to points of discharge in Medina and Bexar Counties (mostly irrigation and municipal wells) and then northeast, parallel or almost parallel to the northeast-trending Balcones faults into Comal and Hays Counties, where it is discharged by wells and springs.

The Kainer and Person Formations of the Edwards Group and the overlying Georgetown Formation compose the Edwards aquifer. The Kainer and Person Formations consist of seven informal members. These members, together with the overlying Georgetown Formation, form the eight informal hydrogeologic subdivisions of the Edwards aquifer.

The Edwards aquifer has relatively large porosity and permeability resulting, in part, from the development or redistribution of secondary porosity. Lithology, stratigraphy, diagenesis, and karstification account for the effective porosity and permeability in the Edwards aquifer outcrop. Karst features that can greatly enhance effective porosity and permeability in the outcrop include sinkholes, dolines, and caves. Porosity in the Edwards aquifer outcrop is either fabric selective, which is related to depositional or diagenetic elements and typically exists in specific stratigraphic horizons; or not fabric selective, which is not related to depositional or diagenetic elements and can exist in any lithostratigraphic horizon. Permeability depends on the physical properties of the rock, such as size, shape, and distribution of pores. Rocks of the Edwards aquifer hydrogeologic subdivisions VI (Kirschberg evaporite member of the Kainer Formation) and III (leached and collapsed members, undivided, of the Person Formation) appear to be the most porous and permeable.

Field observations in the Medina Lake area confirm the findings of previous investigators that Medina Lake mostly overlies rocks of the upper member of the Glen Rose Limestone. The channel downstream of Medina Dam to the upper end of Diversion Lake also overlies the upper member of the Glen Rose Limestone. Most of Diversion Lake overlies a thin section of the Edwards aquifer—hydrogeologic subdivision VIII (basal nodular member) and the basal part of hydrogeologic subdivision VII (dolomitic member). Hydrogeologic subdivisions VIII and VII might be hydraulically connected to Medina Lake at high lake stages.

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Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop, Medina Lake area, Texas

[Section starts near the top of the regional dense member. ft, feet; in., inches; BRB, black rotund body]

Description	Thickness (ft)	Cumulative thickness (ft)
Regional dense member		
Mudstone, pale-brown, nodular, marly, argillaceous; fossils uncommon	10	10
Covered	5	15
Mudstone, pale-brown, dense	2	17
Covered	3	20
Grainstone member		
Mudstone, pale-brown, dense, *miliolid*	4	24
Grainstone, pale-brown to yellow; *miliolid* and allochem, recrystallized	2	26
Covered	4	30
Packstone, pale-brown; *miliolid* and allochem	2	32
Covered	7	39
Mudstone, light-tan to yellow, chalky	2	41
Covered	10	51
Mudstone, light-tan to yellow; locally chalky	2	53
Limestone, light-tan to yellow, crystalline, chalky	2	55
Mudstone and *miliolid* grainstone, pale-brown	1	56
Grainstone, white to pale-brown to gray, *miliolid*	4	60
Mudstone, tan	2	62
Covered	15	77
Kirschberg evaporite member		
Limestone, gray to dark-gray, crystalline, burrowed; locally indistinctly bedded	2	79
Limestone, light-gray, crystalline; locally chalky	2	81
Mudstone, light-gray	1	82
Limestone, light-gray, crystalline	1	83
Covered	4	87
Mudstone, light-tan, gray, crystalline	2	89
Limestone, gray, crystalline, vuggy	3	92
Limestone, gray, crystalline; small, slightly rectangular vugs (boxwork?) common	3	95
Limestone, light-gray, crystalline; locally mottled brown	4	99
Limestone, gray, crystalline; chert float common	7	106

Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop, Medina Lake area, Texas—Continued

Description	Thickness (ft)	Cumulative thickness (ft)
Kirschberg evaporite member—Continued		
Mudstone, light-gray, burrowed; burrow filling is gray crystalline limestone	2	108
Limestone, light-gray, crystalline	1	109
Limestone, light-gray, crystalline, thin-bedded; pale-brown, banded, opaque chert nodules	1	110
Mudstone, light-brown; locally burrowed	2	112
Limestone, light-brown to light-gray, crystalline	1.5	113.5
Chert, light-gray to gray; drusy, opaque nodules	.5	114
Limestone, light-gray to light brownish-yellow, mottled, crystalline	6	120
Chert, light-gray to reddish-brown; dull, opaque nodules up to 1 ft in diameter	1	121
Limestone, gray to light-brown, crystalline; abundantly and irregularly pitted (moonscape)	3	124
Chert, gray, opaque; nodules up to 1 ft in diameter	1	125
Limestone, light-gray to light-brown, crystalline	2	127
Covered	2	129
Limestone, gray, crystalline	.5	129.5
Mudstone, light-gray, marly, chalky; thin calcite-filled veins locally common	2	131.5
Limestone, gray, crystalline, pitted	1	132.5
Dolomitic member		
Mudstone, light-gray to brownish-gray; locally chalky; *Toucasia* uncommon	2	134.5
Limestone, gray, crystalline, chalky	3	137.5
Limestone, gray, crystalline, sugary	1	138.5
Mudstone, gray, marly, chalky	1	139.5
Limestone, light-gray to light-brown, crystalline	1	140.5
Grainstone, light-gray, *miliolid*	1	141.5
Covered	5	146.5
Wackestone to packstone to grainstone, light-gray to white to pale-brown, *miliolid*	2	148.5
Limestone, light-brown to light-gray, crystalline; locally sugary	4	152.5
Covered	4	156.5
Mudstone, gray to brown, dense; locally grainy	2	158.5
Limestone, gray, crystalline; locally chalky; *Toucasia* rare	4.5	163
Wackestone, light-gray, shell fragments; locally crossbedded	2	165
Limestone, light-gray to light-brown, crystalline; locally chalky	6	171

Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop, Medina Lake area, Texas—Continued

Description	Thickness (ft)	Cumulative thickness (ft)
Dolomitic member—Continued		
Wackestone, pale-brown, grainy, burrowed	2	173
Limestone, light-gray, crystalline, chalky, evaporitic	4	177
Limestone, light-gray, crystalline; locally punky (caliche?)	4	181
Mudstone, gray; marly, with 3-in. lens of light-gray *miliolid* packstone near top	1	182
Mudstone to wackestone, light-brown, *miliolid*	2	184
Mudstone, light-gray, mottled, nodular; locally recrystallized	4	188
Wackestone to packstone, pale-brown, shell fragments	2	190
Covered	7	197
Mudstone, white, dense, recrystallized	1	198
Mudstone, white, chalky; *miliolid*, with large, light-gray, opaque, chert nodules common	4	202
Chert, light-gray to pale-brown to pale-violet, nodular, opaque; locally banded	1	203
Limestone, light-gray, crystalline, chalky	5	208
Packstone to grainstone, light-gray, dense, *miliolid*; *Toucasia* shell fragments common	2	210
Mudstone, white to light-brown, marly, chalky	2	212
Grainstone, white, *miliolid*, vuggy; locally honeycombed; *Turritella* and pelecypod shell fragments common	.5	212.5
Mudstone, white, thin-bedded, marly; beds irregular and indistinct in top 3 to 4 in.	3	215.5
Wackestone, pale-brown, shell fragments, burrowed; 3-in. stromatolitic layer at top of interval	5	220.5
Mudstone, pale-brown to light-gray, dense, recrystallized	5	225.5
Wackestone to packstone, pale-brown, shell fragments, crossbedded; locally *Turritella* and shell-fragment grainstone	4	229.5
Grainstone, white to pale-brown, *miliolid*; locally shell-fragment coquina	1	230.5
Mudstone, pale-brown to white, dense	2	232.5
Limestone, light-gray, crystalline, vuggy; small (about 1/16-in. diameter) vugs common	1.8	234.3
Mudstone, pale-brown, chalky to dense, burrowed (burrow filling is light-gray crystalline limestone); stylolite at top of bed	1.4	235.7
Mudstone, light-gray to pale-brown, burrowed; gray, crystalline limestone burrow filling projects out beyond matrix giving a lumpy appearance; large (up to 3-in. diameter) dog-tooth, spar-lined vugs and *Chondrodonta* fragments uncommon	4.3	240
Limestone, pale-brown, crystalline	3.5	243.5
Grainstone to packstone, white, *miliolid*, layered; locally chalky	1.5	245
Grainstone to packstone, pale-brown to white, *miliolid* and shell fragments; locally chalky	2	247

Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop, Medina Lake area, Texas—Continued

Description	Thickness (ft)	Cumulative thickness (ft)
Basal nodular member		
Claystone, white to light-gray, soft, recessive	3	250
Mudstone, pale-brown, vuggy; BRB traces rare	.5	250.5
Wackestone, pale-brown, *Turritella*; locally, honeycombed *miliolid* grainstone	2	252.5
Claystone, white, soft, nodular, recessive	1	253.5
Mudstone, white, soft, nodular, thin-bedded, recessive	4	257.5
Mudstone, white, marly, nodular, lumpy; BRB traces common; pelecypod shell fragments locally abundant	9	266.5
Wackestone, pale-brown to light-gray, marly; *Exogyra texana* and pelecypod shell fragments common	3	269.5
Wackestone to packstone, light-gray, *miliolid*; *Turritella* and oyster shell fragments	7	276.5
Mudstone, light-gray, dense	1	277.5
Mudstone, white, marly, nodular; bedding indistinct	4	281.5
Wackestone to packstone, light-gray to pale-brown, dense; locally nodular; *Turritella* and oyster shell fragments	7	288.5
Mudstone, pale-brown, nodular; indistinctly bedded	4	292.5
Mudstone, white to pale-brown, dense; BRB traces abundant	2	294.5
Mudstone, pale-brown, evaporitic; locally honeycombed; BRB traces common; top 0.5 ft of honeycombed layer is recessive	2.5	297
Mudstone, white, marly	3	300
Contact of the Edwards Group with the upper member of the Glen Rose Limestone		