In cooperation with the Edwards Aquifer Authority

Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Outcrop, Medina County, Texas

Water-Resources Investigations Report 00–4195

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

Cover:

Rudistid reef in top of Devils River Formation, Seco Creek near Valdina Farms. Photograph by Ted Small, October 1992.

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By Ted A. Small and Allan K. Clark

U.S. GEOLOGICAL SURVEY
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Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Outcrop, Medina County, Texas

By Ted A. Small *and* Allan K. Clark

Abstract

The hydrogeologic subdivisions of the Edwards aquifer outcrop in Medina County 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 most porous and permeable rocks of the Devils River Formation in Medina County appear to be in the top layer. The upper member of the Glen Rose Limestone, the lower confining unit, has much less porosity and permeability than that observed in 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 Edwards aquifer outcrop include sinkholes, dolines, and caves. The Edwards aquifer rocks in Medina County change from the eight-member Edwards Group to the essentially indivisible Devils River Formation. The facies change occurs along a line extending northwestward from just south of Medina Lake.

INTRODUCTION

The Edwards aquifer in the Balcones fault zone (fig. 1) 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.

In Medina County, rocks of the Edwards aquifer crop out in the northern part in an approximately 2- to 10-mile-wide, east-west band that completely crosses the county. These rocks are composed of the Edwards Group (Rose, 1972) and the Devils River Formation (Lozo and Smith, 1964). Barnes (1983) shows the approximate location of the facies change from the Edwards Group to the Devils River Formation with a dashed line trending northwestward. The southern boundary of the Edwards aquifer outcrop is the irregular line formed by the contact of the Devils River Formation with the upper confining unit (pl. 1).

Most recharge to the Edwards aquifer is from direct infiltration of precipitation and streamflow loss in the recharge zone. Recharge to the Edwards aquifer averaged 676,000 acre-feet per year during 1934–97 (D.S. Brown, U.S. Geological Survey, written commun., 1998). Streams that originate in the topographically rugged Hill Country north of the Edwards aquifer recharge zone generally flow to the south, cross the Edwards aquifer outcrop in the Balcones fault zone, and lose much, if not all, of their flow to faults, fractures, caves, and sinkholes in the outcrop. After entering the aquifer, the water generally moves eastward through Medina County to points of discharge in Medina and Bexar Counties (mostly irrigation and municipal wells) and then northeastward, parallel or almost parallel to the northeast-trending Balcones faults in Comal and Hays Counties, where it is discharged by wells and springs.

The U.S. Geological Survey, in cooperation with the Edwards Aquifer Authority, mapped the outcrop of the Edwards aquifer and described its hydrogeologic characteristics (porosity and permeability) to document

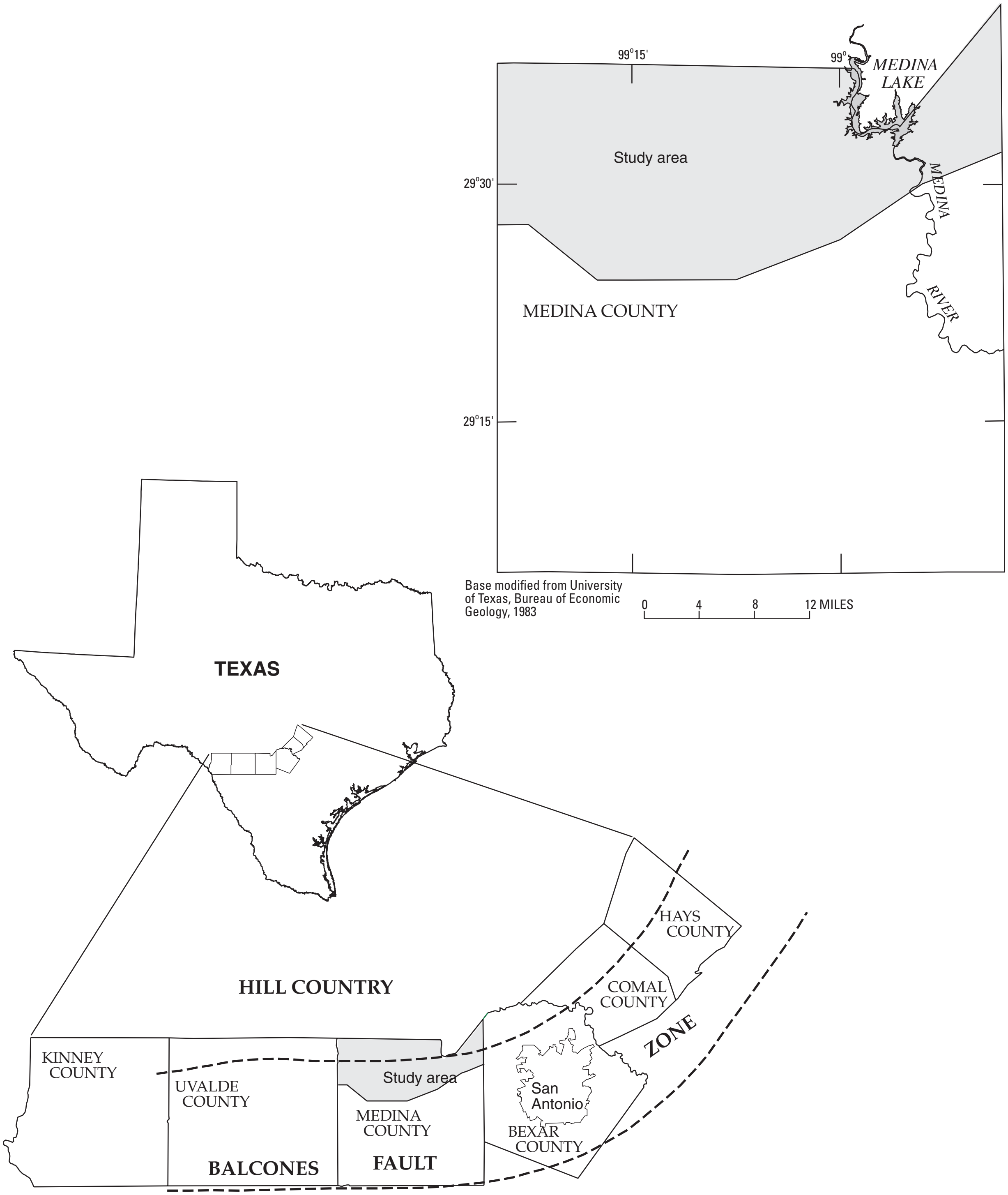

Figure 1. Location of the study area.

conditions pertinent to movement and contamination of ground water. This report describes the geologic framework and hydrogeologic characteristics of the Edwards aquifer outcrop in the Medina County study area (fig. 1). 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 aquifer.

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 and of Lozo and Smith (1964) for the Devils River Formation were used to map the Edwards aquifer outcrop in Medina County. The carbonate-rock classification 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), 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 outcrop (table 1). The hydrogeologic subdivisions of the outcrop of the Edwards aquifer in Medina County 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 County. The Upper Cretaceous Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Group, Anacacho Limestone, and Escondido Formation; and the Quaternary Leona Formation and alluvium are juxtaposed against the Edwards Group or the Devils River Formation on the southeastern side of the Haby Crossing fault or other faults (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 unweathered outcrop could be examined.

Displacement on most faults in the study area 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 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 in the field or in aerial photographs. Faults were inferred on the basis of the location of lineaments on photographs in areas where only slight stratigraphic dissimilarities were indicated, or where the faults extend beyond the mapped area.

Several fault traces and the configuration of some hydrogeologic subdivisions have been modified and updated with data obtained from previously inaccessible areas. Therefore, the hydrogeologic map of the Edwards aquifer outcrop in the Medina Lake area (Small and Lambert, 1998) does not everywhere match the map of this report.

Acknowledgments

Special thanks are extended to Dr. C.I. Smith for his help in identifying the rudist reef at the top of the Devils River Formation; and to the Edwards Aquifer Authority; Medina County Underground Water Conservation District; Emmit Schmidt, Ranch Manager of the Flying A Ranch; Armadigger, Inc.; D&K Drilling Co.; Marion Heisler; and M and E Enterprises, Inc.; for providing well information, drillers' logs, and geophysical logs. Also, thanks are extended to M.G. Schuhart, William Coffee, Joel and Gabrielle Mosier, and William Hightower, and other property owners who granted permission to enter their property, aided in the collection of field data, and supplied valuable information.

GEOLOGIC FRAMEWORK

General Features

Previous mapping done in Medina County identified the rock units to the group or formation levels only. Sayre (1936) mapped the Edwards and Georgetown Limestones as a single unit. Sayre (1936) also mapped the Glen Rose Limestone. William F. Guyton and Associates (1955) described the characteristics of the "Edwards Limestone Reservoir" in the San Antonio area and produced a map showing 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. Holt (1956) indicated that the distribution of the rocks, now known as the Edwards Group (Rose, 1972), is not as widespread as previously mapped. Barnes (1983, 1992) shows the distribution of the rocks

Table 1. Summary of the lithologic and hydrologic properties of the hydrogeologic subdivisions of the Edwards aquifer outcrop, Medina County, Texas

[Hydrogeologic subdivisions modified from Maclay and Small (1976); groups, formations, and members 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
Quaternary		Alluvium	AQ	0–30	Siltstone to sandstone	Sandstone and silt	None	High porosity/high permeability
Quaternary		Leona Formation	AQ	0–65	Sand, gravel, silt, and clay	Chert and limestone	Rare to none	Low to high porosity/ low permeability
Upper Cretaceous	Upper confining unit	Escondido Formation	AQ	300	Shale, sandstone, and limestone	Gray sandstone and shale	Rare to none	Low to high porosity/ low permeability
Upper Cretaceous	Upper confining unit	Anacacho Limestone	CU	240–400	Fossiliferous limestone and marl	Red-brown to light-gray limestone; marl	Rare	Low to high porosity/ low permeability
Upper Cretaceous	Upper confining unit	Austin Group	CU	225–350	Buff to white chalk; limestone and marl	White, light-gray limestone	Rare	Low porosity/low permeability
Upper Cretaceous	Upper confining unit	Eagle Ford Group	CU	30–50	Brown, flaggy shale and argillaceous limestone	Dark-brown shale; petroliferous odor	None	Low porosity/low permeability
Upper Cretaceous	Upper confining unit	Buda Limestone	CU	40–50	Buff, light-gray, dense mudstone	White, dense limestone	None	Low porosity/low permeability
Upper Cretaceous	Upper confining unit	Del Rio Clay	CU	40–50	Blue-green to yellow-brown clay	Blue-green to medium-brown shale; *Ilymatogyra arietina*	None	Low porosity/low permeability
Lower Cretaceous	Edwards aquifer: I	Georgetown Formation	Karst AQ; not karst CU	0–20	Reddish-brown, gray to light-tan, marly limestone	Red-brown to gray marly limestone; *Waconella wacoensis*	None	Low porosity/low permeability
Lower Cretaceous	Edwards aquifer: II	Devils River Formation; Edwards Group; Segovia Formation; 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
Lower Cretaceous	Edwards aquifer: III	Devils River Formation; Edwards Group; Segovia Formation; Person Formation: 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
Lower Cretaceous	Edwards aquifer: IV	Devils River Formation; Edwards Group; Segovia Formation; Person Formation: 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
Lower Cretaceous	Edwards aquifer: V	Devils River Formation; Edwards Group; Fort Terrett Formation; Kainer Formation: Grainstone member	AQ	50–60	*Miliolid* grainstone; mudstone to wackestone; chert	White crossbedded grainstone	Few	Not fabric/ recrystallization reduces permeability
Lower Cretaceous	Edwards aquifer: VI	Devils River Formation; Edwards Group; Fort Terrett Formation; Kainer Formation: 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
Lower Cretaceous	Edwards aquifer: VII	Devils River Formation; Edwards Group; Fort Terrett Formation; Kainer Formation: 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
Lower Cretaceous	Edwards aquifer: VIII	Devils River Formation; Edwards Group; Fort Terrett Formation; Kainer Formation: Basal nodular member	Karst AQ; not karst CU	50–60	Shaly, nodular limestone; mudstone and *miliolid* grainstone	Massive, nodular and mottled; abundant gastropods and *Exogyra texana*	Large lateral caves at surface; a few caves near Koenig Creek (see plate 1)	Fabric; stratigraphically controlled/large conduit flow at surface; no permeability in subsurface
Lower Cretaceous	Trinity aquifer	Lower confining unit: Upper member of 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

of the Edwards aquifer and the approximate location of the San Marcos Platform/Devils River trend facies change. Collins (1995a, b; 1997a, b, c) mapped the Walnut, Kainer, and Person Formations of the Edwards aquifer outcrop on the Medina Lake, San Geronimo, Timber Creek, and Twin Hollow quadrangles and divided the Devils River Formation into an upper and lower member on the Texas Mountain, Timber Creek, and Twin Hollow quadrangles in Medina County.

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 to the southeast in Medina County, and the approximate thickness of the rocks to be about 450 to 785 feet. Lozo and Smith (1964) measured and described about 447 feet (of about 500 to 600 feet) of rocks in the Devils River Formation in an area about 30 miles west of Medina County. The dashed line (shown on pl. 1) separating the Edwards Group from the Devils River Formation was initially proposed in 1964 by F.E. Lozo and C.I. Smith (C.I. Smith, oral commun., 2000). Barnes (1983) reported that the Devils River Formation crops out in Medina County and distinguished the Devils River Formation from the Edwards Limestone, undivided.

A series of faults extends from the southwestern part of the study area toward the northeast, as part of the Balcones fault zone (fig. 1, pl. 1). A few cross-faults trend southeastward to northwestward. In general, 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 the fault have similar weathering characteristics, and possibly because the rate of movement is no faster than the rate of erosion.

Some of the faults in Medina County 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.

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. Therefore, faults in the study area with a vertical displacement of about 225 feet or greater were designated as flow-barrier faults. The Woodard Cave fault and the Haby Crossing fault (about 600 feet vertical displacement) (pl. 1) are considered to be flow-barrier faults (Maclay and Small, 1984, p. 33).

Stratigraphy

The Lower Cretaceous Glen Rose Limestone ranges in thickness from about 350 to 500 feet, and generally is a 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). The top part of the upper Glen Rose Limestone is considered to be essentially impermeable (Maclay and Small, 1984) and serves as a lower confining unit to the Edwards aquifer.

The Edwards Group (Rose, 1972) (table 1) is about 346 to 440 feet thick in Medina County. The Walnut Clay, Comanche Peak Limestone, and Edwards Limestone of Holt (1956) are approximately equivalent to the Edwards Group of Rose (1972) and to the essentially indivisible Devils River Formation of Lozo and Smith (1964). 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 Medina County 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 moderate variations in the overall lithology of the various members and some variations within the individual members.

The Devils River Formation was defined by Lozo and Smith (1964, p. 291, 297) as consisting of rocks that lack marker beds, which would allow for subdivision. According to Lozo and Smith (1964, p. 297), the entire section primarily consists of *miliolid*, pellet, rudist, shell-fragment-lime grainstones and wackestones locally dolomitized, brecciated and chert bearing; rudist mounds and layers are more common in the upper part. According to Miller and others (1984), in an area west of Medina County, the lower Devils River Formation can be divided into the basal nodular, burrowed, dolomitic, and Kirschberg evaporite members. About 100 feet of limestone and chert, located in the upper middle part of the Devils River Formation, crop out along State Highway 173 (pl. 1) about 4 miles north of Haby Crossing fault. In the northwestern part of Medina County, about 4 miles southeast of Woodard Cave (also known as the Valdina Farms Sinkhole) (pl. 1), is a layer of rock at the top of the Devils River Formation consisting mostly of rudist casts. The southern tip of the outcrop is capped by a thin, narrow strip of Georgetown Formation, and an even thinner and narrower strip of Del Rio Clay above the Georgetown Formation.

The Kainer Formation (Rose, 1972, p. 18) is approximately 260 to 320 feet thick in Medina County. The Kainer Formation consists of marine sediments of shaly, nodular, fossiliferous (mostly rudistids and oysters) mudstone and wackestones 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 at 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 County. The lack of major collapsed features might indicate fewer massive evaporite 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 feet thick 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. According to Rose (1972), all of the cyclic and much of the marine members, undivided, on the San Marcos Platform might have been removed by erosion before the deposition of the Georgetown Formation. Rocks belonging to the cyclic and marine members, undivided, were not identified in Medina County (pl. 1).

The Georgetown Formation, which overlies the Edwards Group, was deposited on the eroded surface of the Devils River Formation/Person Formation in deeper water than was characteristic for most of the Edwards Group deposition (Rose, 1972, p. 71). The Georgetown Formation is about 0 to 20 feet thick and generally consists of reddish brown, gray to light-tan, marly limestone, commonly containing the brachiopod *Waconella wacoensis*, formerly *Kingena wacoensis* (table 1). Exposures of the Georgetown Formation were identified in the study area about 3 miles east of State Highway 173 in Bull Creek near the intersection of County Roads 251 and 351 (pl. 1). In the northern part of Seco Creek, about 4 miles southeast of Woodard Cave (pl. 1), an approximately 5-foot-thick outcrop of the Georgetown Formation caps the southern tip of an extensive layer of rocks consisting mostly of casts of *monopleurids(?)* at the top of the Devils River Formation.

The Upper Cretaceous Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Group, Anacacho Limestone, and Escondido Formation compose the upper confining unit of the Edwards aquifer (table 1). In a few places in the study area, sands and gravels of the Quaternary Leona Formation and alluvium (table 1) overlie rocks ranging in age from the Lower Cretaceous Glen Rose Limestone to the Upper Cretaceous Escondido Formation. The Del Rio Clay is about 40 to 50 feet thick and consists of bluish-green to yellowish-brown clay. The Buda Limestone is about 40 to 50 feet thick and consists of buff, light-gray, dense mudstone. The Eagle Ford Group is about 30 to 50 feet thick and consists of brown, flaggy shale and argillaceous limestone. The Austin Group is about 225 to 350 feet thick and consists of buff, light-gray, chalky to marly, fossiliferous limestone and marl. The Anacacho Limestone is about 240 to 400 feet thick and consists of brown to brownish-gray, fossiliferous limestone. The Escondido Formation is about 300 feet thick and consists of gray sandstone and shale. The Leona Formation can be as much as 65 feet thick and consists of sand, gravel, silt, and clay. The alluvium can be as much as 30 feet thick and consists of silt and sand.

HYDROLOGEOLOGIC CHARACTERISTICS

General Features

The Edwards aquifer (pl. 1, table 1) 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 limestone of the Edwards Group in Medina County is random, and cave 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 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.

Permeability is the capacity of a porous rock to transmit water. 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 observed in the field is discussed for the eight hydrogeologic subdivisions of the Edwards aquifer and the upper confining unit, in ascending order. These hydrogeologic subdivisions do not apply to the rocks of the Devils River Formation in Medina County; however, rocks similar in appearance and lithology to the Kirschberg evaporite member and the dolomitic member were recognized in the Devils River Formation.

Hydrogeologic subdivision VIII (basal nodular member) has negligible porosity and permeability; except locally, this subdivision could be regarded as part of the lower confining unit (Maclay and Small, 1984). This subdivision commonly crops out in the northern part of the study area (pl. 1) and, like the outcrops in the large roadcuts along FM 283 east of Medina Lake (pl. 1), shows little permeability. 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 County.

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 and dense limestone beds have little porosity or permeability. Some of the beds contain isolated molds, casts, and burrows with large secondary (fabric selective) porosity but little permeability because the openings rarely are connected. Therefore, the permeable layers generally are restricted to solution-enlarged bedding planes. Ney Cave, located about 8 miles west of Medina Lake (pl. 1), is in this subdivision. Fracture porosity and permeability associated with faults and fractures is probably as common as fabric selective porosity in this member.

Hydrogeologic subdivision VI (Kirschberg evaporite member) generally is considered to be the most porous and permeable subdivision 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. Not fabric selective porosity and permeability associated with faults and fractures is also common.

Hydrogeologic subdivision V (grainstone member) consists of tightly cemented *miliolid* grainstone. The cementation greatly reduces the effective porosity and permeability of this subdivision; however, there is local interparticle and intraparticle porosity and local fracture porosity and permeability.

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 20 feet thick in the study area; caves, faults, and fractures (primarily not fabric selective porosity), and fracture-associated permeability might greatly reduce the effectiveness of the regional dense member 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), about 0 to 20 feet thick, is a marly limestone and generally has negligible porosity and permeability.

The Devils River Formation generally has about the same porosity and permeability as the dolomitic and Kirschberg evaporite members in the study area. However, parts of the previously described roadcut on State Highway 173 and the outcrop 4 miles southeast of Woodard Cave appear to have excellent fabric selective and not fabric selective porosity and permeability.

The upper confining unit (above the Edwards aquifer) consists of the Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Group, Anacacho Limestone, and Escondido Formation. These rocks crop out mostly in the southern part of the study area. Because the Del Rio Clay consists mostly of clay and has negligible effective porosity and permeability, it is probably the most effective part of the upper confining unit. The Quaternary Leona Formation and alluvium consist of silt, sand, gravel, and clay, and are not confining units.

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.

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

The Kainer and Person Formations of the Edwards Group, the Devils River Formation, 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 Devils River Formation is essentially indivisible.

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 the 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 lithostratigraphic 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), and a layer at the top of the Devils River Formation appear to be the most porous and permeable.

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