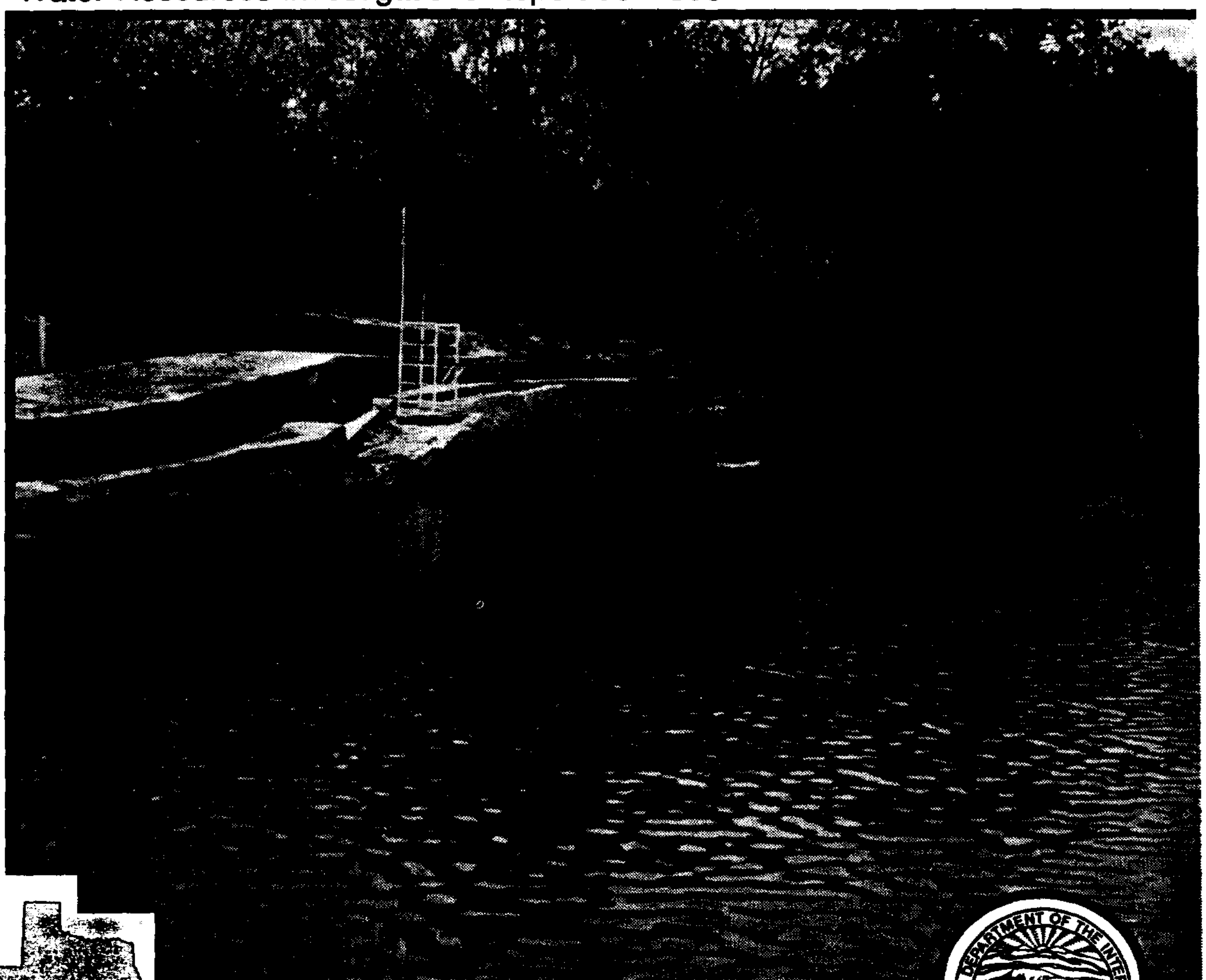
GEOLOGIC FRAMEWORK AND HYDROGEOLOGIC CHARACTERISTICS OF THE EDWARDS AQUIFER OUTCROP (BARTON SPRINGS SEGMENT), NORTHEASTERN HAYS AND SOUTHWESTERN TRAVIS COUNTIES, TEXAS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96–4306



Prepared in cooperation with the
BARTON SPRINGS/EDWARDS AQUIFER CONSERVATION DISTRICT *and the*
TEXAS WATER DEVELOPMENT BOARD

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(Plate is in pocket)

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Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Outcrop (Barton Springs Segment), Northeastern Hays and Southwestern Travis Counties, Texas

By Ted A. Small[1], John A. Hanson[1], *and* Nico M. Hauwert[2]

Abstract

The hydrogeologic subdivisions within the Barton Springs segment of the Edwards aquifer outcrop in northeastern Hays and southwestern Travis 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. Hydrogeologic subdivision II, the cyclic and marine members, undivided, of the Person Formation, also is quite porous and permeable in Hays County. 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 pore size, shape, distribution, fissuring, dissolution, and interconnection of pores and vugs.

The Edwards aquifer rocks that crop out in the Barton Springs segment of the Edwards aquifer generally have the same lithologic characteristics as the Edwards aquifer rocks that crop out in Comal and southwestern Hays Counties. However, in the northeastern part of the segment in Travis County, the rock unit that is apparently equivalent to the basal nodular member of the Kainer Formation is called the Walnut Formation. Because the units appear to be stratigraphically and lithologically equivalent, the basal nodular member is used instead of the Walnut Formation for this report. Essentially all of hydrogeologic subdivision II, which is about 70 feet thick in Hays County, is missing in Travis County.

In the Barton Springs segment of the Edwards aquifer, the aquifer probably is most vulnerable to surface contamination in the rapidly urbanizing areas on the Edwards aquifer outcrop. Contamination can result from spills or leakage of hazardous materials; or runoff on the intensely faulted and fractured, karstic limestone outcrops characteristic of the recharge zone.

[1]U.S. Geological Survey.

[2]Barton Springs/Edwards Aquifer Conservation District.

INTRODUCTION

The Barton Springs segment of the Edwards aquifer (fig. 1) comprises rocks of the Lower Cretaceous Kainer and Person Formations of the Edwards Group (Rose, 1972) and the overlying Georgetown Formation. The Edwards aquifer is one of the most permeable and productive carbonate aquifers in the Nation. The Barton Springs segment includes about 155 square miles (mi^2), is hydrologically independent from the Edwards aquifer in the San Antonio area (Slade and others, 1985), and like the Edwards aquifer in the San Antonio area, is a dissolution-modified, faulted limestone aquifer (Buszka and others, 1990).

The northern boundary of the study area is the Colorado River (fig. 1), and the southern boundary is Lone Man Creek and the Blanco River. The Barton Springs segment of the Edwards aquifer is the source of water for Barton Springs and is the major source of water for more than 30,000 people in northeastern Hays and southwestern Travis Counties (Slade and others, 1985).

According to Senger and Kreitler (1984), recharge to the Edwards aquifer in the Barton Springs

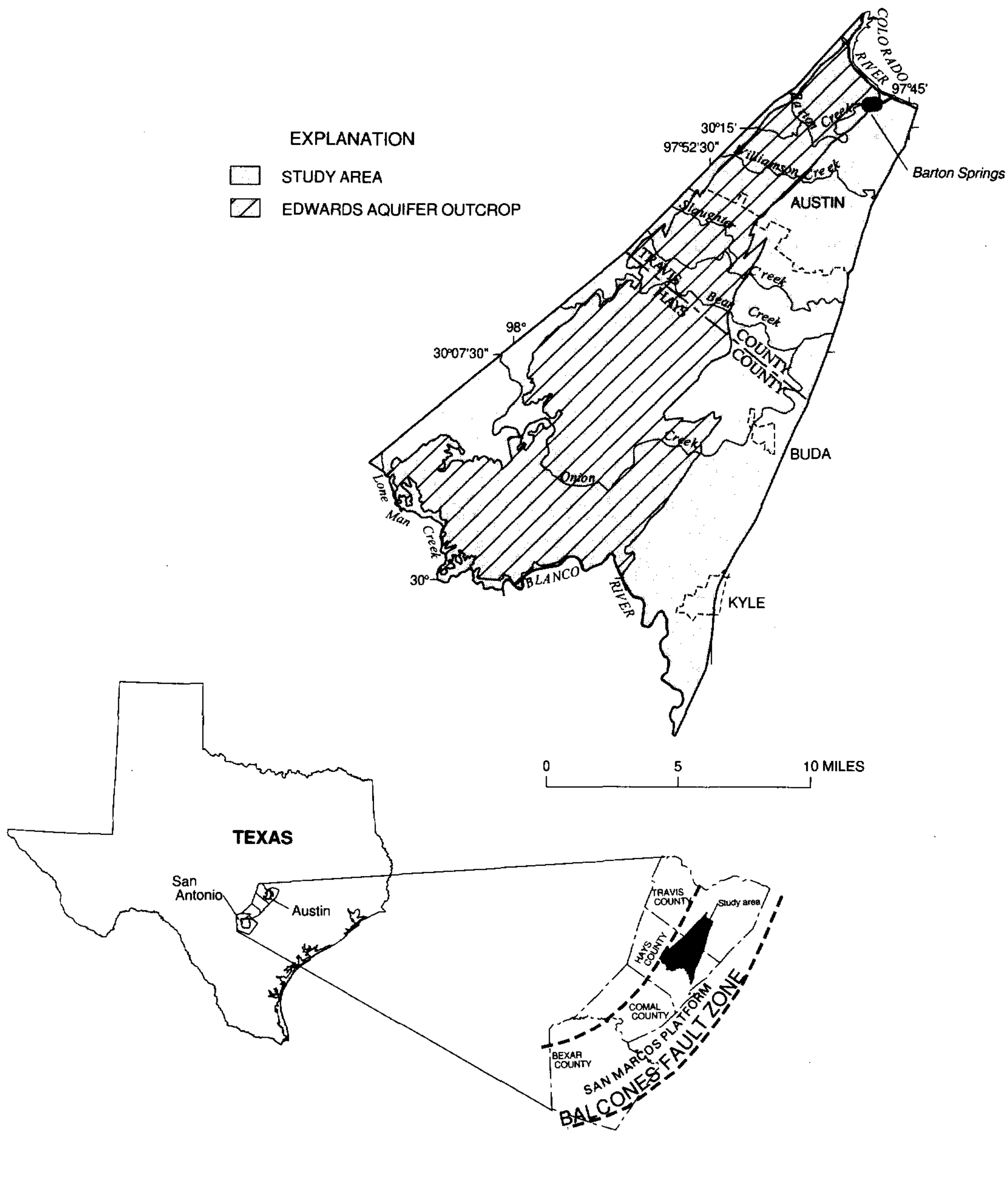

Figure 1. Location of the study area.

segment predominantly occurs along five major creeks: Barton, Williamson, Slaughter, Bear, and Onion (fig. l). These five major creeks and other smaller creeks and streams 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 generally moves northeast to points of discharge, predominantly Barton Springs.

The rugged, scenic, limestone hills of the Edwards aquifer outcrop, locally known as the Hill Country, are the focus of rapidly encroaching residential and commercial development. Kipp and others (1993, p. 1) report that increased development brings a greater threat of contamination to the Edwards aquifer. According to Buszka (1987, p. 2), "Carbonate aquifers such as the Edwards are readily susceptible to ground-water contamination where the presence of pollutants coincides with the outcrop of the aquifer." The aquifer could be contaminated from spills or leakage of hazardous materials; or runoff from the rapidly developing urban areas that surround, or are built on, the intensely faulted and fractured, karstic limestone outcrops characteristic of the recharge zone. Furthermore, some of the hydrogeologic subdivisions that compose the Edwards aquifer have greater effective porosity and permeability than others, and in areas where they crop out, might provide efficient avenues for contaminants to enter the aquifer. The Barton Springs segment of the Edwards aquifer probably is most vulnerable to surface contamination in the rapidly urbanizing areas on the Edwards aquifer outcrop.

The U.S. Geological Survey, in cooperation with the Barton Springs/Edwards Aquifer Conservation District and the Texas Water Development Board, mapped the Edwards aquifer outcrop in the Barton Springs segment of the aquifer and described its 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 Edwards aquifer outcrop in the Barton Springs segment. 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. This information also will help determine the areas of the recharge zone that are most susceptible to potential contamination from land-use practices.

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 on the San Marcos platform (fig. 1) were used to map the Edwards aquifer outcrop in the Barton Springs segment. The carbonate-rock classification system of Dunham (1962) was used for the lithologic descriptions. 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. The hydrogeologic subdivisions of the Edwards aquifer outcrop in the Barton Springs segment in northeastern Hays and southwestern Travis Counties are shown on plate 1.

Recent aerial photographs were used to locate roads and excavations that could provide outcrop exposures for field examination and for orientation in the morphologically similar Edwards aquifer outcrops. In addition, stratigraphic information was ascertained by inspection of surficial expressions and features as indicated by the following examples. The basal nodular member of the Kainer Formation generally supports a luxuriant growth of juniper and oak trees and can be recognized on aerial photographs by dark bands that encircle the typically barren limestone hills of the overlying dolomitic member. The dolomitic member of the Kainer Formation can be identified on aerial photographs by a pattern of concentric rings of sparse vegetation growing on the differentially weathered limestone hills. The regional dense member of the Person Formation can be recognized on aerial photographs as small, light-to-almost-white areas.

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 northeastern Hays and southwestern Travis Counties. The upper member of the Lower Cretaceous Glen Rose Limestone, the lower confining unit (table 1), was mapped adjacent to the Edwards aquifer outcrop along the northwestern boundary of the study area (pl. 1). The upper confining unit, which comprises the Upper Cretaceous Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Group (including igneous material), and Taylor Group

Table 1. Summary of the lithologic and hydrologic properties of the hydrogeologic subdivisions of the Edwards aquifer outcrop (Barton Springs segment), northeastern Hays and southwestern Travis Counties, Texas

[Hydrogeologic subdivisions modified from Maclay and Small (1976); groups, formations, and members modified from Rose (1972); members (1), (2), (3), and (4) modified from Rodda and others (1970); lithology modified from Dunham (1962); and porosity type modified from Choquette and Pray (1970). CU, confining unit; 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	Taylor Group	CU	600	Clay; chalky limestone	Gray-brown clay; marly limestone	None	Low porosity/ low permeability
Upper Cretaceous: Upper confining unit	Austin Group	CU; rarely AQ	130 – 150	White to light-tan to gray limestone	White, chalky limestone; *Pycnodonte aucella* *Inoceramus subquadratus*	None	Low porosity; rare water production from fractures/ low permeability
Upper Cretaceous: Upper confining unit	Eagle Ford Group	CU	30 – 50	Brown, flaggy sandy shale and argillaceous limestone	Thin flagstones; petroliferous	None	Primary porosity lost/ low permeability
Upper Cretaceous: Upper confining unit	Buda Limestone	CU	40 – 50	Buff, light-gray, dense mudstone	Porcelaneous limestone	Minor surface karst	Low porosity/ low permeability
Upper Cretaceous: Upper confining unit	Del Rio Clay	CU	50 – 60	Blue-green to yellow-brown clay	Fossiliferous; *Ilymatogyra arietina*	None	None/primary upper confining unit
Lower Cretaceous: Edwards aquifer, I	Georgetown Formation	CU	40 – 60	Gray to light-tan, marly limestone	Marker fossil: *Waconella wacoensis*	None	Low porosity/ low permeability
Lower Cretaceous: Edwards aquifer, II	Edwards Group, Person Formation: Cyclic and marine members, undivided (4)	AQ	0 – 70	Mudstone to packstone; *miliolid* grainstone; chert	Boxwork vugs; light tan, massive; some *Toucasia*, *Caprinid*, and *Chondrodonta*	Many caves; might be associated with earlier karst development	Laterally extensive; both fabric and not fabric/water-yielding; one of the most porous and permeable; essentially absent in Travis County
Lower Cretaceous: Edwards aquifer, III	Edwards Group, Person Formation: Leached and collapsed members, undivided (4)	AQ	30 – 80	Crystalline limestone; mudstone to wackestone to *miliolid* grainstone; chert; collapsed breccia	Light-gray, bioturbated iron-stained beds separated by massive limestone beds; *Toucasia*, *Chondrodonta*	Extensive lateral development; large rooms	Majority not fabric/ one of the most porous and permeable
Lower Cretaceous: Edwards aquifer, IV	Edwards Group, Person Formation: Regional dense member (3)	CU	20 – 30	Light-tan, dense, argillaceous mudstone	Wispy iron-oxide stains; *Pleuromya knowltoni*, *Ceratostreon texanum*	None; only vertical fracture enlargement	Not fabric/ low permeability; vertical barrier
Lower Cretaceous: Edwards aquifer, V	Edwards Group, Kainer Formation: Grainstone member (2)	AQ	45 – 60	Light-gray, *miliolid* grainstone; mudstone to wackestone; chert	White crossbedded grainstone; *Toucasia*, *Turritella*, and *Chondrodonta*	Few caves	Not fabric/ recrystallization reduces permeability
Lower Cretaceous: Edwards aquifer, VI	Edwards Group, Kainer Formation: Kirschberg evaporite member (1)	AQ	65 – 75	Light-gray, crystalline limestone; chalky mudstone; chert	Boxwork voids, with neospar and travertine frame; *Cladophyllia* and *Turritella*	Probably extensive cave development	Majority fabric/ one of the most porous and permeable
Lower Cretaceous: Edwards aquifer, VII	Edwards Group, Kainer Formation: Dolomitic member (1)	AQ	110 – 150	Mudstone to grainstone; crystalline limestone; chert	Massively bedded, light gray, *Toucasia* abundant; *Dictyoconus walnutensis*, *Caprinid*	Caves related to structure or bedding planes	Mostly not fabric; some bedding-plane fabric/ water-yielding; locally permeable
Lower Cretaceous: Edwards aquifer, VIII	Edwards Group, Kainer Formation: Basal nodular member	Karst AQ; not karst CU	45 – 60	Shaly, fossiliferous, nodular limestone; mudstone; *miliolid* grainstone	Massive, nodular and mottled; *Ceratostreon texanum*, *Dictyoconus walnutensis*, and *Texigryphaea*	Few caves	Fabric/low permeability
Lower Cretaceous: Lower confining unit	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	Some surface cave development	Some water production at evaporite beds/ relatively impermeable

were mapped along the eastern and southeastern boundary of the study area.

Faults were identified in the field by stratigraphic displacement and characteristics related to faulting, such as juxtaposition of unlike formations or members; abrupt change in lithology; slickensides; relatively thick, sometimes vein-like masses of subhedral to anhedral calcite crystals; zones of breccia; and fault gouge composed of soils that greatly resemble caliche, some of which contain cobbles or boulders. Steeply inclined strata, uncommon in the relatively flat-lying Edwards aquifer outcrop, typically represent drag-folding related to faulting. In addition, sharp stream offsets, fractures, lineaments, caves, and springs also might indicate faults.

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 Hays County (Hanson and Small, 1995) does not everywhere match the map of this report.

Acknowledgments

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GEOLOGIC FRAMEWORK

General Features

Northeast-trending faults of the Balcones fault zone (fig. 1) cross northeastern Hays and southwestern Travis Counties. Balcones faults are en echelon, normal, high-angle, and generally downthrown to the southeast in this area. The Mount Bonnell fault (pl. 1), located on the western boundary of the Balcones fault zone, is the major fault of the Balcones fault zone in Travis County (Sellards, 1930). The Mount Bonnell fault continues to the southwest into Hays County, where it is known as the Tom Creek fault (DeCook, 1963). Damon (1924) measured the throw of the Mount Bonnell fault on the north side of the Colorado River to be approximately 670 feet (ft), with the downthrown block to the east. According to Senger and Kreitler (1984, p. 4), displacement on the Mount Bonnell fault decreases to the south, and "* * * throws of en echelon faults east of Mount Bonnell fault generally are less than 50 ft (15 m) in the northwestern part of the zone; these faults increase in displacement to the south toward Hays County." A generalized hydrogeologic section (fig. 2) begins in Hays County just west of the Tom Creek fault (pl. 1), crosses the Edwards aquifer outcrop, and ends in Travis County just east of I–35. This hydrogeologic section illustrates mostly down-to-the-east normal faults and an uneven, but generally southeastern regional dip. The section indicates that Edwards aquifer rocks are placed against progressively younger upper Cretaceous rocks toward the southeastern boundary of the study area.

Geomorphic expression of faulting on the upthrown fault blocks is indicated on topographic maps by the branching of subsequent valleys normal to the consequent valleys, forming a "T-square" morphology of the valleys. The formation of the consequent valleys resulted from the drop in base level of the downthrown block, which initiated headward erosion on the escarpment. The development of the subsequent valleys possibly is the result of faults structurally weakening the consequent valley slopes creating the T-square pattern normal to the natural course of headward erosion (Thornbury, 1962).

Stratigraphy

The Edwards aquifer rocks that crop out in the Barton Springs segment of the Edwards aquifer have, in general, the same lithological characteristics as the Edwards aquifer rocks that crop out in Comal and southwestern Hays Counties (fig. 1). The Edwards Group (table 1) is about 315 to 525 ft thick in the Barton Springs segment of the Edwards aquifer in northeastern Hays and southwestern Travis Counties. The Edwards Limestone of DeCook (1963) is roughly equivalent to the Edwards Group of Rose (1972). According to DeCook (1963, p. 27), the rocks that compose the Edwards aquifer outcrop, except for the Georgetown Formation, generally consist of "* * * light-gray,

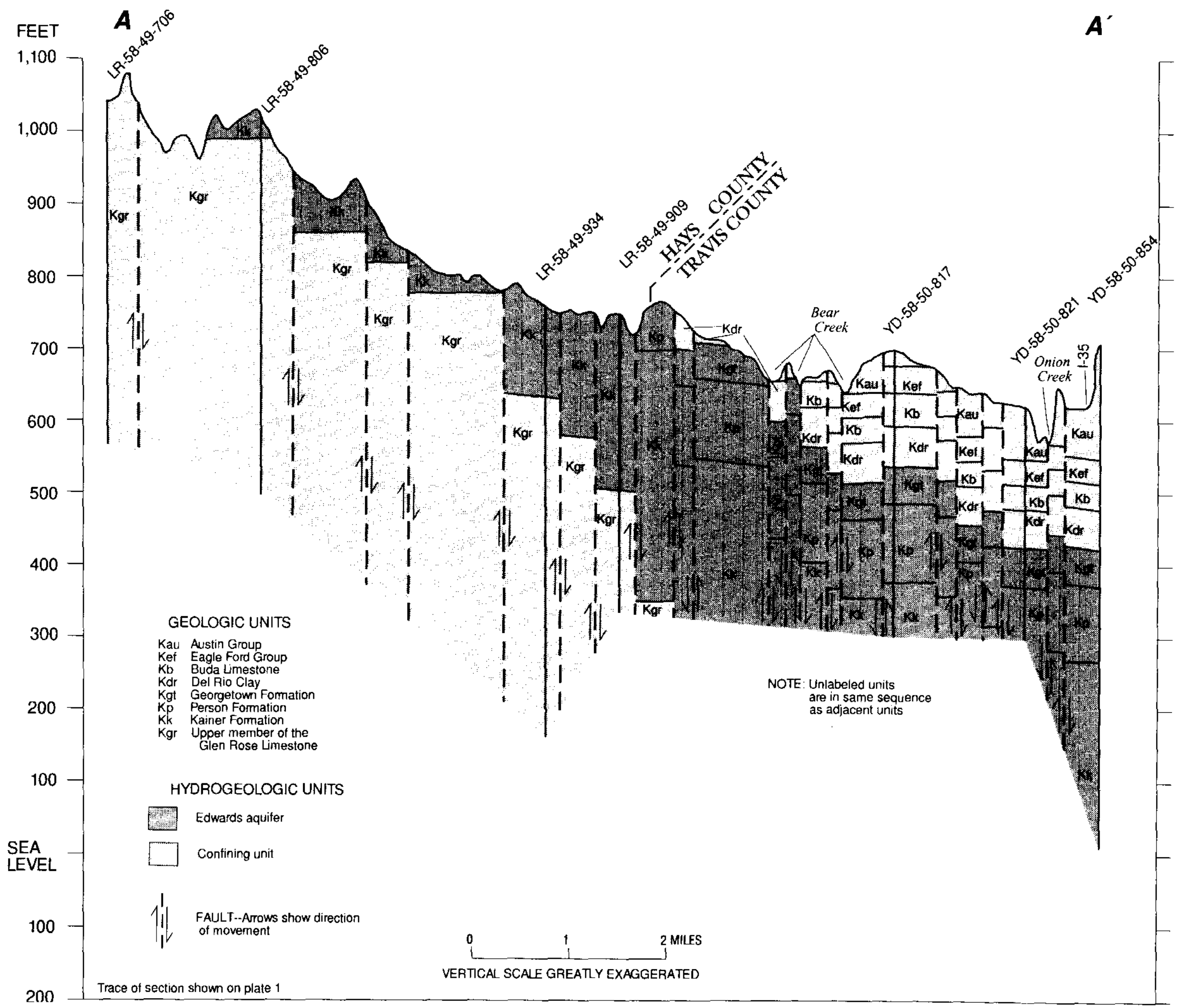

Figure 2. Generalized hydrogeologic section *A–A′* of the Edwards aquifer (Barton Springs segment), northeastern Hays and southwestern Travis Counties, Texas.

brittle, thick-bedded to massive limestone, commonly dolomitic, containing minor beds of argillaceous or siliceous limestone and calcareous shale. Bedded or nodular chert and flint characterize much of the formation." Hill (1901) reported that these rocks are the only flint horizons in the Cretaceous deposits of the United States. This information is useful when mapping the outcrop of the Edwards Group. Massive, nodular limestone beds at the lower part of the Kainer Formation conformably overlie the alternating marl and limestone beds of the upper member of the Glen Rose Limestone in the Barton Springs segment. 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 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 considered part of the aquifer. Except for the Georgetown Formation, the strata that compose the Edwards aquifer were deposited in shallow to very shallow marine water (Rose, 1972) and reflect depositional environments resulting from slight changes in water level, water chemistry, 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.

Rodda and others (1970) mapped the geology of a quadrangle in the western part of Austin in Travis County. Rodda and others (1970) described the upper member of the Glen Rose Limestone, the Walnut Formation (basal nodular member equivalent), and the Edwards Formation (Edwards Group equivalent minus the basal nodular member). Rodda and others (1970, p. 4) described the Edwards aquifer rocks as characterized by rudist limestones, dolomite, nodular chert, and solution collapse features. As stated by Rodda and others (1970, p. 4), "A complete Edwards section is not exposed in the Austin area, but regional relationships suggest that the Edwards is about 300 ft thick * * *."

Rodda and others (1970, p. 4) subdivided the Edwards Formation into four informal members (table 1), which are roughly equivalent to the Edwards Group (Rose, 1972). Members 1 and 2 are equivalent to the Kainer Formation and members 3 and 4 are equivalent to the Person Formation (Senger and Kreitler, 1984).

In central Texas, the Walnut Formation traditionally has been applied to oyster shell marls and marly limestones that overlie the upper member of the Glen Rose Limestone and underlie the massive rudist- and chert-bearing Edwards Formation (Rodda and others, 1970, p. 3). In the Travis County part of the Barton Springs segment, the Walnut Formation appears to be stratigraphically and lithologically equivalent to the basal nodular member of the Kainer Formation in Hays County. Therefore, in this report, the basal nodular member (table 1) is used in Travis County to refer to rocks generally known as the Walnut Formation.

In Hays and Travis Counties, the basal nodular member is the lowermost unit of the Kainer Formation. The basal nodular member is about 45 to 60 ft thick and generally is a dense, shaly, fossiliferous, nodular limestone; or mudstone, with some *miliolid* grainstone.The fossil oyster *Ceratostreon texanum*, formerly *Exogyra texana*, is scattered throughout the member and is abundant in places. In Travis County, the basal nodular member generally is a marly, fossiliferous, nodular, burrowed mudstone, with some *miliolid* grainstone. The fossil oyster *Ceratostreon texanum* also is scattered erratically throughout the member and is abundant locally. In Travis County, *Dictyoconus walnutensis*, a small foraminifera, is abundant in a narrow zone near the top of the formation (Moore, 1967; Rodda and others, 1970). The pelecypod *Texigryphaea* also is scattered throughout the upper part of the formation.

The next higher member, the 110- to 150-ft-thick dolomitic member, is equivalent to the lower part of member 1 of Rodda and others (1970, p. 4). The dolomitic member is a light-gray, dense crystalline limestone with local zones of grainstone and layers of variably burrowed mudstone. The mudstone is strongly dissolutioned in places. A massive *Caprinid* bed is found in the lower one-half of the member; and a 5- to 7-ft-thick zone of thin, rhythmic beds that closely resemble the regional dense member is located near the middle of the member. Chert nodules and thin, discontinuous beds of chert are scattered throughout the member; and rudists, typically *Toucasia*, are common locally. In Travis County, the small foraminifera

Dictyoconus walnutensis is common in a tan-gray, 3-ft-thick zone near the top of the member.

The Kirschberg evaporite member overlies the dolomitic member, is 65 to 75 ft thick in the Barton Springs segment, and is equivalent to the top of member 1 of Rodda and others (1970, p. 4). The Kirschberg evaporite member consists of light-gray, crystalline limestone and chalky to pulverulitic mudstone commonly containing chert nodules and lenses. *Cladophyllia* coral, *Turritella*, and pelecypod steinkerns and molds are common. Boxwork structure thought to represent dissolution of evaporites is common locally. Red clay soils frequently overlie exposures of the Kirschberg evaporite member. Most cave development is in the Kirschberg evaporite member.

The grainstone member overlies the Kirschberg evaporite member and is the uppermost member of the Kainer Formation. This member is equivalent to member 2 of Rodda and others (1970, p. 4) in Travis County. The grainstone member is 45 to 60 ft thick and primarily is a very hard, light-gray to almost white, tightly cemented, *miliolid* grainstone; however, patches of mudstone to wackestone are scattered throughout. Chert nodules and layered chert are common in this member. Locally, *Toucasia* and stubby, spar-filled *Turritella* gastropods are common near the top of the member. *Chondrodonta*, in approximately the same stratigraphic interval as *Toucasia*, also is common. A wackestone containing *Chondrodonta*, *Caprinid*, *Cladophyllia*, and *Monopleura* fossils is found in the middle of the grainstone member in Travis County.

The Person Formation (Rose, 1972) ranges in thickness from less than 50 ft near the Colorado River in Travis County to about 180 ft in the southern part of the study area. The lithology of the Person Formation ranges from mudstone to layers of intensely burrowed mudstone to grainstone to crystalline limestone. The regional dense member is the lowermost unit of the Person Formation and consists of light-tan, dense, argillaceous mudstone with distinctive, wispy, iron-oxide stains (Rose, 1972, p. 25). This member is about 20 to 30 ft thick and is roughly equivalent to member 3 of Rodda and others (1970, p. 5) in Travis County. The fossil clam *Pleuromya knowltoni* is characteristic of this member. *Monopleurid* fossils, and fossil oysters tentatively identified as *Ceratostreon texanum*, are found in the upper one-half of the regional dense member but are not common.

The 30- to 80-ft-thick leached and collapsed members, undivided, overlie the regional dense member. The leached and collapsed members, undivided, were mapped as one unit because they cannot be distinguished as separate members. Senger and Kreitler (1984, p. 4) indicate that the leached and collapsed members, undivided, are roughly equivalent to member 4 of Rodda and others (1970, p. 5). The lithology of the leached and collapsed members, undivided, generally consists of light-gray to light-tan wackestone with lesser amounts of variably burrowed mudstone, grainstone, and crystalline limestone; chert lenses are common as well. The collapsed zones common in this member were caused by the collapse of the overlying limestone into the voids created by early dissolution of the thin evaporite layers and lenses (Rose, 1972, p. 55). The lower 15 ft of the member commonly contains a large collapsed zone. *Toucasia*, *Chondrodonta*, and *miliolid* fossils are characteristic to this member. The base of the member is particularly fossiliferous and contains packstones or grainstones consisting of *Toucasia*, *Chondrodonta*, *Caprinid*, *miliolid*, and rarely *Cladophyllia* fossils.

The cyclic and marine members also were mapped as one unit. According to Rose (1972, p. 71), the cyclic member and much of the marine member were eroded from the axis of the San Marcos platform before deposition of the Georgetown Formation. The cyclic and marine members, undivided, are about 70 ft thick in the southern part of the study area but is essentially absent in Travis County. In the Hays County part of the Barton Springs segment, the lower part of the cyclic and marine members, undivided, consists of light gray-tan, medium-thick to thick beds of variably honeycombed and variably fossiliferous mudstone to packstone with lenses of *miliolid* grainstone. Rudistids, mostly *Caprinid* fossils are relatively common and sometimes form biostromes. *Toucasia* fossils are common locally near the contact with the overlying Georgetown Formation. Chert nodules are common throughout the member. In Travis County, rocks of the marine member range from a pale yellow-tan to light-brown, *miliolid*, *Toucasia*, *Chondrodonta*, and *Caprinid* packstone to a bored, oxidized, *miliolid*, *Toucasia*, *Caprinid* wackestone.

Complete sections of the Edwards Group are not well exposed in the Travis County part of the Barton Springs segment because of faulting and erosion. However, partial sections of 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 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 contact of the Georgetown Formation and the underlying Person Formation is, in places, a slightly red-brown, oxidized, bored, and pitted horizon. The thickness of the Georgetown Formation increases across the Barton Springs segment from about 40 ft in the south to about 60 ft in the north. The lithology of the Georgetown Formation generally consists of gray to light-tan, marly, fossiliferous limestone, usually containing ammonites, oyster-like clams, and the brachiopod *Waconella wacoensis*, formerly *Kingena wacoensis* (Roemer), which is an excellent marker fossil for the Georgetown Formation. Other characteristic Georgetown Formation fossils include *Arctostrea carinata*, formerly *Alectryonia carinata*, and *Texigryphaea washitaensis*.

The Upper Cretaceous Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Group, and Taylor Group overlie the Georgetown Formation and form the upper confining unit of the Edwards aquifer in the Barton Springs segment (table 1). The Del Rio Clay is 50 to 60 ft thick and is a dark blue-green to yellow-brown, variably gypsiferous clay, commonly containing pecten-type fossil clams and an abundance of the fossil oyster *Ilymatogyra arietina*, formerly *Exogyra arietina* (Roemer). These fossil oysters are known locally as "rams horns." The Buda Limestone consists of about 40 to 50 ft of dense, variably nodular, sublithographic or "porcelaneous" limestone (Sellards and others, 1933, p. 397); and light-gray to buff mudstone, commonly containing calcispheres and tiny calcite-filled fractures. The Eagle Ford Group is about 30 to 50 ft thick and consists of thin flagstones of brown, flaggy, sandy shale and argillaceous limestone. Some of the freshly fractured flagstones (thin, brittle slabs) emit a petroliferous odor. Fish teeth are found in the Eagle Ford Group but are rare. The Austin Group is about 130 to 150 ft thick and consists of light-tan to white-to-gray, chalky, variably marly, generally fossiliferous limestone commonly containing the fossil oyster *Pycnodonte aucella*, formerly *Gryphaea aucella*. The pelecypod *Inoceramus subquadratus* is found in the lower 100 ft of the formation (Young and Marks, 1952). Dark, calcareous clays of the lower part of the Taylor Group form the upper layer of the upper confining unit.

Soft, highly weathered, igneous material was found in several locations in the Barton Springs segment in Travis County (pl. 1). Hill and Vaughan (1898) noted the occurrence of basaltic intrusive rocks within a short distance east of the study area, and Young and others (1975; 1982) examined some of the igneous exposures in the study area and believe that they represented explosion craters that were active during deposition of the Austin Group.

Field identification of the various members in the Kainer and Person Formations was based on their characteristic lithologies and fossils (table 1). Red clay soil that resembles the "terra rossa" of Pleistocene age, described by Young (1986, p. 63) as a diagenetically altered paleosol, commonly is evident in outcrops of the Edwards Group but rarely in the Glen Rose Limestone or in the clays, marls, or limestones of the upper confining unit.

In the southern part of the study area in Hays County, the lithologic similarities between the leached and collapsed members, undivided, and the cyclic and marine members, undivided, of the Person Formation make the contact between the two difficult to determine. In this area, the approximate stratigraphic thickness and distance above or below a marker bed was used to locate the approximate contact and identify the unit. A unique colonial coral, identified as *Montastrea* sp. (Finsley, 1989), was observed in places in the lower to middle part of the leached and collapsed members, undivided, but is not common.

HYDROGEOLOGIC CHARACTERISTICS

General Features

Major factors controlling porosity and permeability in the Edwards aquifer outcrop are faulting, stratification, and karstification—a form of diagenesis resulting from extensive dissolution of limestone. Zones of faulted, fractured, and dissolutioned limestone, along with layers of burrowed, honeycombed, and locally cavernous limestone, are common in the Edwards aquifer outcrop. The karst features of the Edwards Group rocks in northeastern Hays and southwestern Travis Counties are characterized by resistant terrain of dense limestone, sparsely dotted with sinkholes and caves that can greatly enhance porosity and permeability.

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.

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. Choquette and Pray (1970, p. 250) noted that vugs and channels are similar in that neither is fabric selective. Vugs and channels differ in shape; "vug" is used to describe the more equidimensional pores; whereas, "channel" is used to describe markedly elongated pores or irregular openings with a marked elongation in one or two dimensions.

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 pore size, shape, and distribution. 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 degree of interconnection of pores and vugs also directly affects permeability. The eight hydrogeologic subdivisions of the Edwards aquifer, the names of the corresponding members, and the type of porosity and permeability observed in the field within the subdivisions are discussed below in ascending order.

Hydrogeologic subdivision VIII (basal nodular member) has little porosity or permeability in the marly facies in the northeastern part of the study area, but might have some interparticle porosity and permeability in the *miliolid* grainstone and nodular limestone beds in the southwestern part of the study area. This subdivision is locally, but not regionally, porous or permeable.

Hydrogeologic subdivision VII (dolomitic member) has local channel porosity and permeability along solution-enlarged bedding planes. This subdivision also has moldic and cavern porosity and permeability associated with Backdoor Spring Cave in a massive *Caprinid* bed near the base of the member on Barton Creek (pl. 1). The rhythmic bed near the middle of the subdivision might act as a minor confining bed, except where it is breached, as it is by Midnight Cave. Breccia and vuggy porosity and permeability associated with faulting are common. Vuggy porosity and permeability also are common in the burrowed zones. Locally, this subdivision is porous and permeable.

Hydrogeologic subdivision VI (Kirschberg evaporite member) generally has common to abundant intercrystalline porosity in the chalky, pulverulitic mudstone, and locally abundant vuggy porosity and permeability associated with faulting and possible evaporite dissolution (Maclay and Small, 1976). Cave and sinkhole development is extensive in this subdivision. This subdivision has both fabric selective and not fabric selective porosity and permeability, and appears to be the most porous and permeable hydrogeologic subdivision in the Kainer Formation.

Hydrogeologic subdivision V (grainstone member) has widely separated interparticle and intraparticle porosity and little permeability in the dense, tightly cemented *miliolid* grainstone, and fracture porosity and permeability associated with faulting in the lower part of the subdivision. Many caves, such as Whirlpool and Cave Y (pl. 1), have entrances in the lower part of this subdivision, although most of the caves are developed in hydrogeologic subdivision VI. Locally, this subdivision is porous and permeable, but overall it is not very porous or permeable.

Hydrogeologic subdivision IV (regional dense member) has a few vertical-shaft caves that breach the subdivision; otherwise, it has little porosity or permeability, except for that associated with faulting. This subdivision probably is the least porous or permeable subdivision and locally might be a confining unit within the Edwards aquifer.

Hydrogeologic subdivision III (leached and collapsed members, undivided) has vuggy and burrow porosity and permeability associated with burrowed zones, breccia and cavern porosity and permeability associated with collapsed zones resulting from dissolution of evaporites, and fracture porosity and permeability associated with faulting. Airmans Cave, Sunset Valley Cave, Driskill Cave (pl. 1), and numerous other caves are developed in this interval. Most of these caves are horizontal and perched above hydrogeologic subdivision IV; however, Sunset Valley Cave and Driskill Cave have developed as vertical shafts.This subdivision appears to be as porous and permeable as subdivision VI.

Hydrogeologic subdivision II (cyclic and marine members, undivided) has moldic and vuggy porosity and permeability associated with rudist zones and with faulting in the southwestern part of the study area. In that area, it is almost as porous and permeable as subdivision III.

Hydrogeologic subdivision I (Georgetown Formation) generally has little porosity and permeability. DeCook (1963, p. 35) stated that, "The shale, marl, and compact limestones of the Georgetown are relatively impermeable and the formation acts as an upper confining bed for water in the Edwards limestone." A few vertical shafts, such as Antioch Cave (pl. 1), breach the subdivision into the underlying subdivision.

SUMMARY

The Barton Springs segment of the Edwards aquifer is a major source of water for northeastern Hays and southwestern Travis Counties. The aquifer primarily consists of dissolution-modified, faulted limestone. The Barton Springs segment is recharged in the areas where it crops out in the Balcones fault zone.

In the Barton Springs segment, the Edwards aquifer probably is most vulnerable to surface contamination in the rapidly urbanizing areas on the Edwards aquifer outcrop. Contamination can result from spills or leakage of hazardous materials; or runoff on the intensely faulted and fractured, karstic limestone outcrops characteristic of the recharge zone.

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 generally coincide with the eight informal hydrogeologic subdivisions of the Edwards aquifer, which include the overlying Georgetown Formation. The Edwards aquifer rocks that crop out in the Barton Springs segment of the Edwards aquifer have, in general, the same lithological characteristics as the Edwards aquifer rocks that crop out in Comal and southwestern Hays Counties. However, in the northeastern part of the segment in Travis County, the rock unit that is apparently equivalent to the basal nodular member of the Kainer Formation is called the Walnut Formation. Because the rock units appear to be stratigraphically and lithologically equivalent, the basal nodular member is used instead of the Walnut Formation for this report. Essentially all of hydrogeologic subdivision II (cyclic and marine members, undivided, of the Person Formation), which is about 70 ft thick in Hays County, is missing in Travis County.

The major factors controlling porosity and permeability in the Edwards aquifer outcrop are faulting, stratification, and karstification. Karst features in the study area, which can greatly enhance porosity and permeability, include sinkholes 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 pore size, shape, distribution, fissuring, dissolution, and interconnection of pores and vugs. 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. Rocks of these subdivisions appear to be equally susceptible to contamination from surface sources. Hydrogeologic subdivision II (cyclic and marine members, undivided, of the Person Formation) also is quite porous and permeable in Hays County.

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Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop (Barton Springs segment), Travis County, Texas

[Section starts at contact of Edwards Group with the overlying Georgetown Formation. ft, feet; sp., species; RDM, regional dense member; in., inches]

Description	Thickness (ft)	Cumulative thickness (ft)
Cyclic and marine members, undivided (essentially absent in Travis Co.)		
Leached and collapsed members, undivided		
Bored and iron-oxidized unconformable surface	0	0
Covered	1.6	1.6
Grainstone, light tan, allochem	.9	2.5
Mudstone, light tan, burrowed, *Toucasia*	1.9	4.4
Mudstone, light tan; *Toucasia* and spar-filled shell fragment	3.5	7.9
Wackestone, light tan gray; *Caprinid* and *Toucasia*	4.8	12.7
Packstone (biostrome?), light tan gray; *Chondrodonta* and *Toucasia*; corrals, tentatively identified as *Montastrea* sp. occasionally found 20 to 40 ft above contact of the RDM	5.8	18.5
Mudstone, light tan gray, punky; pinpoint intercrystalline porosity	8.5	27
Wackestone, light tan; allochem and *miliolid*	1.2	28.2
Mudstone, light tan	3.5	31.7
Mudstone, light tan; wispy, with a few spar-filled shell fragments	.4	32.1
Mudstone, tan brown; good vuggy porosity	2.8	34.9
Mudstone, tan; wispy, with *Toucasia* fragments	1.2	36.1
Mudstone, tan; *Toucasia* fragment	1	37.1
Mudstone, tan brown; excellent vuggy porosity	7.4	44.5
Mudstone, light tan gray, punky to pulverulitic; pinpoint intercrystalline porosity	3.5	48
Mudstone, light tan	2	50
Mudstone, light tan, with a few spar-filled shell fragments	2.7	52.7
Mudstone, light tan, *miliolid*	1.3	54
Mudstone, light tan; *miliolid*, with a few spar-filled shell fragments	.7	54.7
Mudstone, light tan	1.7	56.4
Mudstone, light tan gray, punky, dissolutioned; good burrow porosity	3.4	59.8
Wackestone, light tan gray, *Toucasia*	2.7	62.5
Regional dense member		
Mudstone, tan, argillaceous; wispy, with a few *Monopleura*	2.5	65
Mudstone, tan to tan gray, nodular argillaceous; wispy, *Pleuromya knowltoni* (index fossil for RDM), *Protocardia* sp., *Exogyra* sp. wackestone	17.1	82.1
Mudstone, light tan gray, wispy	2.6	84.7
Mudstone, light brown; vuggy porosity with terra rossa infilling	.8	85.5
Mudstone, light tan gray, wispy	1.1	86.6
Mudstone, light tan gray, porcelaneous, wispy	2	88.6
Mudstone, light tan, fissile, wispy	2.6	91.2
Grainstone member		
Grainstone, light tan; *miliolid*, with stubby spar-replaced *Turritella* and round to subround clasts that resemble RDM lithology	1.6	92.8
Grainstone, light tan; *miliolid*, with *Toucasia*	.9	93.7
Packstone, light tan; *miliolid*, with few spar-replaced shell fragments	2.9	96.6
Mudstone, light tan; *miliolid* and *Toucasia* wackestone	1.8	98.4
Mudstone, light tan gray, wispy (resembles RDM)	.6	99
Mudstone, light tan, mottled	1.8	100.8
Mudstone, light tan, with few black specks (shell fragments or fecal material?)	.8	101.6
Mudstone, light tan, fissile	.4	102

Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop (Barton Springs segment), Travis County, Texas—Continued

Description	Thickness (ft)	Cumulative thickness (ft)
Grainstone member—Continued		
Mudstone to *miliolid* grainstone, light tan; spar-replaced *Turritella*; shell fragments, with black specks; abrupt change at upper and lower bedding planes (storm surge?)	2	104
Mudstone, light tan, thin-bedded	.3	104.3
Mudstone, light tan, *miliolid*; spar-replaced pelecypod fragments; blue-gray chert nodules at 105 ft	1.2	105.5
Wackestone, light tan gray; *Chondrodonta* and *Toucasia*; scattered *miliolids*	3.2	108.7
Wackestone, light tan gray; *Chondrodonta*, *miliolid*, and shell fragment	4.6	113.3
Mudstone, light tan, wispy	.3	113.6
Packstone, light tan, *miliolid*	1.3	114.9
Mudstone, light tan gray, *miliolid*	.6	115.5
Chert bed, blue gray	.3	115.8
Limestone, tan white, recessive, pulverulitic; *Chondrodonta*, *Caprinid*, *Cladophyllia*, and *Monopleura* wackestone (biostrome?); 3- to 4-in. blue-gray chert bed at 121 ft; blue-gray chert nodules at 123 ft; intercrystalline to cavernous porosity	7.7	123.5
Mudstone, light tan gray	1.1	124.6
Micrite, light tan, punky; good vuggy porosity	2.3	126.9
Wackestone, tan brown, *miliolid*	1.5	128.4
Mudstone, light tan gray, punky, with light gray chert nodules; collapsed breccia porosity	2.7	131.1
Mudstone, tan gray, crinkly bedded (algal?)	.9	132
Micrite, tan gray, punky; vuggy porosity	.4	132.4
Wackestone to grainstone, tan; *miliolid*, with blue-black chert nodules at 134 ft	3.1	135.5
Kirschberg evaporite member		
Chert, black to blue gray	.5	136
Limestone, tan white, recessive, pulverulitic; intercrystalline to cavernous porosity	3.2	139.2
Mudstone, tan white, punky, dedolomitized, with small *Turritella* and pelecypod molds; pinpoint to moldic porosity	7.1	146.3
Mudstone, light tan, punky; intercrystalline porosity; blue-brown chert nodules	4.3	150.6
Mudstone, light tan, dedolomitized; pelecypod molds common; pinpoint to moldic porosity	3.3	153.9
Mudstone, light tan	1.3	155.2
Mudstone, tan white, punky; 2-in. algal mat at 155.4 ft; intercrystalline porosity	4.6	159.8
Mudstone, light tan, dedolomitized, with pelecypod and *Turritella* molds; pinpoint to moldic porosity	1.9	161.7
Mudstone, light tan	1.3	163
Chert, brown; 5-in. thick	.4	163.4
Mudstone, light tan, punky	2.6	166
Wackestone, tan, *miliolid*	.6	166.6
Mudstone, light tan to tan gray, punky, wispy	1.4	168
Mudstone, light tan, rhythmic bedded	.7	168.7
Mudstone, light tan, dedolomitized, wispy; pinpoint to fenestral porosity	.9	169.6
Limestone, light tan, pulverulitic; intercrystalline porosity	4.1	173.7
Mudstone, light tan gray, punky, with pelecypod molds; intercrystalline to moldic porosity	1.4	175.1
Limestone, light tan gray, pulverulitic; intercrystalline porosity	1	176.1
Micrite, light tan, punky, wispy	.8	176.9
Limestone, light tan gray, pulverulitic, with pelecypod molds; intercrystalline to moldic porosity	.3	177.2
Mudstone, light tan, punky, dedolomitized, with *Turritella* and pelecypod molds; intercrystalline to moldic porosity	2.9	180.1
Mudstone, tan, punky, dedolomitized, with scattered brown to blue-gray chert nodules	5.8	185.9
Mudstone, tan, very porous, with euhedral to subhedral calcite concretions; dissolutioned burrow porosity	6.1	192
Mudstone, tan, punky to pulverulitic, with calcite concretions; collapsed with relict bedding; intercrystalline to breccia porosity	11.2	203.2

Table 2. Description of composite stratigraphic section of the Edwards aquifer outcrop (Barton Springs segment), Travis County, Texas—Continued

Description	Thickness (ft)	Cumulative thickness (ft)
Dolomitic member		
Mudstone, tan; dissolutioned burrow porosity	5.5	208.7
Wackestone, tan gray; *Dictyoconus walnutensis*, with scattered shell fragments	11.4	220.1
Mudstone, tan gray, punky to pulverulitic; intercrystalline porosity	2.9	223
Mudstone, tan, wispy	3.0	226
Wackestone, light tan, *miliolid*	.8	226.8
Grainstone, light tan; *miliolid*, upgrading to *miliolid* wackestone with spar-filled shell fragments	2.2	229
Mudstone, tan white, pulverulitic; mottled and iron-oxide stained	2.2	231.2
Mudstone to wackestone, tan, *miliolid*, with iron-oxide stains	1.8	233
Mudstone, tan, *miliolid*; dissolutioned burrows, some infilled with chert; burrow porosity	4.6	237.6
Mudstone to wackestone, light tan; *miliolid*, with spar-replaced pelecypod fragments	5.2	242.8
Mudstone, tan; 2-in. sparrite seam at 243 ft	1.5	244.3
Mudstone, tan gray, vuggy; good vuggy porosity	1.2	245.5
Mudstone, light tan gray, wispy (mimics RDM); rhythmic, thin to medium beds	8.8	254.3
Mudstone, tan gray; *Toucasia* and *Neithea* sp. wackestone, with some *miliolids*	8.1	262.4
Mudstone, tan, punky to pulverulitic; intercrystalline porosity	4	266.4
Mudstone, tan, wispy; *Toucasia* fragments and scattered *miliolids*	5.2	271.6
Mudstone, light tan, with spar-replaced pelecypod fragments	4.1	275.7
Grainstone to packstone, light tan, *miliolid* and allochem; black specks (fecal?) toward top	5.4	281.1
Mudstone, tan, vuggy; *Caprinid* molds; *Chondrodonta* and chert; excellent moldic porosity	1.5	282.6
Mudstone, light tan gray, punky, with some chert	6.2	288.8
Grainstone to packstone, light tan, *miliolid*	2.9	291.7
Mudstone, light tan, with scattered chert nodules	8.4	300.1
Mudstone, light tan; vuggy porosity	1.5	301.6
Mudstone, light tan	3.2	304.8
Mudstone, tan; vuggy porosity	8.7	313.5
Wackestone, tan; *Turritella* and shell fragment	2.9	316.4
Basal nodular member		
Mudstone, light tan, marly; nodular, with *Salenia* sp., *Texigryphaea* sp., and *Ceratostreon texanum*	11.9	328.3
Inaccessible	5.9	334.2
Mudstone, light tan gray; marly, nodular, with *Texigryphaea* sp.	7.9	342.1
Mudstone, light tan gray; marly, nodular, with *Texigryphaea* sp., *Ceratostreon texanum*, and *Turritella*; pelecypods, echinoids, and *Neithea* sp.	9.2	351.3
Mudstone, light gray, dense, with shell fragments and *Ceratostreon texanum*	3.2	354.5
Mudstone, light tan, burrowed, with *Texigryphaea* sp., *Ceratostreon texanum*, and pelecypods; *Turritella* wackestone	1.3	355.8
Mudstone to *miliolid* grainstone, light tan, dense, with *Ceratostreon* fragments; bitumen-lined stylolite at 350 ft	3.5	359.3
Wackestone, light tan gray, burrowed, with *Protocardia* sp., *Ceratostreon texanum*, *Turritella*, and *Gryphaea*	5.8	365.1
Mudstone, light gray tan, burrowed, with some *Turritella*	3.3	368.4
Wackestone, light gray; *Turritella*, with *Tylostoma* sp., echinoids, and echinoid spines	3.7	372.1
Mudstone, light gray, burrowed, with *Ceratostreon texanum* and *Turritella*	5.2	377.3
Contact of the Edwards Group with the upper member of the Glen Rose Limestone		

GEOLOGIC FRAMEWORK AND HYDROGEOLOGIC CHARACTERISTICS OF THE EDWARDS AQUIFER OUTCROP (BARTON SPRINGS SEGMENT), NORTHEASTERN HAYS AND SOUTHWESTERN TRAVIS COUNTIES, TEXAS

US. GEOLOGICAL SURVEY

(1) Large Scale Map located in the Official File, may be copied upon request.

Hydrogeologic Subdivisions of the Edwards Aquifer Outcrop Plate 1

Please Contact Research and Planning Fund Grants Management Division (512) 463-7926