USGS
science for a changing world

Geologic Map of the Edwards Aquifer In Northern Medina and Northeastern Uvalde Counties, South-central Texas

Open-File Report 2006-1372

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

GEOLOGIC MAP OF THE EDWARDS AQUIFER IN NORTHERN MEDINA AND NORTHEASTERN UVALDE COUNTIES, SOUTH-CENTRAL TEXAS

By Allan K. Clark[1], Jason R. Faith[1], Charles D. Blome[2], and Diana E. Pedraza[1]

OPEN-FILE REPORT 2006-1372

[1]U.S. Geological Survey, San Antonio, TX 78249

[2]U.S. Geological Survey, Denver, CO 80225

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2006

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod/
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
Its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov/
Telephone 1-888-ASK-USGS

Contents

Plate

Figure

GEOLOGIC MAP OF THE EDWARDS AQUIFER IN NORTHERN MEDINA AND NORTHEASTERN UVALDE COUNTIES, SOUTH-CENTRAL TEXAS

By Allan K. Clark[1], Jason R. Faith[1], Charles D. Blome[2], and Diana E. Pedraza[1]

INTRODUCTION

The southern segment of the Edwards aquifer in south-central Texas (fig. 1) is one of the most productive subsurface reservoirs of ground water in the world, providing water to more than a million people in the San Antonio region. The Environmental Protection Agency (EPA) has declared the aquifer to be a sole-source water supply (van der Leeden and others, 1990). In the study area, the upper Trinity aquifer (Glen Rose Limestone) forms the catchment area for the Edwards aquifer, and it intercepts some surface-water flow above the Edwards recharge zone. The Trinity may also contribute to the Edwards' water budget by subsurface flow across formation boundaries at depth. Dissolution, karst development, and faulting/fracturing in both aquifers directly control aquifer geometry by compartmentalizing the aquifer and creating unique ground-water flowpaths. The map coverage of this report includes the Edwards aquifer catchment area, the entire recharge zone, plus an updip fringe of the confined zone, between the Sabinal River (on the west) and the Medina River (on the east) in northern Medina and northeastern Uvalde Counties. The northern boundary coincides with the northern limits of Medina and Uvalde Counties.

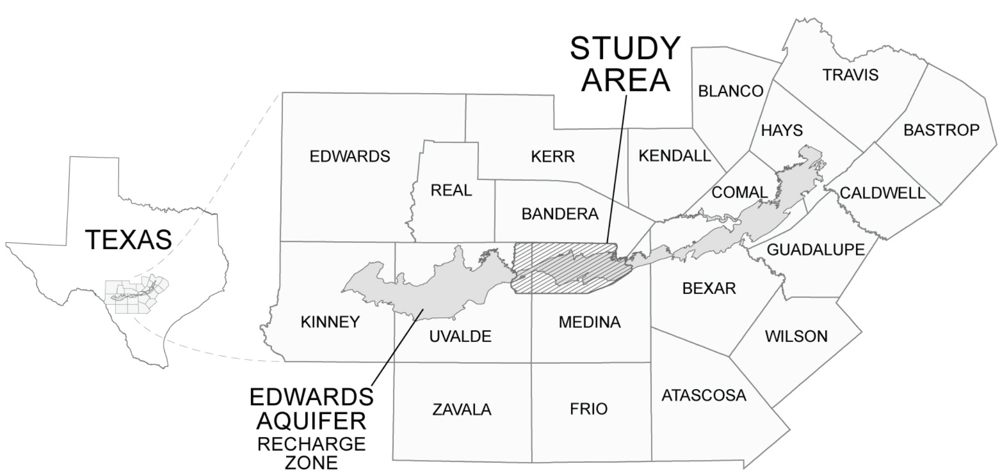

Figure 1. Map showing the study area and the southern segment of the Edwards aquifer.

The geology of the Edwards aquifer in the northeast part of the recharge area is characterized by the Kainer and Person Formations, which are subdivided into seven informal hydrostratigraphic units. In the area west of San Antonio in Medina, Uvalde and Kinney Counties, significant facies changes exist across the Devils River trend reefal facies (Maclay and Small, 1984, plate 1). About ninety percent of the study area is underlain by the Georgetown and Devils River Formations.

The Devils River Formation yields large quantities of irrigation water to fertile bottomland areas of Medina and Uvalde Counties, where the success of farming and ranching activities has long depended upon water from the Edwards aquifer. The remaining ten percent of the study area includes the southwestern margin of the San Marcos platform (plate 1), where the Edwards aquifer consists of the Edwards Group (Rose, 1972).

The Balcones fault zone, the principal structural feature in the region, is characterized by an *en-echelon* network of high-angle, southwest- to northeast-trending faults that vertically displace the Lower Cretaceous rocks of the Edwards aquifer. These faults, together with local karst features, are largely responsible for the complexity of the ground-water flow system in the study area.

The U.S. Geological Survey (USGS), in cooperation with the San Antonio Water System (SAWS), began a project in 2001 to better delineate the geology and ground-water flow paths in northern Medina and northeastern Uvalde Counties. The purpose of this mapping is to improve the understanding of the geologic framework and hydrogeologic setting of the Edwards aquifer.

SPATIAL DATASETS

All digital spatial datasets generated during the study are stored as Universal Transverse Mercator (UTM) projections with a horizontal datum of North American Datum 1983 (NAD83). The surface raster datasets have the aforementioned horizontal projection but reference the North American Vertical Datum 1988 (NAVD 88). GIS datasets used in this report have Federal Geographic Data Committee (FGDC)-compliant content-level metadata (Federal Geographic Data Committee, 1994).

GEOLOGIC FRAMEWORK

The geologic framework in south-central Texas is complicated by three primary factors that affect the hydrogeologic setting of the Edwards aquifer. These factors include, but are not limited to, lithofacies transition, complex faulting, and karst development. These factors have individually and interactively affected the evolution and subsequent productivity of the Edwards aquifer since meteoric waters first entered the ground-water system.

Depositional Setting

The Lower Cretaceous rocks that comprise the Edwards aquifer were deposited upon the landward margin of the Comanche continental shelf which was sheltered from storm waves and deep ocean currents by the Stuart City reef trend in the ancestral Gulf of Mexico (pl. 1, inset). Subsidence across a tectonic hinge line (Smith, 1981) that skirted the southern edge of this carbonate shelf kept most of the study area submerged within a curved bank of reefal growth known as the Devils River trend. Greater rates of subsidence south of the hinge line caused fundamental differences between rocks deposited within the Devils River trend and those deposited in deeper water inside the Maverick Basin (Smith and others, 2000). Depositional environments inside the Maverick Basin were effectively isolated from those elsewhere on the Comanche shelf by the Devils River trend, which today contains the Devils River Formation (Miller, 1984, p. 17–21).

Concurrent with deposition inside the Maverick Basin, the Devils River trend facies (plate 1, inset), now an area of partly to completely dolomitized miliolid- and rudist-bearing limestones, formed around the western, northern, and eastern margins of the Maverick Basin (Lozo and Smith, 1964, p. 291–297). Nodular, burrowed, dolomitic, and evaporitic rock sequences that make up the lower parts of the Devils River Formation were deposited in partly restricted, tidal flat environments somewhat similar to those over the San Marcos and central Texas platforms (Miller, 1984). In contrast, upper parts of the Devils River Formation formed in mostly open, shallow marine environments of moderate to high energy and under relatively unrestricted circulation that enhanced the growth of rudist bioherms and biostromes.

Following tectonic uplift, subaerial exposure, and erosion near the end of Early Cretaceous time, south-central Texas was again submerged during a major marine transgression. By the beginning of Late Cretaceous time, the Stuart City reef had been breached (Rose, 1972, p. 17), the Maverick Basin was no longer subsiding, and the Devils River trend was no longer an active reef complex. Depositional environments associated with the Maverick Basin, Devils River trend, and San Marcos platform were finally curtailed as south-central Texas was blanketed by Del Rio Clay deposits (Smith and others, 2000).

Balcones Fault Zone

During Late Oligocene through Early Miocene time, large-scale normal faulting created the Balcones fault zone, within which 3,000 feet of Cretaceous strata were significantly faulted and fractured. The resulting fault blocks were downthrown and rotated differentially in a southwest-to-northeast-trending, *en-echelon* arrangement (Maclay, 1995, p. 8–12). The fractures associated with the high-angle, mostly down-to-the-south faults, facilitated the percolation of carbon dioxide-enriched meteoric water, which increased the solubility of allochems (fossil parts, intraclasts, pellets, and oolites), evaporites (principally anhydrite and gypsum), and other unstable minerals (such as aragonite and high-magnesium calcite). The two cross-sections on plate 1 illustrate the displacement of aquifer-bearing rock units across faults and the steep north-to-south down-dip gradient.

General Stratigraphy

Current delineation of the lithostratigraphic and hydrostratigraphic subdivisions comprising the Edwards aquifer in the study area is the result of numerous studies by the petroleum industry, academic institutions, and government agencies. Stratigraphic details not discussed in the section entitled “Descriptions of Map Units” are summarized below, from bottom (geologically oldest) to top (youngest).

The upper member of the Glen Rose Limestone is of Early Cretaceous age and forms the lower confining unit of the Edwards aquifer (Maclay and Small, 1984). The upper member of the Glen Rose Limestone, which ranges from 200 to 300 feet thick in the study area, conformably underlies the Devils River Formation in the Devils River trend and the Edwards Group in the San Marcos platform.

The Devils River Formation in the Devils River trend is stratigraphically equivalent to the Edwards Group (Kainer and Person Formations or Fort Terrett and Segovia Formations) in the San Marcos platform and Edwards Plateau, respectively. Although the lateral transition between the Devils River Formation and the Kainer and Person Formations is gradational, the Devils River Formation lacks the distinguishing characteristics that allowed its Kainer and Person Formation counterparts to be informally subdivided into as many as nine hydrostratigraphic units (Lozo and Smith, 1964). This lack of distinguishing characteristics within the Devils River Formation results from a transition in depositional environments between relatively shallow parts of the Comanche shelf toward the northeast and the relatively deep Maverick Basin to the southwest (Smith and others, 2000). Differences between the shelf and basin environments increased rapidly as rates of subsidence accelerated south of the tectonic hinge line. Consequently, the stratigraphic differences between the Devils River Formation and the laterally adjacent eastern counterparts of the San Marcos platform increase upward from the base.

Although the scarcity of marker beds has impeded separation of the Devils River Formation into more than an informal recognition of lower and upper parts, Miller (1984) and Clark (2002) have attempted to informally divide the lower part into basal nodular, burrowed, dolomitic, and Kirschberg evaporite hydrostratigraphic units. The lower 60-70 feet of Miller’s subdivided section in northern Uvalde County consists of rocks resembling the basal nodular member of the Fort Terrett Formation (Rose, 1972, p. 32–

34) and Kainer Formation of the central Texas and San Marcos platforms, respectively. Miller's basal nodular unit is overlain by 30-40 feet of thin- to massive-bedded, burrowed mudstone. Upward from its base, this mudstone sequence becomes thicker bedded and less burrowed and contains chert that can be traced laterally as either nodules or thin beds into the Fort Terrett and the Kainer Formations (Clark, 2003). Miller's burrowed unit is overlain by roughly 150 feet of partially to completely dolomitized, rudist-bearing wackestone and grainstone, which he equated to the dolomitic member of the Fort Terrett and Kainer Formations. Approximately 60 feet of highly leached, recrystallized, brecciated, dark-gray, sparry limestone characterizes what Miller (1984) mapped as the Kirschberg evaporite member in outcrops of the Devils River Formation in northern Uvalde County.

Whereas Miller (1984, p. 13) considered the lower part of the Devils River Formation to be "...laterally continuous with and indistinguishable from the Fort Terrett Formation," he found the upper part to be "quite different" from stratigraphically equivalent rocks to the north. The upper 160–250 feet of the Devils River Formation typically consists of light-gray wackestone, packstone, miliolid grainstone, and rudist boundstone. Biohermal rudist (caprinid, radiolitid, and *Chondrodonta*) mounds are found in the uppermost 50 feet. Shell-fragment wackestones and grainstones, recrystallized and calichified limestone, and irregular nodules or thin beds of chert are scattered throughout and are abundant locally (Miller, 1984, p. 17). Fossilized caprinids, as well as several varieties of rudists, are present locally where they commonly form packstone or boundstone and have been replaced by chert (Clark, 2003).

The Edwards Group south of the Colorado River was defined to include the Kainer and Person Formations over the San Marcos platform and the Fort Terrett and Segovia Formations over the central Texas platform (Rose, 1972, p. 18). These strata are stratigraphically equivalent to the Fredericksburg Group of central Texas (Adkins, 1933, p. 322), which includes the Walnut, Comanche Peak, and Edwards Limestone Formations north of the Colorado River (Lozo, 1959).

In the San Marcos platform, the Kainer Formation consists of, from oldest to youngest, the: (1) basal nodular, (2) dolomitic, (3) Kirschberg evaporite, and (4) grainstone hydrostratigraphic members. Marine deposits of the basal nodular member conformably overlie the Glen Rose Limestone and are predominantly composed of shaley, nodular, and fossiliferous mudstone to wackestone, the nodular nature of which results from the compaction of highly bioturbated sediment (Shinn and others, 1977). The intertidal and supratidal mudstones of the chert-bearing dolomitic member grade upward into supratidal, evaporitic, crystalline limestones of the Kirschberg evaporite member. The Kirschberg grades upward into miliolid grainstones of the erosionally resistant grainstone member of predominately shallow marine origin.

The Person Formation is composed of, from oldest to youngest, the: (1) regional dense, (2) leached and collapsed (undivided), and (3) cyclic and marine (undivided) hydrostratigraphic members. The regional dense member is a dense, easily recognized argillaceous mudstone (Small, 1985). The overlying leached and collapsed member is composed largely of dolomitic biomicrite, burrowed mudstone, and crystalline limestone with local occurrences of collapsed breccia, chert, and stromatolitic limestone. Because the cyclic and marine member (locally crossbedded, upward-grading cycles of mudstone, packstone, and miliolid grainstone) has not been identified in the study area, it is assumed that it was removed by erosion prior to deposition of the overlying Georgetown Formation (Rose, 1972, p. 23–25).

The upper confining unit of the Edwards aquifer in the study area is composed mostly of impermeable, interbedded shale, siltstone, limestone, chalk, and marl of Late Cretaceous age. From oldest-to-youngest, these rocks include the Georgetown Formation (Clark and Clark, study in progress), Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Group, Anacacho Limestone, and Escondido Formation. The Georgetown Formation unconformably overlies the Person Formation in the San Marcos platform area and the Devils River Formation in the Devils River trend. Typically, the Georgetown Formation consists of reddish-brown, gray to light-tan, marly limestone and contains the brachiopod *Waconella wacoensis* (formerly *Kingena wacoensis*). Ranging from 0 to about 20 feet thick in the study area, the Georgetown Formation formed atop an eroded surface of Lower Cretaceous rocks in an open-shelf depositional environment characterized by deeper water than was typical during deposition of the underlying Edwards Group (Rose, 1972).

The Del Rio Clay consists of bluish-green to yellowish-brown clay and thin beds of impermeable limestone; iron nodules and the fossil oyster *Ilymatogyra arietina* [formerly *Exogyra arietina* (Roemer, 1849)] are abundant locally. The Buda Limestone consists of buff to light-gray, dense mudstone (Dunham, 1962), which weathers from a smooth gray to a grayish white, with a nodular appearance, typically ensuring that its contact with the underlying Del Rio Clay is distinct and easily recognized. The Eagle Ford Group consists of brown, flaggy, locally petroliferous, sandy shale and argillaceous limestone. The Austin Group is composed of massive, chalky, locally marly, generally fossiliferous mudstone that commonly contains the fossil oyster *Gryphaea aucella*. The Anacacho Limestone, exposed west of Verde Creek and south of the Seco Creek and Lincoln faults, consists of massive mudstone or packstone with interbedded bentonitic clay. The Escondido Formation, exposed south of the Haby Crossing fault in the extreme southeastern part of the study area, consists of fine-grained sandstone with interbedded shale, clay, and pyroclastic material.

DESCRIPTION OF MAP UNITS

Quaternary and Upper Tertiary Stratigraphy

Qal **Alluvium (Quaternary)—**Alluvium is comprised of unconsolidated gravel, sand, silt, and clay along streams and rivers that are inundated regularly. The gravel contains mostly limestone and chert. Low terrace deposits found along minor drainages include some local outcrops that have been subdivided by Collins (1997c)

Ql **Leona Formation (Pleistocene)—**The Leona Formation is composed of lenticular beds of sand, gravel, silt, and clay. The pebbles and cobbles in the Leona predominantly contain limestone with some chert. Coarser gravels are present near the base of the formation with silt increasing upwards. The Leona is locally a prolific ground-water source and has rare cavern development and variable (low to high) porosity due to the poor sorting in the gravels. Locally, silt and clay cement significantly reduces the permeability. In general, the formation is thickest near the stream channels or older abandoned meander channels. Ranges in thickness from a few feet to 8 feet

QTu **Uvalde Gravel, older alluvium (Quaternary and Upper Tertiary)—**Mostly gravel and sand with some silt and clay. Well-rounded, pebble- to cobble-sized gravels are common with few boulders. The unit contains mostly chert and limestone pebbles and cobbles, commonly cemented by caliche. Deposits typically cap topographically high areas. The precise age of the unit is unknown but is estimated to be approximately Quaternary to late Tertiary in age. Thickness ranges from several feet to more than 10 feet

Upper Cretaceous Stratigraphy

Kes **Escondido Formation—**Exposed south of the Haby Crossing fault in the extreme southeastern part of the study area, the Escondido consists of fine-grained sandstone, with interbedded shale, clay, and pyroclastic material. Unit also includes a thin (as much as ~30 feet) lower marl and mudstone unit called the Corsicana Marl. Outcrops are not common. Thickness ranges from 550 to 900 feet

Kac **Anacacho Limestone—**Exposed west of Verde Creek and south of the Seco Creek and Lincoln faults. Typically consists of massive mudstone or packstone with interbedded bentonitic clay. Grain-rich limestone is common. Light gray to white in outcrop view, thin- to thick-bedded, glauconitic, and contains fossil fragments. Thickness ranges from 240 to 500 feet

Kan **Navarro and Taylor Groups, undivided**—Lithologic similarity makes the Navarro and Taylor difficult to differentiate in many areas. Mapped only in the San Marcos Platform where the unit contains gray to brown clay and marly limestone. Very low porosity and permeability, with no cavern development. The groups are sometimes considered confining units in the Edwards aquifer region (Hanson and Small, 1995). Thickness averages 600 feet

Ka **Austin Group**— Commonly called the Austin Chalk, it is composed of massive, chalky, locally marly, generally fossiliferous mudstone. It is identified in the field as white, chalky limestone (microgranular calcite) containing the fossil oyster *Gryphaea aucella*, abundant *Inoceramus* prisms, minor foraminifera and ostracode tests as well as echinoid debris. The chalky mudstone forms ledges and alternates with marl and locally with bentonitic seams. Glauconitic pyrite nodules partly weathered to limonite are also found. Thick caliche is common on the surfaces of most outcrops. Thickness ranges from 135 to 200 feet.

The Austin Group is generally referred to as an Edwards aquifer-confining unit. However, there is local occurrence of ground water associated with its fractures. There is minor cavern development and low to moderate porosity and permeability. Forms thick black soil with juniper and live oak in low-relief areas

Kef **Eagle Ford Group**—Consists of brown, flaggy petroliferous (locally), sandy shale and argillaceous limestone. The upper part contains limestone and shale and is dark gray in color. Limestone is generally light, yellowish brown, flaggy, and occurs in beds as thick as 4 feet. The lower part of the unit contains silty, brown, laminated siltstone and weathers easily, forming flat to gently rolling topography. Is known as lignite by local drillers. Thickness ranges from 15 to 40 feet.

No cavern development is evident and the primary porosity has been lost, thereby reducing permeability. Outcrops are rare in the mapped area and are generally covered with dark-brown soil. Strata at slope break of the Eagle Ford/Buda contact are commonly fossiliferous with oysters, ostracodes, foraminifers, fish bones, teeth, and *Inoceramus* prisms present

Kb **Buda Limestone—** Consists of light-gray to pale-orange mudstone, which weathers dark gray to brown, and buff to light-gray, dense mudstone, which weathers from a gray to a grayish-white, nodular appearance. Commonly contains calcite-filled veins and is glauconitic and locally fossiliferous with abundant shell fragments. Unit is thinner bedded and argillaceous near its upper contact. The upper contact with the Eagle Ford Formation is disconformable, sharp, conspicuous, and outcrops as resistant caps on hills. Lower part of formation contains soft, chalky limestone. Thickness ranges from 40 to 56 feet.

The Buda Limestone weathers to form thin, red-brown soil containing rounded cobbles of limestone, and is less glauconitic and iron-oxide-stained than the older Georgetown Formation (Collins, 1997a, 1997b, 1997c, 1998, 1999a, 1999b). The Buda also contains more fossil gastropods than the Austin Group in addition to burrows filled with chalky marl. The Buda fossils include abundant pelecypods, foraminifers, ostracodes, serpulids, echinoid spines, and bryozoans. Locally, solitary corals and green algae are also found. The unit has minor karst features with low porosity

Kdr **Del Rio Clay—**Consists of bluish-green to yellow-brown clay with thin beds of impermeable limestone; iron nodules and the fossil oyster *Ilymatogyra arietina* [formerly *Exogyra arietina* (Roemer, 1849)] are abundant locally. The Del Rio becomes less calcareous and more gypsiferous up section and weathers light to yellowish gray. The unit is slope forming or under hanging where slumped below the overlying Buda Limestone. Upper contact is gradational with the Buda Limestone. Lower contact is gradational with the Devils River Formation or Georgetown Formation (where present). Thickness ranges from 15 to 60 feet.

The unit contains highly expansive soil, has no significant porosity or permeability or recognized cavern development, and is the primary upper confining unit of the Edwards aquifer system. Unweathered Del Rio Clay is composed of kaolinite, illite, and lesser amounts of montmorillonite (Collins, 2000). Water tanks for livestock are commonly found on outcrops

Lower Cretaceous Stratigraphy

Kg **Georgetown Formation—**Reddish-brown, gray to light-tan, marly limestone containing the brachiopod *Waconella wacoensis* (formerly *Kingena wacoensis)*. Unconformably overlies the Person Formation throughout the San Marcos platform and the Devils River Formation where it occurs in the Devils River trend. Thickness ranges from 0 to about 20 feet

San Marcos platform facies

The Person and Kainer Formations of the Edwards Group were divided into nine informal lithostratigraphic units by Rose (1972). These units, including the Georgetown Formation, were further modified by Maclay and Small (1976) into eight informal hydrostratigraphic members that comprised the Edwards aquifer. Current mapping (Clark and Clark, in progress) recommend moving the Georgetown Formation into the upper confining unit of the Edwards aquifer. The Person and Kainer Formations are not included as map units in this report.

Person Formation—Consists of variably burrowed mudstone, grainstone and crystalline limestone. The formation also contains collapsed breccia, dolomitized biomicrite, and stromatolitic limestone. Chert is locally abundant and common fossils include pelecypods, gastropods, and rudistids (Collins, 2000). Thickness ranges from 170 to 180 feet

Kpcm **Cyclic and marine member—**Comprised of chert-bearing mudstone to packstone and *miliolid* grainstone. It weathers to massive, light-tan outcrops with scattered *Toucasia* present. The cyclic and marine member is hydrologically one of the most productive hydrostratigraphic units because of its large number of subsurface caverns associated with incipient karstification. The very permeable cyclic and marine unit has laterally extensive, fabric and non-fabric selective porosity (Small and Hanson, 1994; Stein and Ozuna, 1995). Thickness ranges from 10 to 100 feet

Kplc **Leached and collapsed member—**Considered the most cavernous in the San Marcos platform facies. It is a crystalline limestone (mudstone to grainstone-rich) with lesser amounts of chert, collapsed breccia, and isolated stromatolitic limestone. The leached and collapsed unit is identified in the field by bioturbated iron-stained beds separated by massive limestone beds and the presence of the fossil coral, *Montastrea* sp. The unit is classified as having non-fabric-selective porosity and high permeability rates (Small and Hanson, 1994). Thickness ranges from 70 to 100 feet

Kprd **Regional dense member—**Comprised of argillaceous mudstone that is considered a major barrier to vertical ground-water flow in the Edwards aquifer. Small and Clark (2000, p. 4) reported the occurrence of wispy iron-oxide stains and stated that the unit is susceptible to erosion. Very few caverns have been found, but vertical fracture enlargement does occur locally in this non-fabric selective porosity, low permeability unit (Small and Hanson, 1994). Thickness ranges from 16 to 24 feet

Kainer Formation—Contains lithologies that range from mudstones to miliolid grainstones to crystalline limestone. Much of the formation is fossiliferous and is typified by rudistid-rich mudstones and wackestones that grade into dolomitic mudstones with evaporites and miliolid grainstones. Other fossil groups include oysters and gastropods (Rose, 1972; Abbott, 1977). Chert occurs throughout the unit in varying amounts but is locally abundant (Collins, 2000). Thickness ranges from 250 to over 300 feet

Kkg **Grainstone member—**Contains white, chert-bearing, *miliolid* grainstone, mudstone to wackestone. Cross-bedding and ripple marks can be found in the grainstone. Cavern development is rare to nonexistent throughout the unit. Classified as having non-fabric selective porosity and low permeability as a result of recrystallization (Stein and Ozuna, 1995; Small and Clark, 2000). Thickness ranges from 50 to 60 feet

Kkke **Kirschberg evaporite member—**Consists of highly altered crystalline limestone, chalky mudstone, and chert. Identified by boxwork voids with neospar and travertine framing. Extensive cavern development throughout the unit makes the Kirschberg evaporite one of the most porous (mostly fabric-selective porosity) and permeable members of the Kainer Formation. No common fossils are identified within this unit (Stein and Ozuna, 1995). Thickness ranges from 50 to 60 feet

Kkd **Dolomitic member—**Mudstone to grainstone, and crystalline limestone with chert. Cavern development is directly related to faults, fractures, and bedding planes. Exhibits non-fabric selective porosity except where solution along bedding planes yields water. The massively bedded dolomitic unit weathers to light gray in outcrop and has abundant *Toucasia* sp. (Stein and Ozuna, 1995; Small and Clark, 2000). Thickness ranges from 110 to 140 feet

Kkbn **Basal nodular member—**Considered regionally to be a lower confining unit, it is locally water bearing through dissolution along bedding planes. Shaley, nodular limestone, burrowed mudstone to wackestone with minor lateral cavern development at the surface and exhibits non-fabric selective porosity. Commonly identified in the field as containing black rotund bodies ("brb's") and the occurrence of *miliolids*, gastropods, and *Exogyra texana* (Stein and Ozuna, 1995; Clark, 2003). Thickness ranges from 20 to 70 feet

Devils River trend facies

Kdvr **Devils River Formation—**Unit is chronostratigraphically equivalent to the Edwards Group (Kainer and Person Formations or Fort Terrett and Segovia Formations) over the San Marcos and central Texas platforms, respectively. Although the lateral transition between the Devils River Formation and the Kainer and Person Formations is gradational, the Devils River Formation lacks the distinguishing characteristics that have allowed its Kainer and Person counterparts to be subdivided (informally) into as many as seven different hydrostratigraphic members (Lozo and Smith, 1964; Maclay and Small, 1976). Thickness ranges from approximately 450 feet near the facies transition of the San Marcos

Platform to approximately 550 feet near the Sabinal River in eastern Uvalde County

Kgru **upper member of the Glen Rose Limestone—**Contains alternating beds of light-gray to yellowish-brown limestone, dolomitic limestone, and argillaceous limestone and marl. Carbonate textural fabrics include wackestone, packstone, and grainstone. The upper member of the Glen Rose Limestone unconformably underlies the Devils River Formation in the Devils River trend and the Edwards Group over the San Marcos platform. Comprises the catchment area of the Edwards aquifer in outcrop and is the lower confining unit in the subsurface (Maclay and Small, 1984). It contains minor evaporite layers and sedimentary structures indicating upward-shoaling cycles. Some intervals of disturbed bedding and collapse breccia are also present and possibly were created by evaporite dissolution. Thickness ranges from approximately 200 to 300 feet in northern Medina County.

This unit can typically be identified on the outcrop from a characteristic "stair-step" topography that results from the preferential weathering of its relatively nonresistant intervals of marl as opposed to the comparatively resistant layers of limestone and dolostone (Stricklin and others, 1971, p. 23). The unit is locally burrowed and produces honeycomb porosity in some areas. Fossil evidence includes sparse casts of marine faunas, specifically molluscan steinkerns (*Protocardia texana* and others), rudistids, oysters, echinoids, gastropods (*Tylostoma* sp., *Turitella* sp.), the foraminifera *Orbitolina minuta*, as well as local dinosaur tracks.

Surface cavern development associated with faults and fractures and some water production along evaporite beds have been noted, but are rare. Possesses mostly nonfabric-selective porosity and generally low permeability (Small and Clark, 2000; Clark, 2003)

ACKNOWLEDGMENTS

The authors would like to thank the cooperator; the San Antonio Water System (SAWS) for their support, especially the personnel of the Hydrologic Studies and Assessment section and the Water Quality section. The personnel of the SAWS aided in obtaining rights of easement for monitor wells and for surveying the drill sites. We would also like to thank Mr. Tom Gonzales (SAWS) for logging the monitor wells. Special thanks are extended to property owners in the study area and to the County of Medina for allowing the USGS to drill monitoring wells on their property. Thanks are extended to Mr. John Waugh (SAWS), Mr. Kirk Nixon (SAWS), and Richard Saathoff and his family for their interest and patience during drilling operations on their ranch.

REFERENCES CITED

Abbott, P.L., 1977, Effect of Balcones faults on groundwater movement, south central Texas: Texas Journal of Science, v. 29, no. 1 and 2, p. 5–14.

Adkins, W.S., 1933, The Mesozoic Systems in Texas, *in* The geology of Texas, v. I, Stratigraphy: Austin, University of Texas, Bureau of Economic Geology Bulletin 3232, p. 239–518.

Clark, A.K., 2002, Geologic Framework and Hydrogeologic Characteristics of the Edwards Group Outcropping in Northern Uvalde County, Texas: San Antonio, Texas, University of Texas at San Antonio, M.S. thesis, p. 416.

_______ 2003, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer, Uvalde County, Texas, U.S. Geological Survey Water-Resources Investigations Report 03–4010, 10 p.

Collins, E.W., 1997a, Geologic map of the Timber Creek quadrangle: Austin, Tex., University of Texas, Bureau of Economic Geology, scale 1:24,000.

______ 1997b, Geologic map of the Twin Hollow quadrangle: Austin, Tex., University of Texas, Bureau of Economic Geology, scale 1:24,000.

______ 1997c, Geologic map of the Texas Mountain quadrangle: Austin, Tex., University of Texas, Bureau of Economic Geology, scale 1:24,000.

______ 1998, Geologic map of the Sabinal NE quadrangle: Austin, Tex., University of Texas, Bureau of Economic Geology, scale 1:24,000.

______ 1999a, Geologic map of the Comanche Waterhole quadrangle: Austin, Tex., University of Texas, Bureau of Economic Geology, scale 1:24,000.

______ 1999b, Geologic map of the Flatrock Crossing quadrangle: Austin, Tex., University of Texas, Bureau of Economic Geology, scale 1:24,000.

______ 2000, Geologic map of the New Braunfels, Texas 30x60 minute quadrangle: Geologic framework of an urban-growth corridor along the Edwards aquifer, south-central Texas: Bureau of Economic Geology, Miscellaneous Map no. 39, map with 28 p. text.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, *in* Classification of Carbonate Rocks Symposium: American Association of Petroleum Geologists Memoir 1, p. 108–121.

Federal Geographic Data Committee, 1994, Content standards for digital geospatial metadata (June 8): Washington, D.C., Federal Geographic Data Committee.

Hanson, J.A., and Small, T.A., 1995, Geologic framework and hydrogeologic characteristics of the Edwards aquifer outcrop, Hays County, Texas: U.S. Geological Survey Water-Resources Investigations Report 95–4265, 10 p.

Lozo, F.E., Jr., 1959, Stratigraphic relations of the Edwards Limestone and associated formations in north-central Texas, *in* Symposium on Edwards Limestone in Central Texas: University of Texas, Bureau of Economic Geology Publication 5905, p. 1–19.

Lozo, F.E., Jr., and Smith, C.I., 1964, Revision of Comanche Cretaceous stratigraphic nomenclature, southern Edwards Plateau, southwest Texas: Gulf Coast Association of Geological Societies Transactions, v. 14, p. 285–306.

Maclay, R.W., 1995, Geology and hydrology of the Edwards aquifer in the San Antonio area, Texas: U.S. Geological Survey Water-Resources Investigations Report 95–4186, 64 p.

Maclay, R. W., and Small, T. A., 1976, Progress report on the geology of the Edwards aquifer, San Antonio area, Texas, and preliminary interpretation of borehole geophysical and laboratory data on carbonate rocks: U.S. Geological Survey Open-File Report 76-627, 65 p.

Maclay, R.W., and Small, T.A., 1984, Carbonate geology and hydrology of the Edwards aquifer in the San Antonio area, Texas: U.S. Geological Survey Open-File Report 83–537, 72 p.

Miller, B.C., 1984, Physical stratigraphy and facies analysis, Lower Cretaceous, Maverick basin and Devils River trend, Uvalde and Real Counties, Texas, *in* Smith, C.L., ed., Stratigraphy and structure of the Maverick basin and Devils River trend, Lower

Cretaceous, southwest Texas -- A field guide and related papers: South Texas Geological Society, p. 3-33.

Roemer, Ferdinand, 1849, Texas, Mit besonderer Rücksicht auf deutche Auswanderung und die physischen Verhältnisse des Landes nach eigener Beobachtung geschildert: Adolph Marcus, Bonn, 464 p., 1 map.

Rose, P.R., 1972, Edwards Group, surface and subsurface, central Texas: Austin, University of Texas, Bureau of Economic Geology Report of Investigations 74, 198 p.

Shinn, E.A., Halley, R.B., Hudson, J.H., and Lidz, B.H., 1977, Limestone compaction: An enigma: Geology, vol. 5. p. 21–24.

Small, T. A., 1985, Identification and tabulation of geological contacts in the Edwards aquifer, San Antonio area, Texas: Texas Department of Water Resources LP-199, 54 p.

Small, T.A., and Clark, A.K., 2000, Geologic framework and hydrogeologic characteristics of the Edwards aquifer outcrop, Medina County, Texas: U.S. Geological Survey Water-Resources Investigations Report 00–4195, 10 p.

Small, T.A., and Hanson, J.A., 1994, Geologic framework and hydrogeologic characteristics of the Edwards aquifer outcrop, Comal County, Texas: U.S. Geological Survey Water-Resources Investigations Report 94-4117.

Smith, C. I., 1981, Review of the geologic setting, stratigraphy, and facies distribution of the Lower Cretaceous in northern Mexico, *in* Smith, C.I., and Brown, J.B., eds., Lower Cretaceous stratigraphy and structure, northern Mexico Field trip guidebook: West Texas Geological Society Publication 81-74, p. 1-27.

Smith, C.I., Brown, J.B., and Lozo, F.E., 2000, Regional Stratigraphic Cross Sections, Comanche Cretaceous (Fredericksburg- Washita Division), Edwards and Stockton Plateaus, West Texas: Interpretation of Sedimentary Facies, Depositional Cycles, and Tectonics: Bureau of Economic Geology, Cross Sections (CS) 0011, 39 p.

Stein, W.G., and Ozuna, G.B., 1995, Geologic framework and hydrogeologic characteristics of the Edwards aquifer recharge zone, Bexar County, Texas: U.S. Geological Survey Water-Resources Investigations Report 95-4030.

Stricklin, F.L., Jr., Smith, C.I., and Lozo, F.E., 1971, Stratigraphy of Lower Cretaceous Trinity deposits of central Texas: Austin, University of Texas, Bureau of Economic Geology Report of Investigations 71, 63 p.

van der Leeden, F., Troise, F.L., and Todd, D.K., 1990, The water encyclopedia: Chelsea, Mich., Lewis Publishers, Inc., p. 808.