INTRODUCTION

The Trinity aquifer is a regional water source in the Hill Country of south-central Texas that supplies water for agriculture, commercial, domestic, and stock purposes. Rocks of the Glen Rose Limestone, which compose the upper zone and upper part of the middle zone of the Trinity aquifer, crop out at the Camp Stanley Storage Activity (CSSA), a U.S. Army weapons and munitions supply, maintenance, and storage facility in northern Bexar County (San Antonio area) (fig. 1). On its northeastern, eastern, and southern boundaries, the CSSA abuts the Camp Bullis Training Site, a U.S. Army field training site for military and Federal government agencies.

During 2003, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army, studied the outcropping Glen Rose Limestone at the CSSA and immediately adjacent area (Camp Stanley study area, fig. 1) to identify and map the hydrogeologic subdivisions and faults of the Glen Rose Limestone at the facility. The results of the study are intended to help resource managers improve their understanding of the distribution of porosity and permeability of the outcropping rocks, and thus the conditions for recharge and the potential for contaminants to enter the Glen Rose Limestone. This study followed a similar study done by the USGS at Camp Bullis (Clark, 2003).

The purpose of this report is to present the geologic framework and hydrogeologic characteristics of the Glen Rose Limestone in the study area. The hydrogeologic nomenclature follows that introduced by Clark (2003) for the outcropping Glen Rose Limestone at Camp Bullis in which the upper member of the Glen Rose Limestone (hereinafter, upper Glen Rose Limestone), which is coincident with the upper zone of the Trinity aquifer, is divided into five intervals on the basis of observed lithologic and hydrogeologic properties. An outcrop map, two generalized sections, related illustrations, and a table summarize the description of the framework and distribution of characteristics.

Methods of Investigation

Geophysical well logs from monitor wells, geologic data, aerial photographs, and previous reports were compiled to aid in field mapping. The field mapping of hydrogeologic subdivisions, which were identified from outcrops, was done on 7 1/2-minute USGS topographic maps with the aid of a global positioning system. Distinctive marker beds were identified in the field and used to correlate hydrogeologic subdivisions in the study area. The field-mapped data were input to a geographic information system, which was used to produce the map of hydrogeologic subdivisions and the sections.

Lithologic and hydrogeologic descriptions are from field observation at the CSSA and adjacent Camp Bullis. Lithologic descriptions are based on Dunham's (1962) carbonate-rock classification system in which rock is identified on the basis of depositional texture—fine to coarse—as mudstone, wackestone, packstone, and grainstone. Porosity type, in the context of the position and boundaries of the pore space, is identified as fabric selective or not-fabric selective under the sedimentary carbonate classification system of Choquette and Pray (1970). In that system, porosity that reflects the textural and structural features of the rock—that is, the "fabric elements," which comprise the depositional particles and later-formed diagenetic elements—is classified as fabric selective. If no relation between the pore space and the fabric elements can be discerned, then the porosity is classified as not-fabric selective. The degree of permeability was qualitatively estimated from field observation and porosity type.

Fault traces identified in the field were based on observed lithologic or stratigraphic incongruities. Some faults also were identified from well logs. Strike and dip of faults and beds were noted from field observation of outcrops. Observed fracture orientations were imported into a graphic software package for creating a rose diagram (Golden Software, Inc., 2003).

Sections were constructed to show the generalized configuration of hydrogeologic subdivisions at depth. Thicknesses of hydrogeologic subdivisions were obtained from selected well logs in the study area or assumed to be the same as those of hydrogeologic subdivisions mapped at Camp Bullis (Clark, 2003).

Acknowledgments

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GEOLOGIC FRAMEWORK

General Features

Rocks exposed in the study area are of Lower Cretaceous age and sedimentary in origin and were deposited in a shallow marine-shelf environment. In all areas within the boundaries of the CSSA, the rocks are Glen Rose Limestone (fig. 1). These rocks are fossiliferous limestones, alternating and interfingered with mudstone, wackestone, packstone, and grainstone; and where present, more massive carbonates are interbedded and interfingered with evaporites and marls.

Faults in the study area are part of the Miocene-age Balcones fault zone. The Balcones fault zone is an extensional system of faults that generally trends southwest to northeast in south-central Texas. The faults are primarily normal, en echelon, and downthrown to the southeast. Fault displacement generally is assumed to be nearly vertical owing to lack of evidence for nonvertical displacement at depth; however, observed dip angles at the surface range from 52 to 75 degrees. Variability in the strike and dip of faults in the outcrop probably results from stress-strain relations in, and the inconsistent competence of, the rocks the faults pass through.

Subparallel fault segments in a zone of normal faults generally are connected by zones that transfer displacement between the overlapping faults (for example, Morley and others, 1990). Transfer zones that occur between normal fault segments that have the same dip direction are called "relay ramps" (Peacock and Sanderson, 1994) (fig. 2). Such structures could influence ground-water flowpaths at the CSSA, as will be described in a subsequent section. Some evidence of at least one relay ramp in the study area was observed: Although most fault displacements identified at CSSA are 20 feet or less, north of well MW–10 (fig. 1), a series of closely spaced faults results in about 50 feet of displacement. These faults might be part of a relay ramp.

Two primary sets of fractures were identified at CSSA (fig. 3). One set of fractures is oriented northwest to southeast (roughly north 50 degrees west [320 degrees]), perpendicular to the trend of the Balcones fault zone. A smaller set of fractures is oriented southwest to northeast, parallel to the Balcones fault zone (roughly north 50 degrees west [320 degrees]). The fractures in both directions likely are the result of extensional forces in the Balcones fault zone.

Section *A–A′* (figs. 1, 4) extends about 4 miles from south to north through seven wells. Section *B–B′* (figs. 1, 5) extends about 1.3 miles from west to northeast through four wells. Section *A–A′* shows a gradual topographic decline from north to south and downdropping of units at the southern end of the section because of faulting. Both sections show exposure of relatively older rocks in topographically low areas not influenced by faulting.

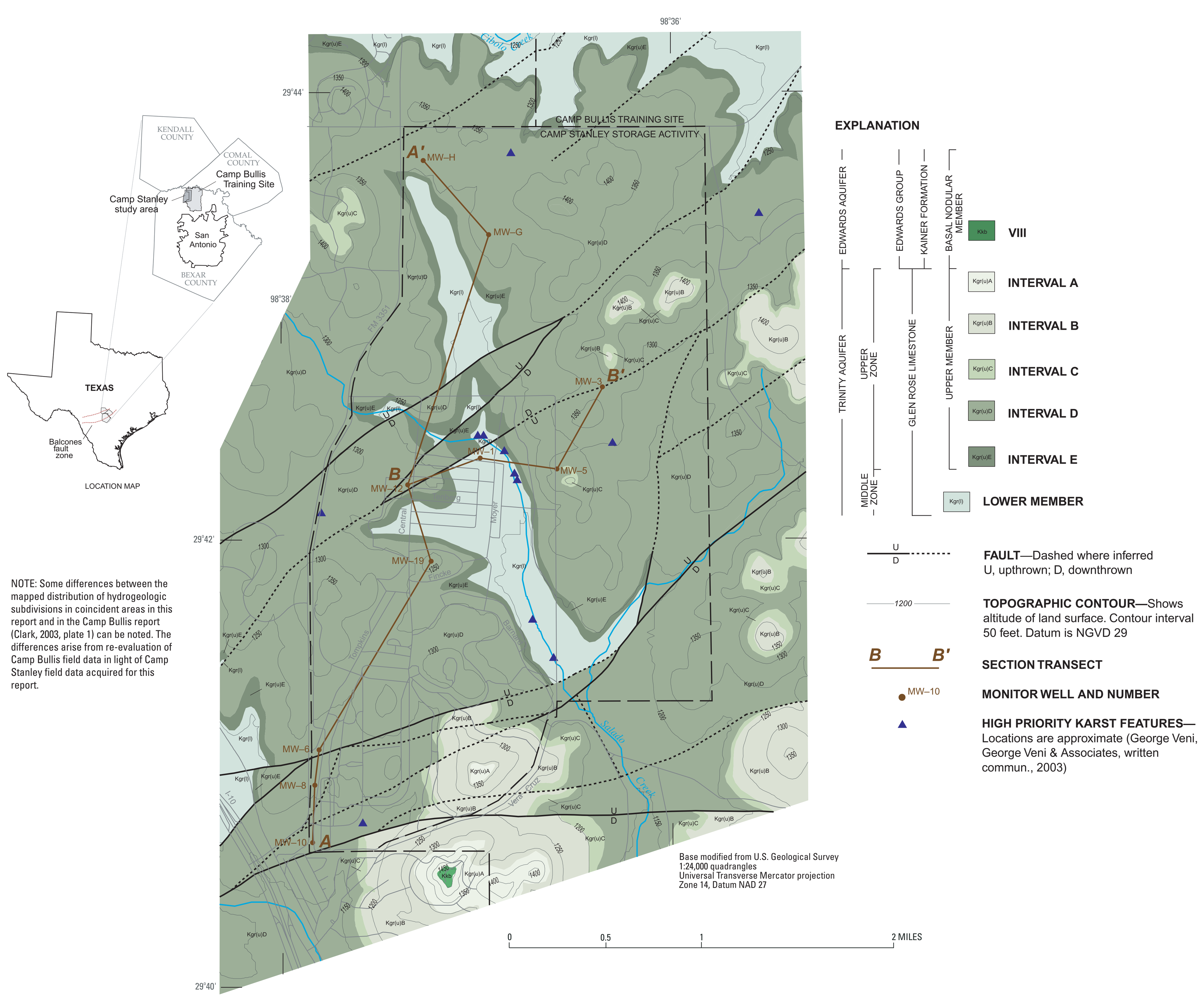

Figure 1. Outcropping hydrogeologic subdivisions and lower member of the Glen Rose Limestone, Camp Stanley Storage Activity and immediately adjacent area, Bexar County, Texas.

Stratigraphy

The Glen Rose Limestone (table 1) conformably overlies the Bexar Shale member of the Pearsall Formation (not exposed in the study area). The contact is gradational and interfingering. The 60- to 70-foot-thick Bexar Shale member typically is a mixture of dark mudstone, clay, and shale (Barker and Ardis, 1996). The Glen Rose Limestone is subdivided (informally) into an upper and lower member. The two members are separated by a regionally extensive marker bed known as the "*Corbula* bed" (Whitney, 1952), which is a grainstone composed of the small fossil clam *Corbula martinae*.

Table 1. Summary of the lithologic and hydrogeologic properties of the hydrogeologic subdivisions of the Glen Rose Limestone and associated units that crop out, Camp Stanley Storage Activity and immediately adjacent area, Bexar County, Texas.

[Group, formations, and members modified from Forgotson (1956), Rose (1972), Ashworth (1983); hydrogeologic subdivisions (aquifers, zones, intervals) from Maclay (1995), Barker and Ardis (1996), Clark (2003); lithologic terminology modified from Dunham (1962); and porosity type modified from Choquette and Pray (1970). AQ, aquifer; CU, confining unit; *, not exposed in study area]

Group, formation, member			Hydrogeologic subdivision			Hydrologic function	Thickness (feet)	Lithology	Field identification	Karst features	Porosity type/ permeability
Edwards Group	Kainer Formation	Basal nodular member	Edwards aquifer		VIII[1]	AQ karst; CU not karst	50–60	Shaley, nodular limestone, mudstone, and *miliolid* grainstone	Massive, nodular, and mottled; abundant gastropods and *Exogyra texana*	Large lateral caves at surface	Fabric; stratigraphically controlled/large conduit flow at surface
Glen Rose Limestone		Upper member	Trinity aquifer	Upper zone	Interval A	AQ associated with fractures and karst; CU if not	[2]30–120	Alternating and interfingering medium-bedded mudstone, wackestone, and packstone with solution zones locally	Near contact with Edwards Group; stair-step topography; devoid of fossils; evaporite beds locally	Some caves below contact with Edwards Group. Caves associated with fractures and bedding planes	At surface, not-fabric selective fracture and cavern porosity; probably very permeable near contact with Edwards Group, which decreases with depth, breccia porosity associated with collapse resulting from dissolution of evaporite beds
Glen Rose Limestone		Upper member	Trinity aquifer	Upper zone	Interval B	CU; AQ associated with fractures and karst	120–150	Alternating and interfingering mudstones, clays, wackestone, and packstones	Devoid of fossils; stair-step topography; evaporite bed at top of zone	Few caves	Fabric selective interparticle porosity and not-fabric selective fracture and some cavernous porosity; generally low permeability away from caves and solutionally enlarged fractures
Glen Rose Limestone		Upper member	Trinity aquifer	Upper zone	Interval C	AQ	10–20	Yellow-to-white calcareous mud and vuggy mudstone	Yellow calcareous mud, with springs and seeps; topography tends to be flat; few fossils	No known caves	Fabric selective, breccia and moldic (boxwork) porosity
Glen Rose Limestone		Upper member	Trinity aquifer	Upper zone	Interval D	AQ associated with bioherms; CU above and below bioherms	135–180	Alternating beds of wackestone, packstone, and marl; thin-bedded "platy" mudstone; thick-bedded biostromes locally	Profuse *Orbitolina texana*; "platy" mudstone bed; generally low relief; stair-step topography not well defined	Relative abundance of caves related to fractures and bedding planes.	Both fabric and not-fabric selective porosity; vug, fracture, cavern, and moldic porosity within biostrome; in lower 90 feet very low porosity, primarily fracture related.
Glen Rose Limestone		Upper member	Trinity aquifer	Upper zone	Interval E	AQ	7–10	Yellow-to-white calcareous mud and vuggy mudstone	Yellow-to-white calcareous mud, with springs and seeps; topography tends to be flat; *Corbula* bed at base separating upper and lower Glen Rose Limestone; numerous fossils	No known caves	Fabric selective, breccia and moldic (boxwork) porosity
Glen Rose Limestone		Lower member	Trinity aquifer	Middle zone		AQ in bioherms and evaporite bed; also associated with karst and fractures; CU elsewhere	320–340	Thick-bedded mudstone; thin- to medium-bedded mudstone, wackestone, packstone, and grainstone	Massive mudstone	Relatively more caves than in other subdivisions except interval D	Both fabric and not-fabric selective porosity; large fracture, cavern, and moldic porosity within bioherms; mudstones and marls primarily fracture porosity; low permeability in mudstones and marls; good permeability in bioherms
Pearsall Formation		Bexar Shale member	Trinity aquifer	Middle zone		CU	60–70	Dark mudstone, clay, and shale	*	*	*

[1] Referred to as "hydrostratigraphic zone" VIII by Maclay (1995).

[2] 30-40 feet thick at Camp Stanley Storage Activity.

The lowermost mapped unit in the study area is the lower member of the Glen Rose Limestone (hereinafter, lower Glen Rose Limestone), which from well logs appears to be about 320 to 340 feet thick at the CSSA. About 20 to 30 (vertical) feet of the unit is exposed in the central part of the CSSA along the bed of Salado Creek (fig. 1). Although mostly covered with alluvium and vegetation, the exposed rocks of the unit are a massive mudstone to grainstone.

The upper Glen Rose Limestone has been subdivided into five mappable intervals (Clark, 2003) that extend across the CSSA. These intervals (designated A through E) are described below, from oldest to youngest:

Interval E is a solution zone 7 to 10 feet thick that originally was an evaporite bed. Evaporites were subsequently dissolved leaving behind a calcareous mudstone. Often this interval can be detected in caliper logs because it tends to wash out during the drilling process. The *Corbula* bed, which is a very thin-bedded grainstone, lies at the base of Interval E and marks the top of the lower Glen Rose Limestone. Typically the *Corbula* bed is found as float (rock fragments displaced from site of origin) because of its more resistant nature relative to the surrounding calcareous mudstone. In the outcrop, Interval E appears as a yellow-to-white calcareous mud, and in some places, contains gray sparite with boxwork structures. Interval E forms broad, gentle valleys as a result of differences in rates of erosion between Interval E and the overlying Interval D and underlying lower Glen Rose Limestone. This interval also contains numerous species of fossils including the very large gastropod *Nerinea romeri* (Whitney), *Orbitolina texana* (Roemer), *Porocystis globularis* (Giebel), and *Turritella* sp. in addition to numerous species of pelecypods, gastropods, shell fragments, and worm tubes.

Interval D is 135 to 180 feet thick and is composed of alternating beds of wackestone, packstone, and marl. Near the base of Interval D, about 15 to 20 feet above the *Corbula* bed of Interval E, is a second marker bed, a thin-bedded, silty mudstone that has a "platy" appearance. About 95 feet above the base of Interval D is a thick-bedded biostrome, 30 to 40 feet thick, composed of *Caprinuloidea* sp. and mudstone. The biostrome is overlain by 10 to 30 feet of alternating, thin- to medium-bedded wackestone and packstone. Abundant *Orbitolina texana* (Roemer), *Porocystis globularis* (Giebel), *Tapes decepta* (Hill), *Protocardia texana* (Conrad), *Turritella* sp., *Hemiaster* sp., and various fossils and fossil fragments can be found throughout Interval D.

Interval C is a solution zone 10 to 20 feet thick that, like Interval E, originally was an evaporite bed. It is composed of yellow-to-white calcareous mud interspersed with thin layers of mudstone. Some boxwork structure appears in cavities where evaporites have been dissolved. Unlike Interval E, this interval contains few fossils in both diversity and abundance.

Intervals B and A compose the upper 150 to 270 feet of the upper Glen Rose Limestone. Both intervals are composed of alternating and interfingering medium-bedded mudstone to packstone, with solution zones locally. The solution zones were evaporite beds that have been dissolved. Intervals B and A are indistinguishable on the basis of lithology. The distinguishing factor in the field between the two intervals is the greater number of caves present within Interval A. Both intervals are relatively devoid of fossils. Interval B ranges from 120 to 150 feet thick at CSSA. Interval A occurs only in a small area in the southern part of the CSSA, where it ranges from about 30 to 40 feet thick. In the Camp Stanley study area south of the CSSA (at Camp Bullis), the total section of Interval A (as much as 120 feet) is present. The contact between Interval A and the overlying rocks of the Kainer Formation is conformable.

The basal nodular member of the Kainer Formation (hydrostratigraphic zone VIII of Maclay [1995]), is exposed on a hilltop at the very southern part of the study area. The unit consists of shaley, nodular limestone, mudstone, and *miliolid* grainstone and is 50 to 60 feet thick in northern Bexar County (Stein and Ozuna, 1995).

HYDROGEOLOGIC CHARACTERISTICS

Faults and Fractures

High-angle normal faults are the dominant structural feature of the region; however, faults appear to have little effect on recharge and in some places might act as barriers to ground-water flow. The development of relay ramps would have an appreciable effect on ground-water flowpaths on a local scale, allowing water to move downdip at oblique angles to southwest-northeast trending faults. If a breech has developed in a ramp, flow might be parallel to the breech.

Fractures associated with the Balcones fault zone probably facilitate recharge to the upper and middle zones of the Trinity aquifer. The fractures trending northwest to southeast likely are the principal avenues of recharge to the aquifer as a result of extension perpendicular to the Balcones fault zone. Cave development probably is concentrated along extensional fractures.

Observed Porosity and Permeability

The porosity and permeability of the rocks of the Glen Rose Limestone generally are lower than the porosity and permeability of the rocks of the Edwards Group, which form the Edwards aquifer to the south of the study area. Relatively greater permeability in the mapped hydrogeologic subdivisions of the Glen Rose Limestone tends to be related to lithology, zones of higher primary porosity, solutionally enlarged fractures, and karst features (primarily caves).

Fewer karst features were observed at the CSSA than at adjacent Camp Bullis. Preliminary results of a karst inventory at CSSA (George Veni, George Veni & Associates, written commun., 2003) indicate that most karst features occur near the top of Interval D and the top of the lower Glen Rose Limestone (fig. 1).

The observed porosity and permeability of the hydrogeologic subdivisions in the study area are described below, from youngest to oldest:

The porosity of Interval A primarily is associated with fractures and caves and is not-fabric selective. The porosity is interconnected, thus the interval is more permeable relative to Interval B. The interval likely contains avenues for recharge, although its small areal extent limits its relevance in terms of the potential for recharge.

Interval B contains little porosity and permeability. Not-fabric selective fracture porosity appears to be the dominant type with some minor cave development along solutionally enlarged fractures. Most fractures have little solution enlargement. This interval acts as a confining unit, except in the few places where cave development has occurred.

Interval C contains fabric selective boxwork porosity and breccia porosity associated with collapse resulting from solution of evaporites. This interval tends to channel water laterally to discharge at springs and seeps. This interval commonly is covered with soil and vegetation.

The porosity and permeability of Interval D generally are low. However, fabric selective, moldic porosity occurs in the biostrome near the top of the interval. The biostrome also contains not-fabric selective porosity associated with vugs, fractures, and caves. This porosity appears interconnected, thus making the biostrome one of the more permeable zones of the study area. The major part of Interval D is dominated by not-fabric selective porosity, primarily in the form of fractures and caves. Permeability is relatively high in the few areas in areas where fractures or caves have been solutionally enlarged.

Like Interval C, Interval E contains fabric selective porosity in the form of moldic boxwork structures and collapse breccia associated with the dissolution of evaporites. This interval acts as a lateral conduit for flow, as reflected by the numerous seeps and springs that appear within its exposed outcrop.

The 20 to 30 feet of lower Glen Rose Limestone exposed in the study area contains not-fabric selective porosity associated with fractures and caves, and in some places, fabric selective moldic porosity. Many of the karst features at the CSSA mapped by Veni (George Veni, George Veni & Associates, written commun., 2003) occur where the lower Glen Rose Limestone is exposed along Salado Creek. The lower Glen Rose Limestone probably is one of the more permeable units in the study area.

SUMMARY

The Camp Stanley Storage Activity (CSSA) overlies the Trinity aquifer in northern Bexar County, Tex. The Glen Rose Limestone comprises the upper zone and the upper part of the middle zone of the Trinity aquifer and crops out in the study area. During 2003, the USGS, in cooperation with the U.S. Army, mapped the hydrogeologic subdivisions and faults of the Glen Rose Limestone at the CSSA and immediately adjacent area (Camp Stanley study area) to help resource managers improve their understanding of the distribution of porosity and permeability of the outcropping rocks, and thus the conditions for recharge and the potential for contaminants to enter the Glen Rose Limestone.

The rocks of the Glen Rose Limestone are fossiliferous limestones, alternating and interfingered with mudstone, wackestone, packstone, and grainstone; and where present, more massive carbonates are interbedded and interfingered with evaporites and marls. High-angle normal faults in the study area are part of the Miocene-age Balcones fault zone, an extensional system of faults that generally trends southwest to northeast in the region. Although faults are the dominant structural feature of the region, they appear to have little effect on recharge and in some places might act as barriers to ground-water flow. Two primary sets of fractures were identified at CSSA, the larger oriented northwest to southeast, perpendicular to the trend of the Balcones fault zone, and the smaller oriented southwest to northeast, parallel to the Balcones fault zone. In contrast to faults, fractures associated with the Balcones fault zone probably facilitate recharge.

The Glen Rose Limestone is subdivided (informally) into an upper and a lower member. On the basis of previous mapping by the USGS at adjacent Camp Bullis, the upper Glen Rose Limestone in the study area has been subdivided into five mappable intervals, designated (youngest to oldest) A through E.

Intervals A and B (alternating and interfingering medium-bedded mudstone to packstone, with solution zones locally) compose the upper 150 to 270 feet of the upper Glen Rose Limestone at the Camp Stanley study area. Interval A occurs only in a small area in the southern part of the CSSA, where it ranges from about 30 to 40 feet thick. The only distinguishing factor in the field between the two intervals is the greater number of caves present within Interval A. The porosity of Interval A, which primarily is associated with fractures and caves (not-fabric selective), is interconnected and thus the interval is more permeable relative to Interval B. Interval B contains little porosity and permeability.

Interval C is a solution zone 10 to 20 feet thick that originally was an evaporite bed. The interval contains fabric selective boxwork porosity and breccia porosity and tends to channel water laterally, as reflected by seeps and springs.

Interval D (alternating beds of wackestone, packstone and marl) is 135 to 180 feet thick. The porosity and permeability of Interval D generally are low, although fabric selective, vug, fracture, cavern, and moldic porosity that is interconnected occurs in a 30- to 40-foot-thick biostrome near the top of the interval, which makes the biostrome one of the more permeable zones of the study area.

Interval E is a 7- to 10-foot-thick solution zone that, like Interval C, originally was an evaporite bed. Also like Interval C, the interval contains fabric selective boxwork porosity and breccia porosity and tends to channel water laterally, as reflected by numerous seeps and springs.

The lower Glen Rose Limestone (massive mudstone to grainstone) exposed in the study area contains not-fabric selective porosity associated with fractures and caves and probably is one of the more permeable units in the study area.

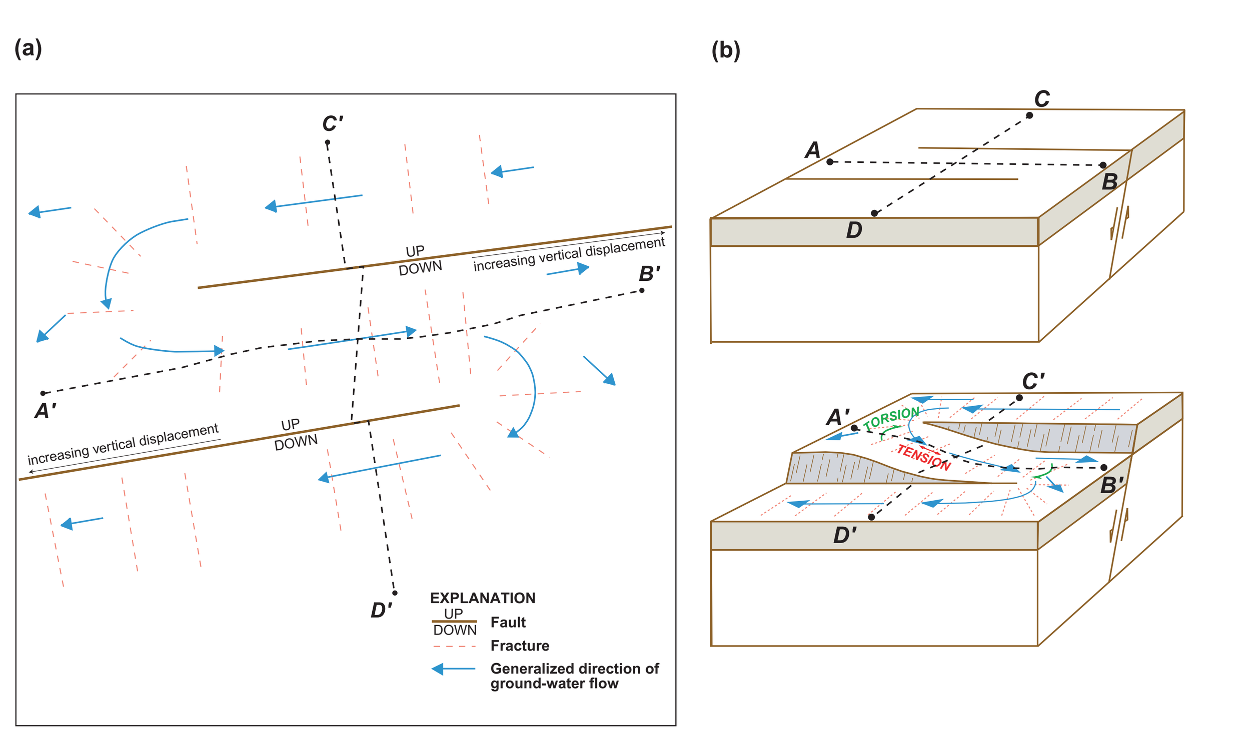

Figure 2. Conceptual model of a relay ramp (a) plan view, and (b) oblique views before and after the occurrence of fault displacement and surface deformation, showing hypothetical undeformed lines *AB* and *CD* and deformed lines *A′B′* and *C′D′*, respectively (modified from Peacock and Sanderson, 1994, fig. 8).

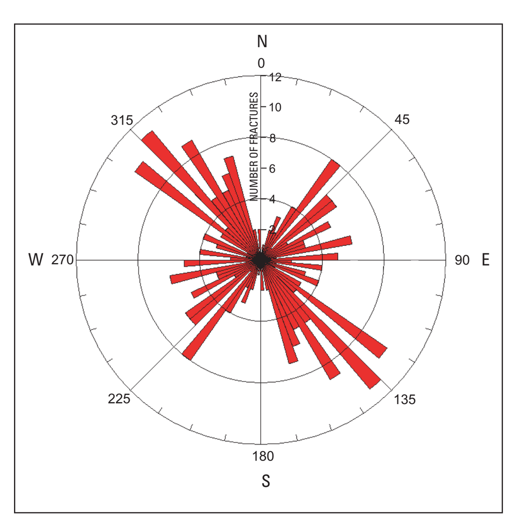

Figure 3. Rose diagram showing orientation of observed fractures, Camp Stanley Storage Activity and immediately adjacent area, Bexar County, Texas.

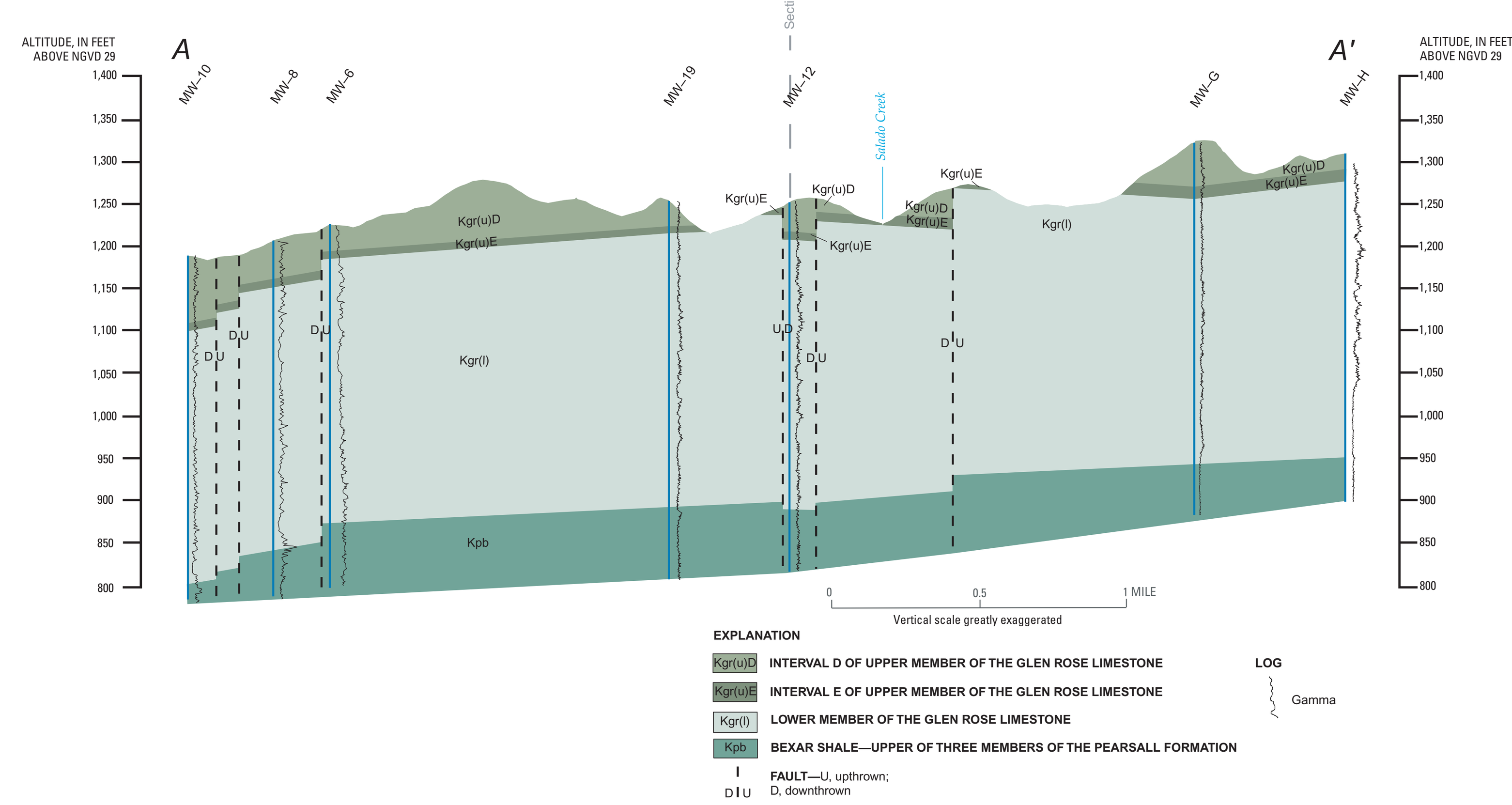

Figure 4. Section *A–A′*, south to north, Camp Stanley Storage Activity, Bexar County, Texas.

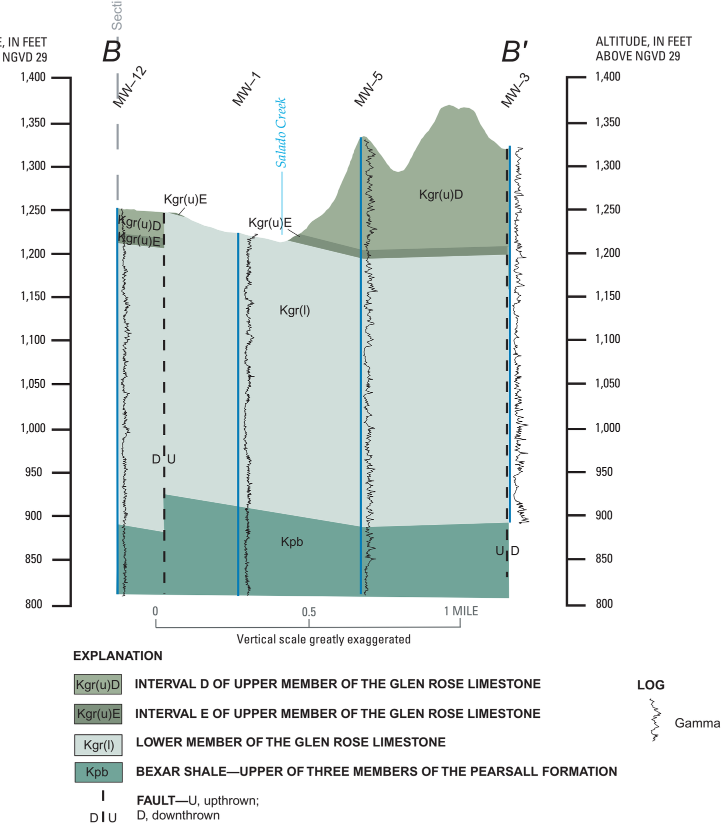

Figure 5. Section *B–B′*, west to northeast, Camp Stanley Storage Activity, Bexar County, Texas.

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VERTICAL DATUM

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)

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GEOLOGIC FRAMEWORK AND HYDROGEOLOGIC CHARACTERISTICS OF THE GLEN ROSE LIMESTONE, CAMP STANLEY STORAGE ACTIVITY, BEXAR COUNTY, TEXAS

By
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2004

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