Summary Report for the 1997–1998 STATEMAP Project: Geological Mapping to Support Improved Data Base Development and Understanding of Critical Aquifers of Texas

by

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Summary Report for the 1997-1998 STATEMAP Project: Geological Mapping to Support Improved Data Base Development and Understanding of Critical Aquifers of Texas

This Texas STATEMAP project involves the geologic mapping of areas where improved geologic information can impact development, land use, public education, environmental protection, and the economy. The study is divided into two subprojects. Work for subproject 1 deals with the second year of mapping for a three-yr mapping study of karst aquifer areas undergoing rapid urban growth along the Edwards aquifer and recharge zone. Three map areas are included in subproject 1: West San Antonio, Austin–Georgetown, and Del Rio (fig. 1). These areas include some of the fastest growing urban areas in Texas. Development of this area has been further stimulated by NAFTA because the region is traversed by major transportation routes from Mexico. Part of the Edwards aquifer is currently the sole-source aquifer of San Antonio. Geologic maps of subproject 1 areas provide basic information necessary for managing water and land resources and construction practices.

Mapping for subproject 2 involves two areas of the Texas Panhandle that include public lands of State parks (fig. 2). The map areas include outcrops of Tertiary Ogallala and Triassic Dockum strata, units that supply water to the productive agricultural industry and people of the High Plains of Texas. Maps of subproject 2 areas will help the State better manage the resources of the State parks, and provides the basis for educating both professionals (such as local water districts, planners, and politicians) and the general public about the High Plains aquifer and geology and about geologic processes.

Nineteen maps, each scale 1:24,000, were completed during this past contract year. Methods used to map the areas included following standard field techniques, studying aerial photographs, and reviewing previous work. Unit contacts and faults are portrayed on the maps by solid and dashed lines to reflect the relative clarity of the features observed in the field and on aerial photographs. Faults and unit contacts drawn as solid lines are relatively more distinct in the field and on aerial photographs than where they are drawn by dashed lines. Dotted fault lines

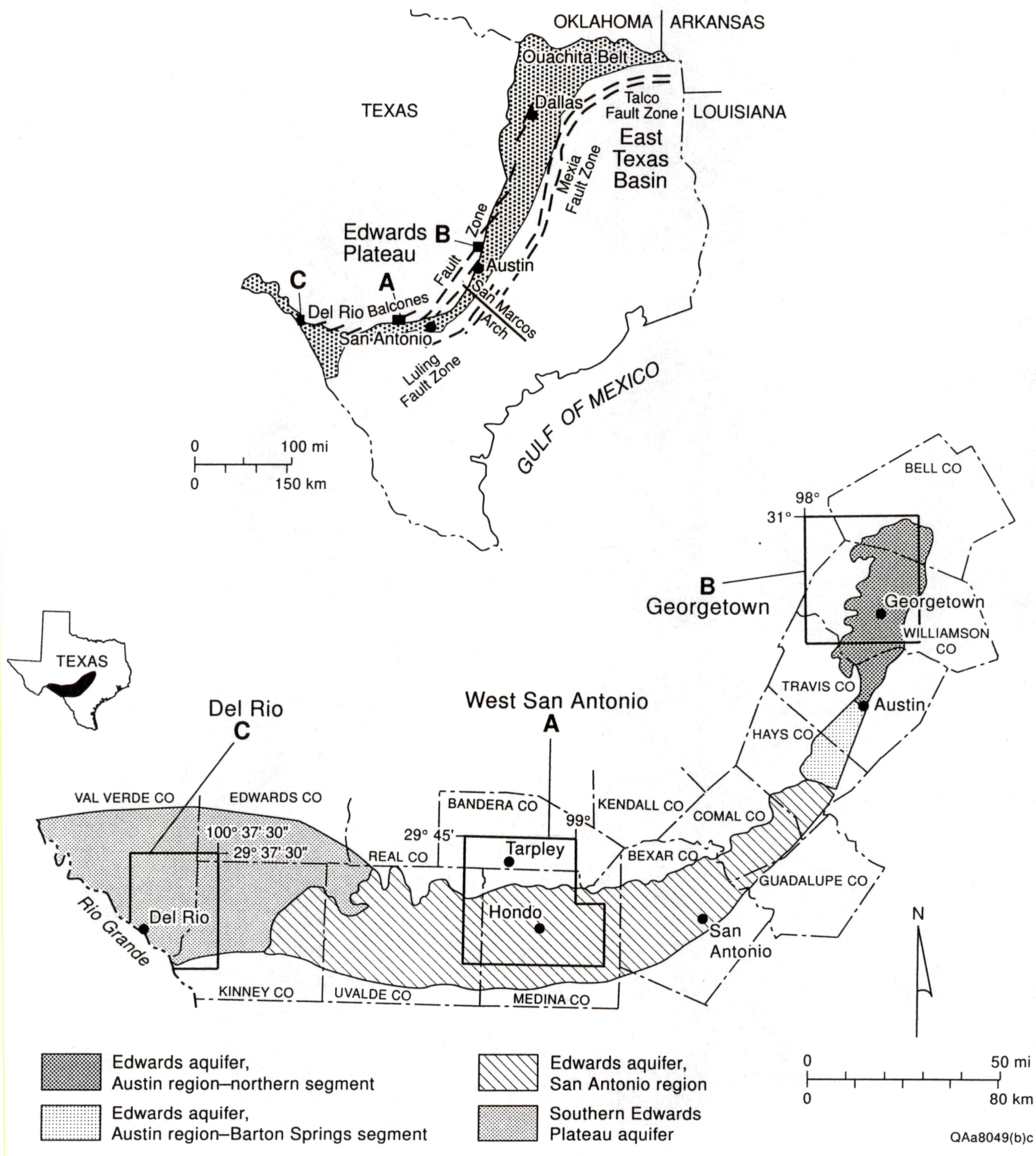


Figure 1. Location of subproject 1 map areas, (a) West San Antonio, (b) Austin–Georgetown, and (c) Del Rio Corridors. These map areas include parts of the Balcones Fault Zone and the Edwards aquifer and Edwards aquifer recharge zone.

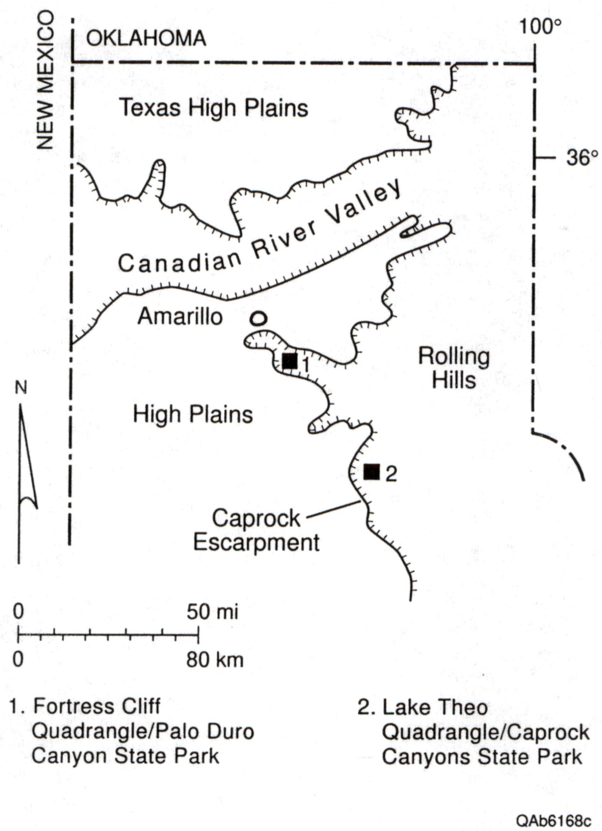


Figure 2. Location of the Texas Panhandle subproject 2 map areas.

show where faults are covered. Most strata in the study areas are almost flatlying and commonly have very low regional dips of less than a degree. Some exceptions exist locally where strata dipping between 2° and 6° have been recognized on aerial photographs or in the field, where a distant view allows recognition and measurement of low stratal dips. Other local exceptions occur where dipping strata exist adjacent to faults, and where Permian strata in the Texas Panhandle exhibit deformation related to regional evaporite dissolution and collapse of overlying strata.

It is our intent that maps for subproject 1 will ultimately be combined into seamless data sets. Three hard-copy maps at scale 1:100,000 are planned for future publication in addition to digital geologic map data. Cross-section locations and page-sized scales of cross sections shown in this summary report may be revised after the third year of mapping and after final publication plans are determined for 1:100,000-scale maps. Unit descriptions, stratigraphic charts, and correlation diagrams are based on observations made during this study and by earlier workers. Several regional geologic maps, scale 1:250,000, illustrate the regional geology surrounding subproject 1 and 2 map areas (Eifler and others, 1968; Eifler, 1969; Brown and others, 1974; Proctor and others, 1974; Waechter and others, 1977). Some useful previous studies of Central and south-central Texas stratigraphy include Young's (1967) discussion of the Lower Cretaceous and Young and Woodruff's (1985) guidebook of the Upper Cretaceous Austin Group, Rodda and others' (1966) study of Lower Cretaceous rocks, Stricklin and other's (1971) investigation of the Lower Cretaceous Trinity deposits, interpretations of the Lower Cretaceous Edwards Group by Rose (1972) and Abbott (1973), and Moore's (1964, 1996) evaluations of Fredericksburg strata. Previous more local studies are Holt's (1959) report on the geology of Medina County, Adkins and Arick's (1930) investigation of the geology of Bell County, and Freeman's (1968) discussion of the geology west of Del Rio. McFarlan and Menes's (1991) summary of the Lower Cretaceous of the Gulf of Mexico Basin and Sohl and others' (1991) discussion of the Upper Cretaceous of the Gulf of Mexico Basin were also useful, as was Sellards and others' (1932) volume on the stratigraphy of Texas. Previous useful studies of the Permian, Triassic, Tertiary, and Quaternary stratigraphy in the Panhandle map areas include Matthews (1969), Hood (1977a, b), McGowen and others (1979), Seni (1980), Gustavson and others (1981), Fracasso and Kolker (1985a, b), Caran and Baumgardner (1991), Lehman (1992, 1994), and Gustavson (1996).

SUBPROJECT 1

There were 17 maps completed this past year for subproject 1. The three map areas are within the Balcones Fault Zone, which is the main structural control on the geology of the region and on the Edwards Limestone aquifer and recharge zone (fig. 1). The stratigraphy of the map areas is dominated by Cretaceous shallow-marine shelf deposits onlapped by chalk and calcareous, clastic-slope sediments that thicken and change facies across the region (figs. 3, 4, and 5). Late Tertiary and Quaternary gravel and sand deposits locally overlie the older strata (fig. 3). Detailed stratigraphy of the map areas is described in Appendix A — Explanation of Map Units.

In the West San Antonio Corridor, we mapped the Sabinal NE, D'Hanis, Mustang Valley, Hondo, Quihi, Murphy School, Riomedina, and Castroville quadrangles (fig. 6). The geology in the north part of the area mapped during this year consists of faulted Lower and Upper Cretaceous rocks, whereas in the south part of the study area the Cretaceous strata are overlain by late Tertiary and Quaternary gravel and sand deposits. Most of the normal faults within the West San Antonio study area strike N50°-75°E and are downthrown toward the southeast. The larger faults have throws between ~300 and ~500 ft. The important Edwards aquifer strata of this area, Kainer, Person, and Devils River Formations, are ~550 to ~650 ft thick and the composite structural relief of these Edwards aquifer limestones across the West San Antonio study area is as much as ~3,000 ft (fig. 7).

Mapping in the Austin–Georgetown corridor includes the Salado, Youngsport, Ding Dong, Florence, Leander NE, and Leander quadrangles (fig. 8). Strata mapped on these quadrangles consists mostly of limestone, marl and dolomitic limestone of the Lower Cretaceous Glen Rose, Walnut, Comanche Peak, Edwards, and Georgetown Formations (figs. 3 and 4). Faults mostly

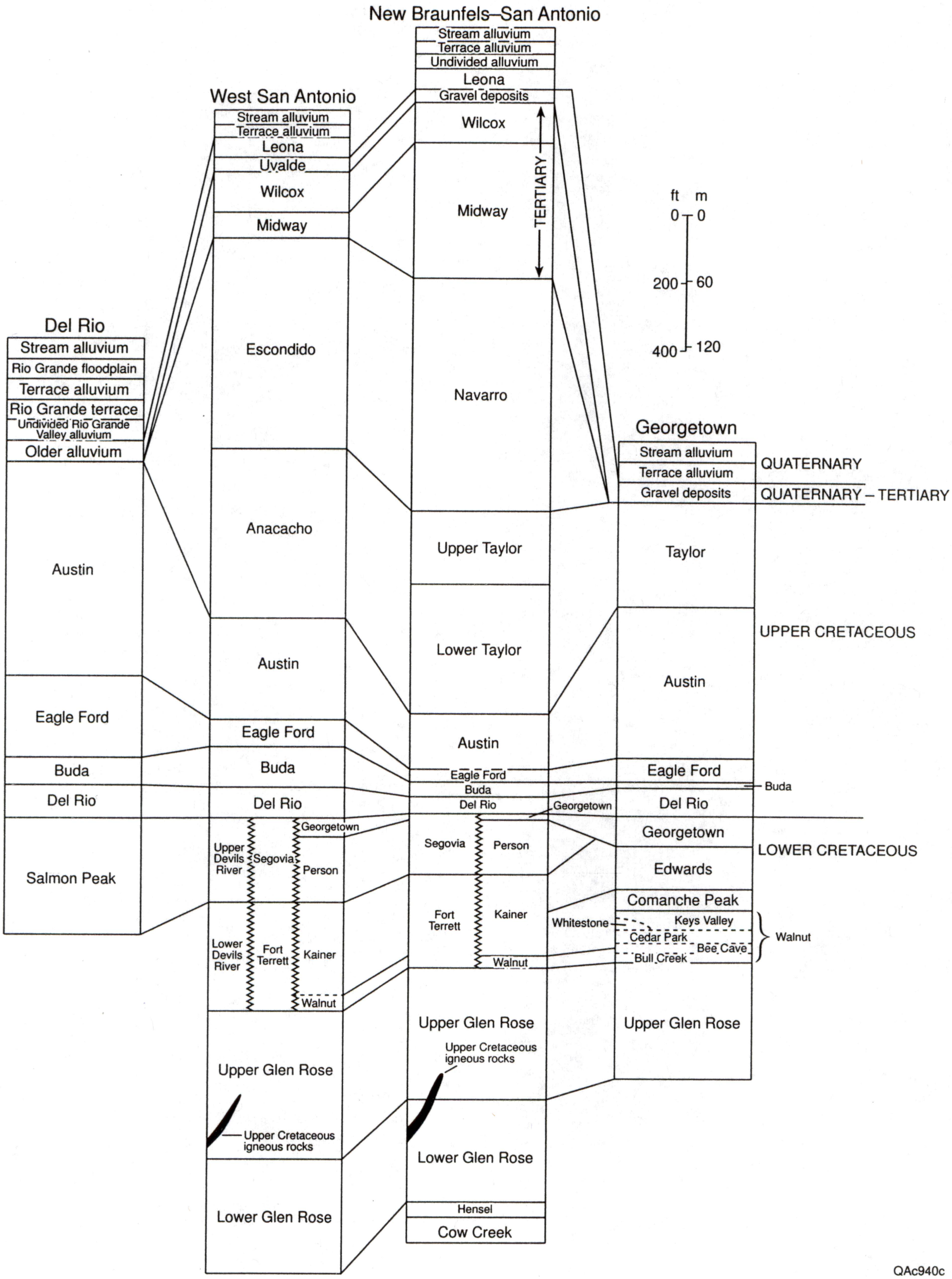


Figure 3. Stratigraphic charts illustrating units for the subproject 1 map areas and for the previous New Braunfels–San Antonio map area.

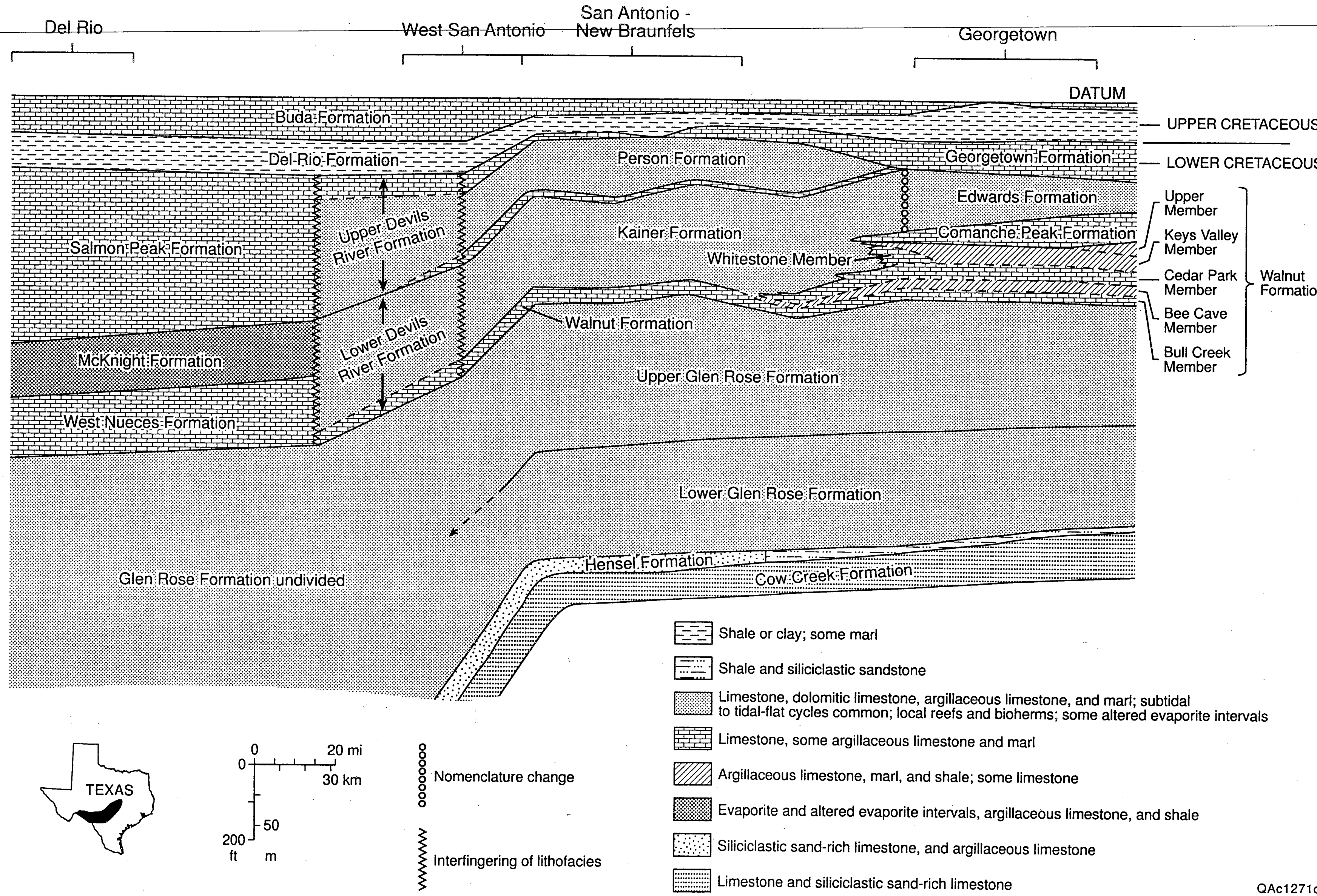


Figure 4. Diagrammatic correlation of lower Cretaceous units across south-central Texas and subproject 1 map areas.

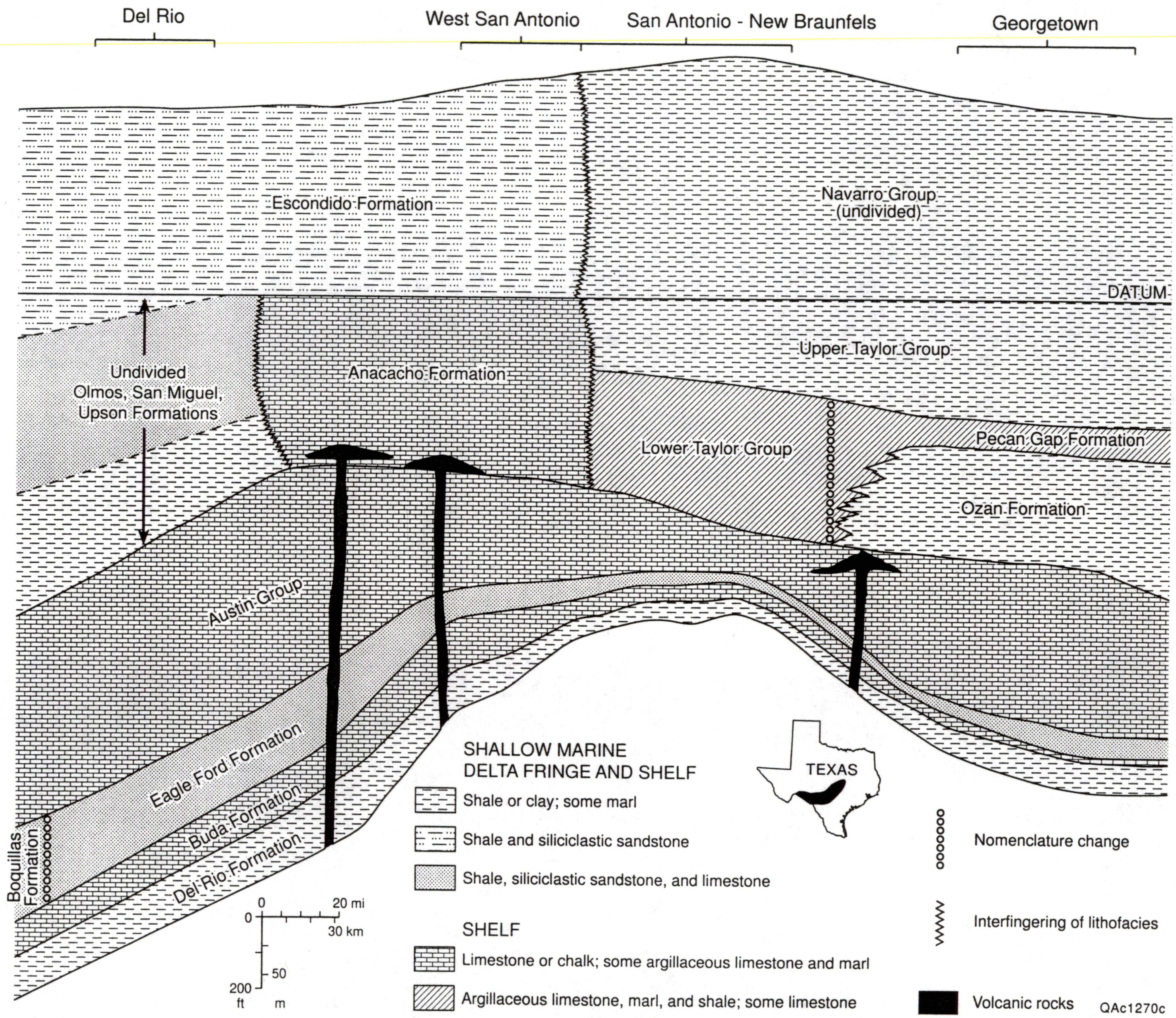


Figure 5. Diagrammatic correlation of upper Cretaceous units across south-central Texas and subproject 1 map areas.

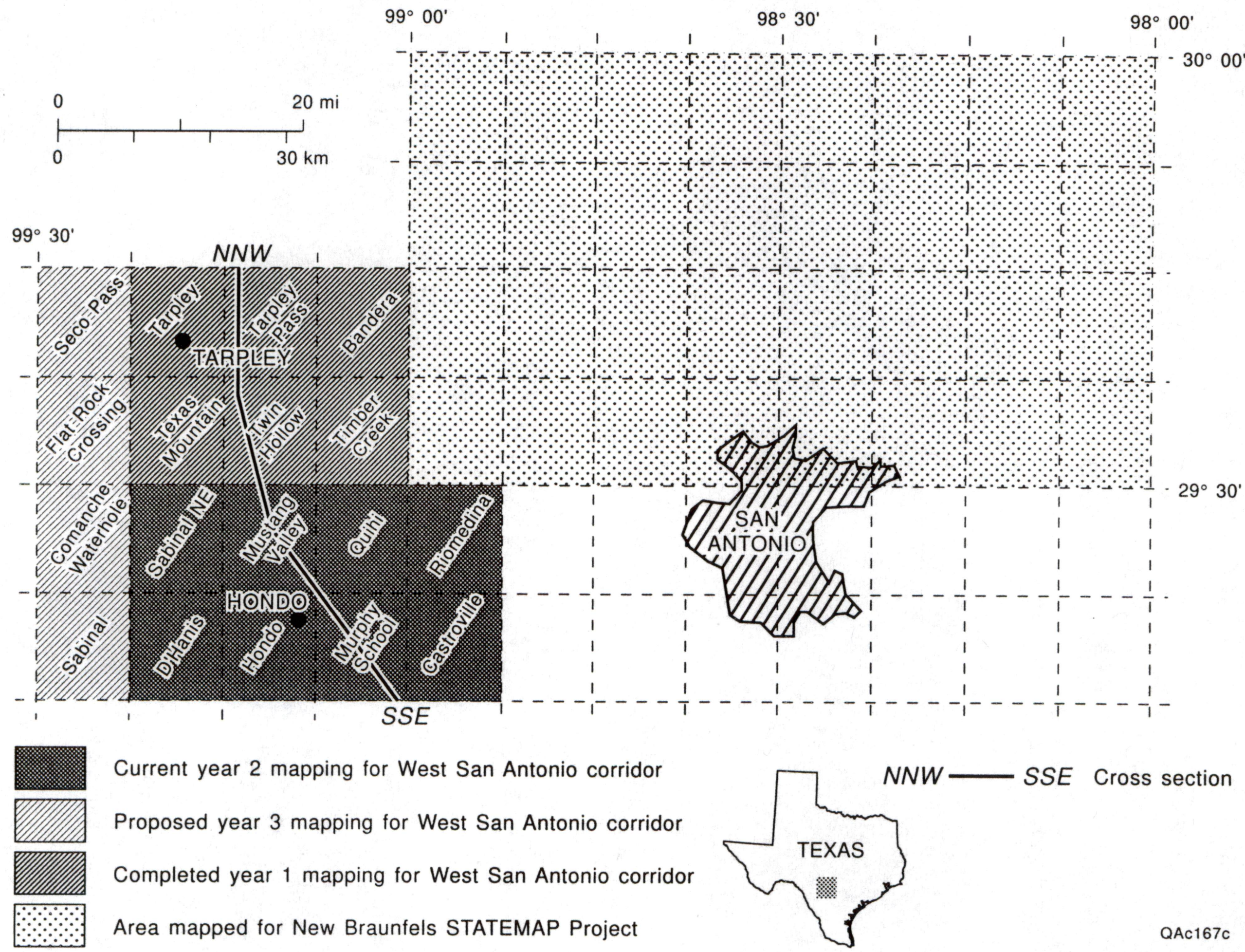


Figure 6. Diagram of 7.5-minute quadrangles that compose the West San Antonio map area. This report discusses the year 2 mapping. Cross section is illustrated in figure 7.

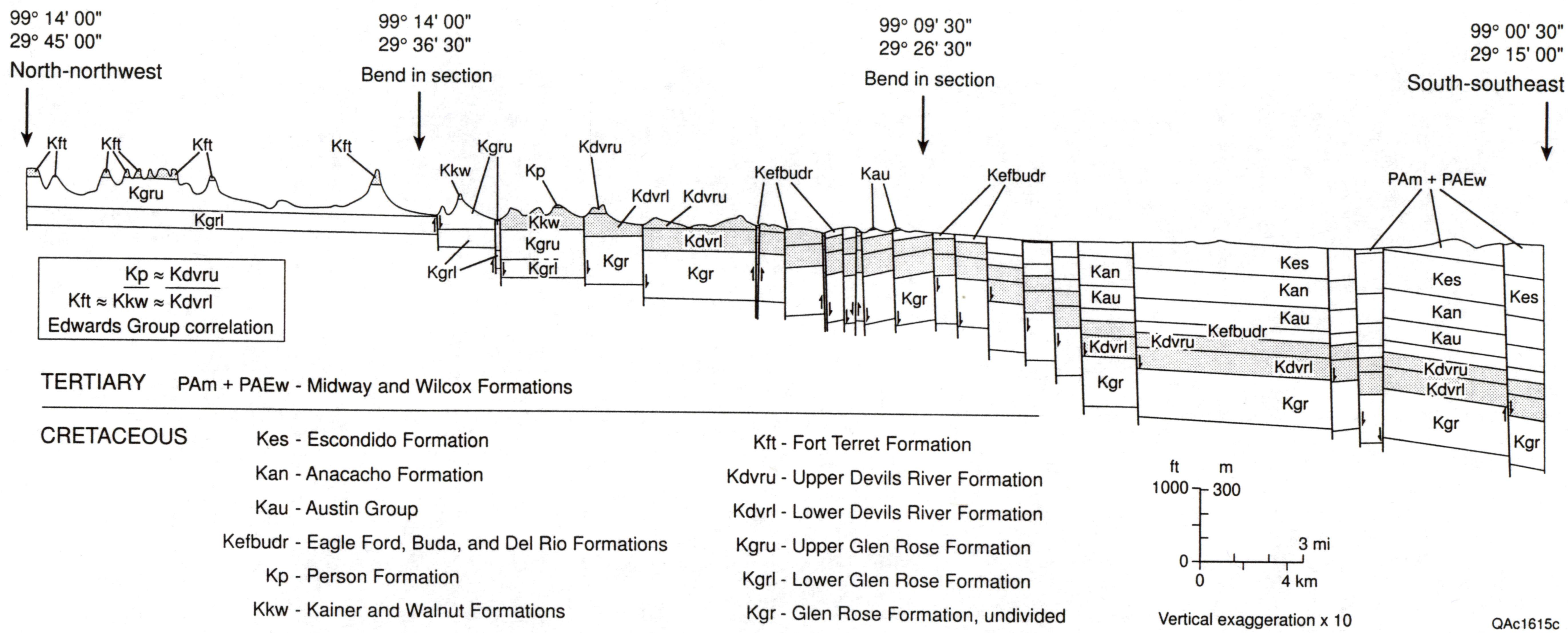


Figure 7. Cross section across West San Antonio map area. Shaded units indicate Edwards aquifer strata. Location of cross section is shown in figure 6.

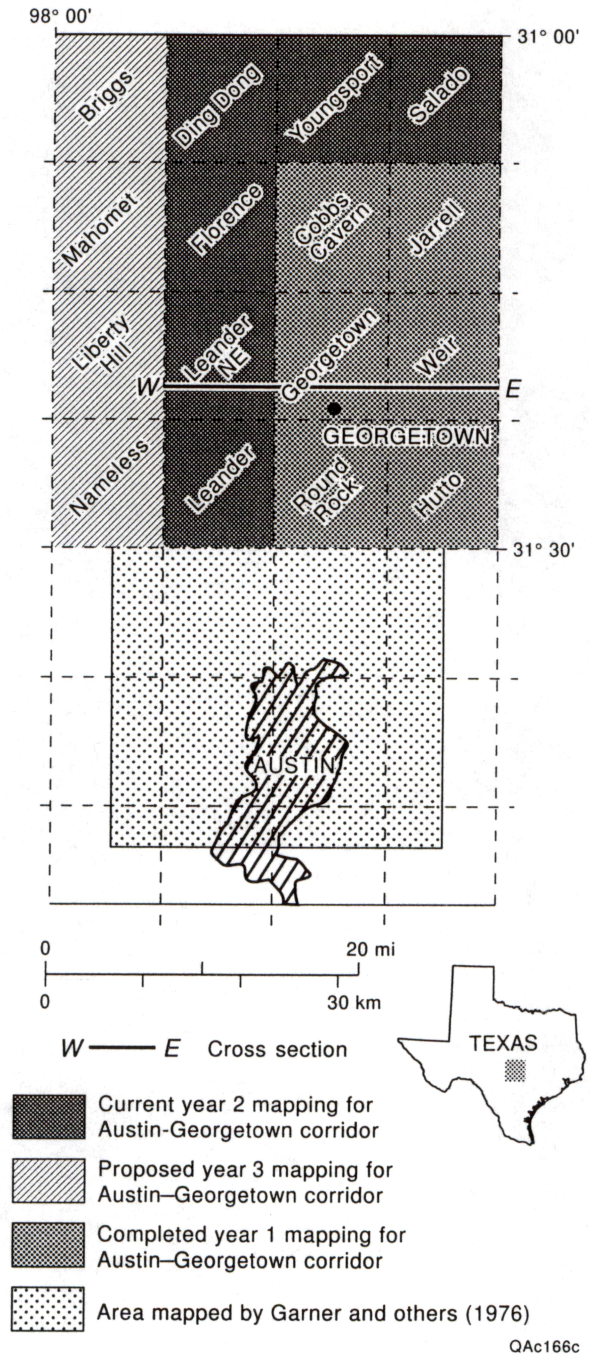


Figure 8. Diagram of 7.5-minute quadrangles that compose the Austin–Georgetown map area. This report discusses the year 2 mapping. Cross section is illustrated in figure 9.

strike 1°-40°E and dip eastward. The Edwards aquifer, ~150 to ~200 ft thick, is made up of Edwards and Comanche Peak Limestones and dolomitic limestones, and the greater porosity is within the Edwards Formation. The composite structural relief of the Edwards Limestone across the map area is as much as 1,200 ft (fig. 9).

In the Del Rio Corridor, we mapped the Del Rio SE, Del Rio NE, and Rough Canyon SE quadrangles (fig. 10). Mapped strata consist mostly of Cretaceous Salmon Peak limestone (aquifer strata), Del Rio clay and calcareous siltstone, Buda limestone, Eagle Ford shale, siltstone, and limestone, and Quaternary to late Tertiary alluvium (figs. 3, 4, and 5). Several northeast-striking faults cut across the area and are part of a broad, east-northeast-trending anticline that crosses the mapped area (fig. 11).

SUBPROJECT 2

The two 1:24,000-scale quadrangles mapped for subproject 2, Fortress Cliff and Lake Theo, contain Palo Duro Canyon and Caprock Canyons State Parks, respectively (fig. 2). Geology of the Lake Theo quadrangle consists of Permian, Triassic, Tertiary, and Quaternary strata (figs. 12 and 13) exposed along the Eastern Caprock Escarpment, a distinct topographic divide that separates the High Plains of the Texas Panhandle from the topographically lower Rolling Plains. The escarpment straddles the western edge of the Lake Theo quadrangle. Units exposed at the escarpment are Permian Quartermaster sandstone, siltstone, and mudstone (Gustavson and others, 1981; Fracasso and Kolker, 1985a, b), Triassic Dockum sandstone, conglomerate, and mudstone (McGowen and others, 1979; Lehman, 1994), and Tertiary Pliocene-Miocene Ogallala caliche, sand, silt, and gravel (Seni, 1980; Gustavson, 1996). Quaternary Blackwater Draw silt, sand, and mud caps Ogallala deposits on the High Plains. Ogallala and Dockum strata contain the High Plains aquifer located west of the map area. Blackwater Draw deposits, the main surficial unit on the High Plains, support the extensive agricultural development of the High Plains region. Rugged topography has formed across the north part of the map where stream drainages have incised into the Permian Quartermaster Formation and Whitehorse/Cloud Chief

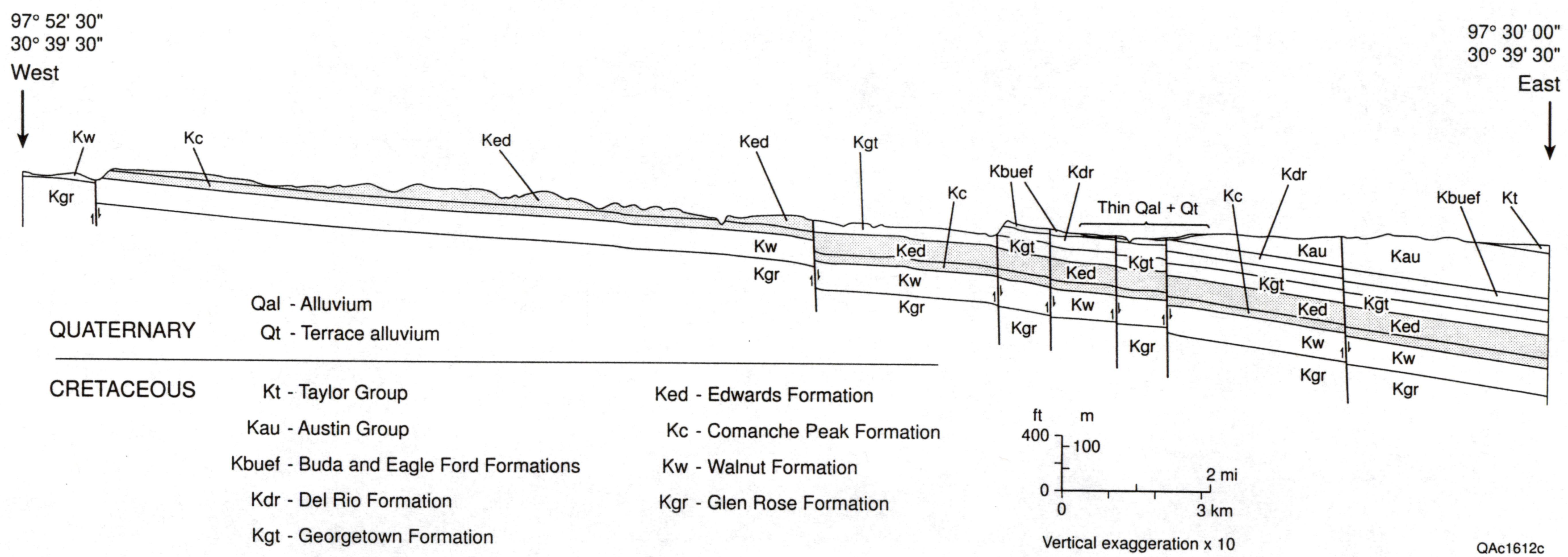


Figure 9. Cross section across Georgetown map area. Shaded units indicate Edwards aquifer strata. Location of cross section is shown in figure 8.

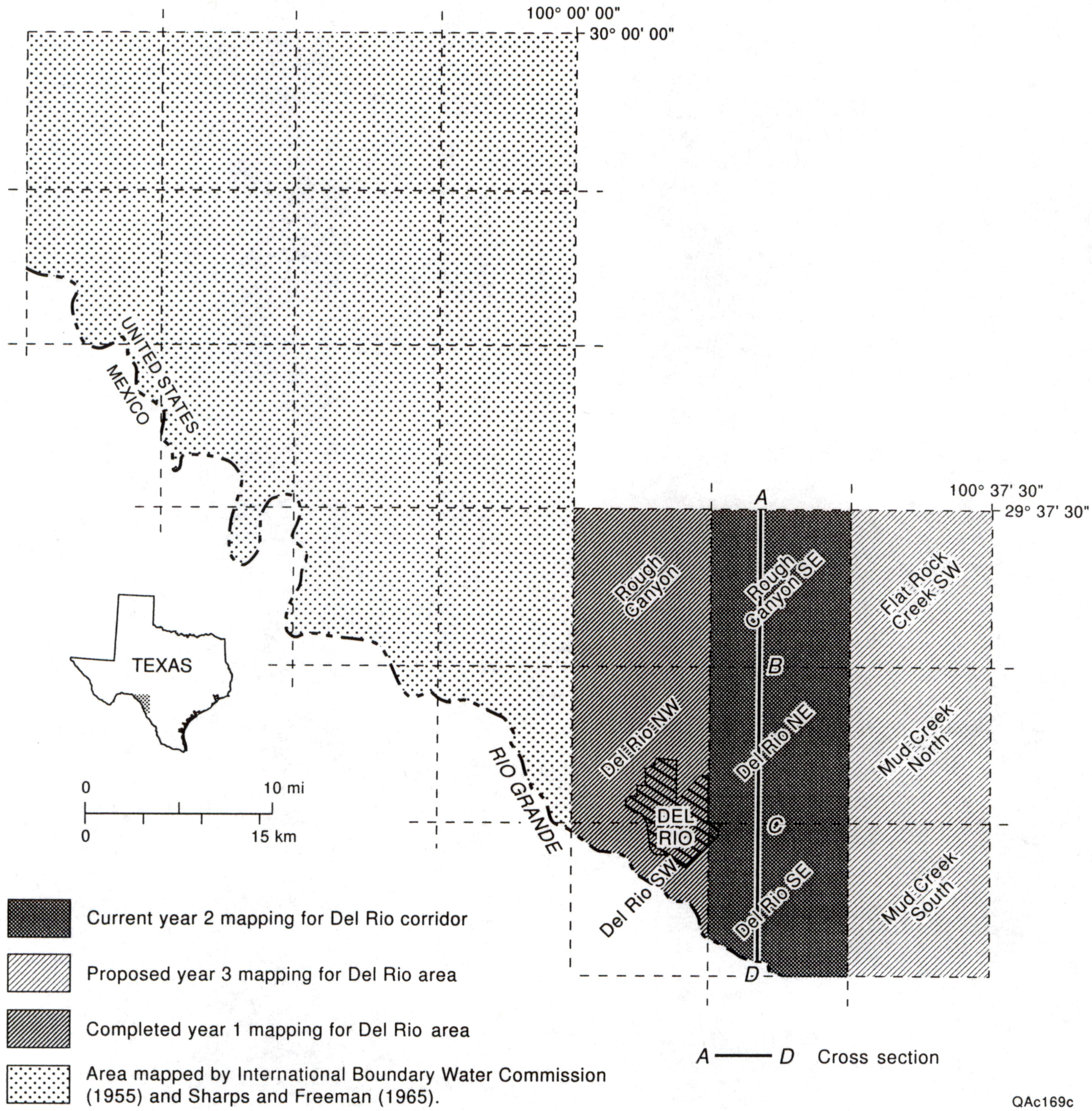


Figure 10. Diagram of 7.5-minute quadrangles that compose the Del Rio map area. This report discusses the year 2 mapping. Cross section is illustrated in figure 11.

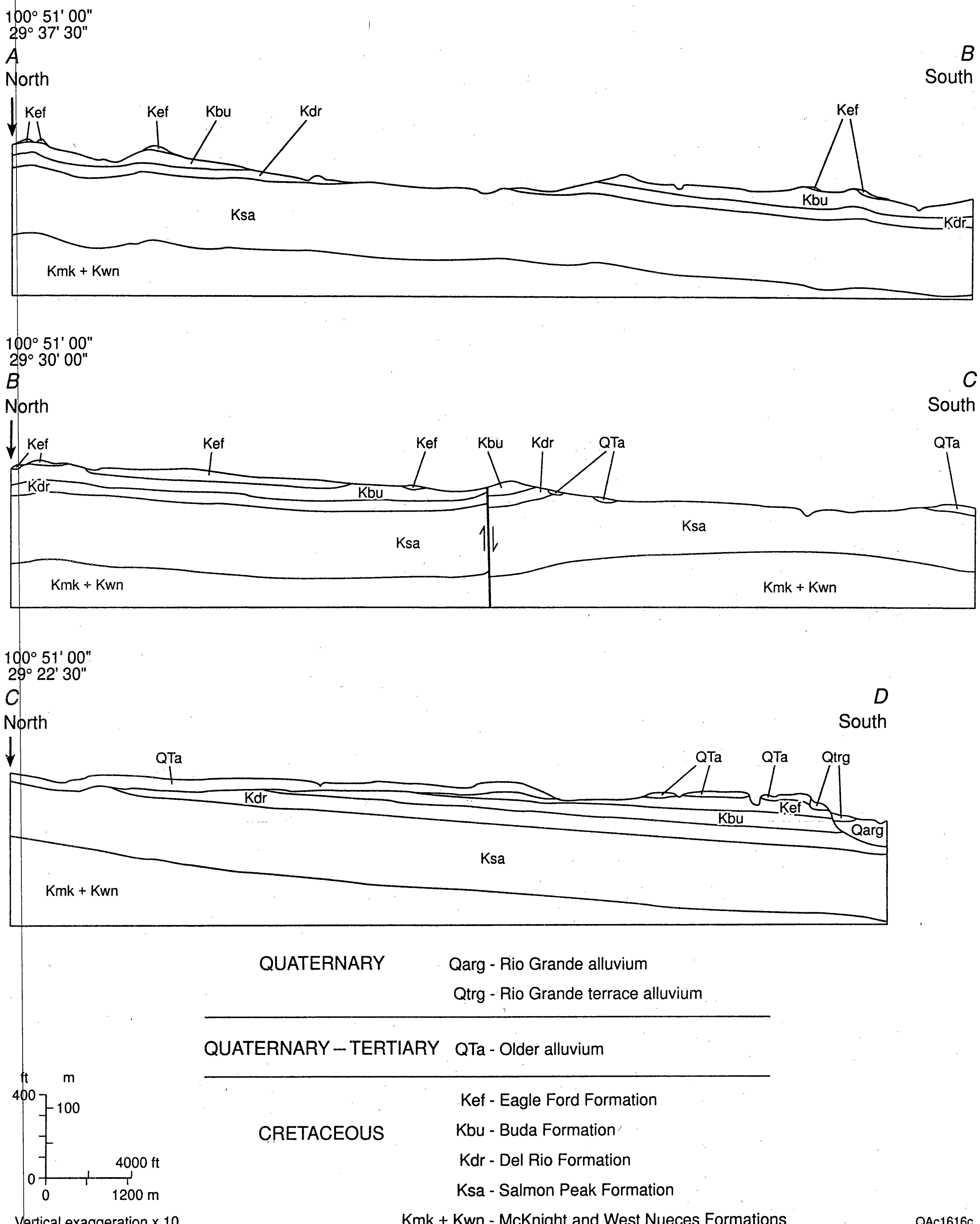
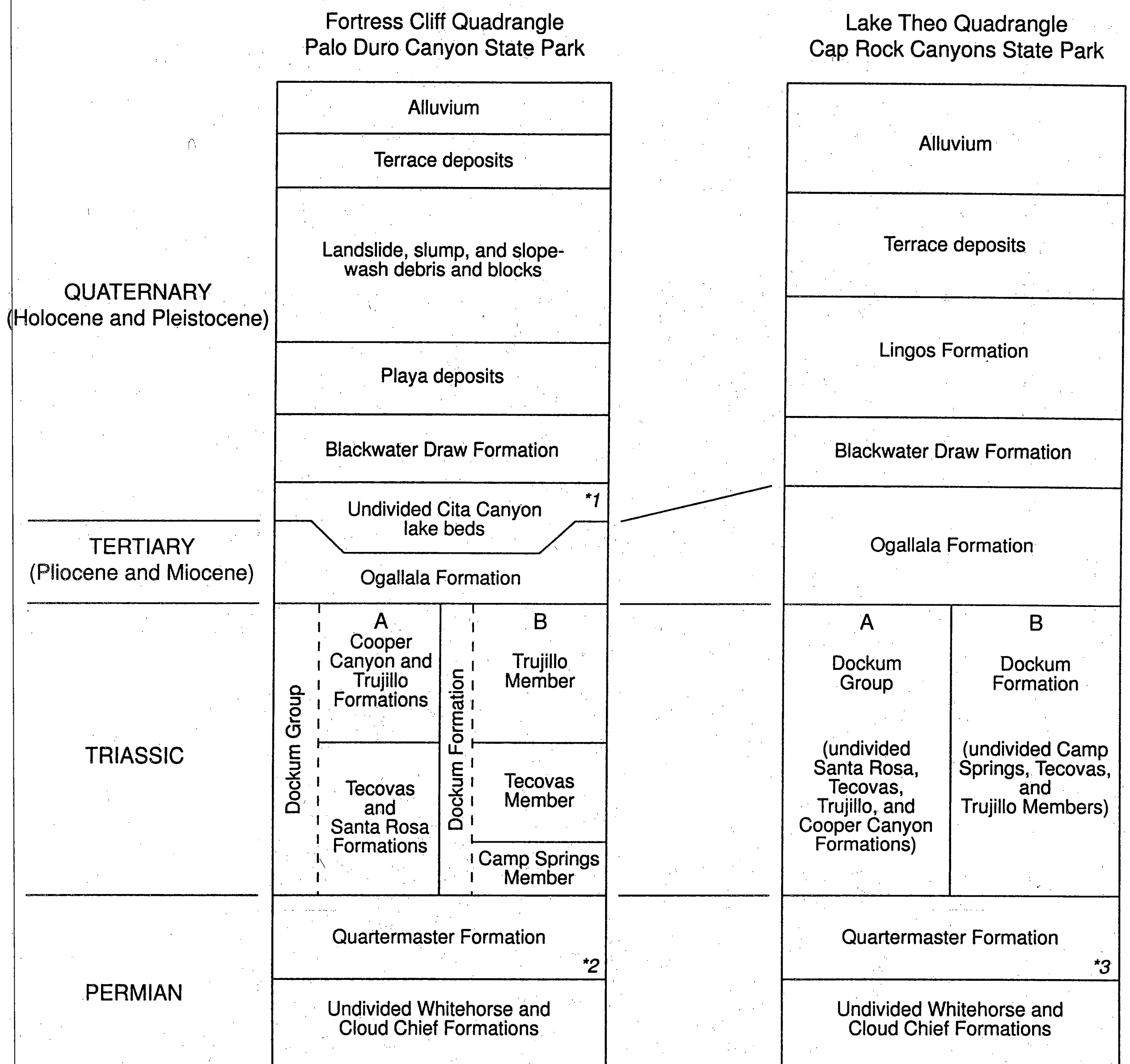


Figure 11. Cross section across Del Rio map area. Location of cross section is shown in figure 10.



Ash: *1 Approximately 600,000 years B.P. (Johnston and Savage, 1955; Hood, 1977a; Izett and Wilcox, 1982)
*2 Not dated (Fracasso and Kolker, 1985a)
*3 251 ± 4 m.y. (Lower of two ashes; Fracasso and Kolker, 1985a, b)

A Nomenclature following Lehman (1994)
B Nomenclature proposed by Lucas and others (1994)

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Figure 12. Stratigraphic charts illustrating units for the subproject 2 map areas.

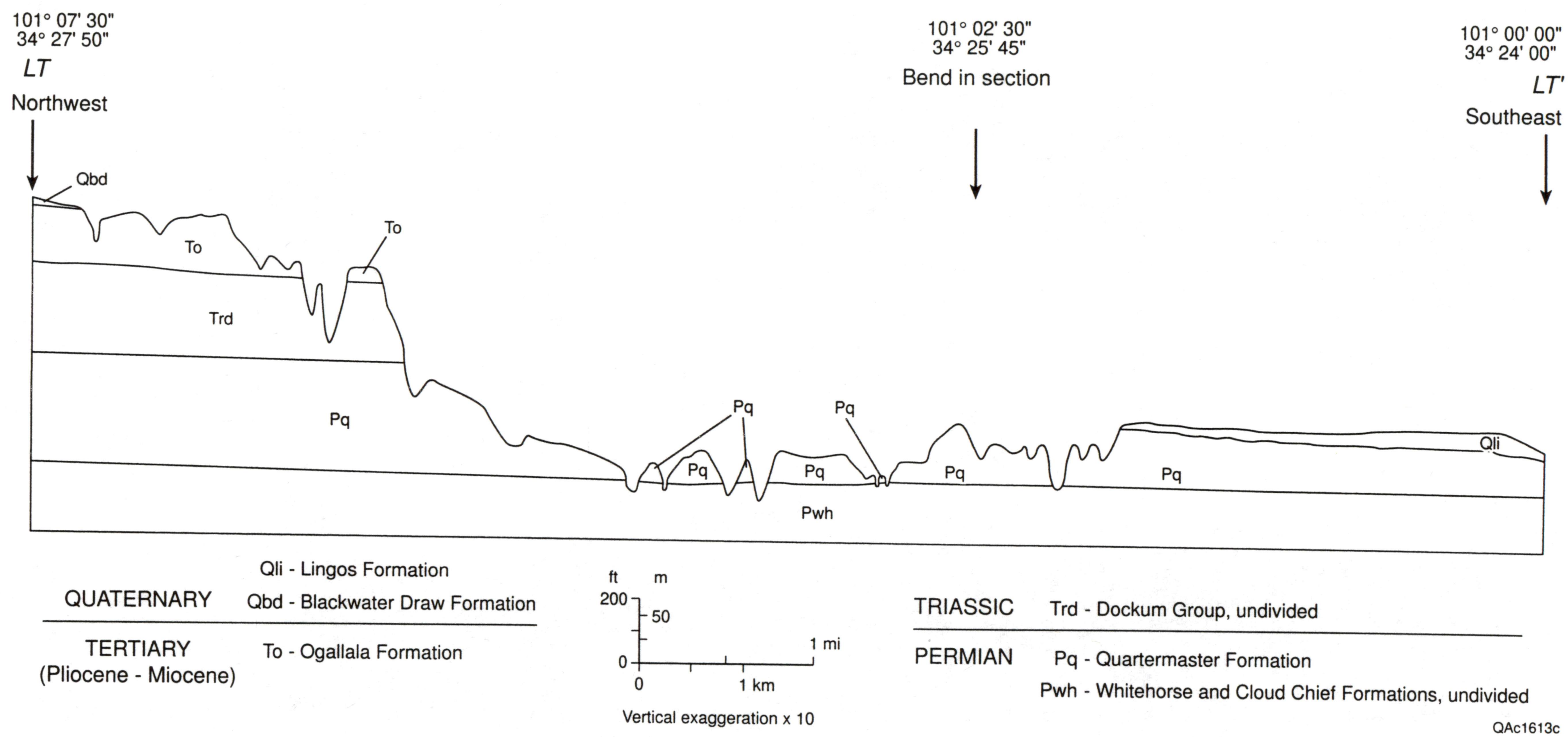

Figure 13. Cross section across the Lake Theo quadrangle. Location of cross section is shown on the geologic map of the quadrangle.

sandstone, siltstone, mudstone, and gypsum beds (fig. 13). Dissolution of subsurface Permian evaporite strata has resulted in subsidence and collapse of outcropping lower Quartermaster and Whitehorse/Cloud Chief strata. This subsidence has caused small folds and fractures that are filled with gypsum (Collins, 1984; Goldstein and Collins, 1984). At the south part of the Lake Theo quadrangle, Lingos Formation sand, silt, gravel, and mudstone form an apron of relatively undissected sediment overlying Permian and Triassic strata east of the Caprock Escarpment (Caran and Baumgardner, 1991). Lingos' deposits are a local source of shallow ground water.

The geologic units of the Fortress Cliff quadrangle, somewhat similar to those of the Lake Theo quadrangle, consist of Permian, Triassic, Tertiary, and Quaternary strata (figs. 12 and 14) that are exposed in Palo Duro and North Cita Canyons. These canyons have been incised into the High Plains of the Texas Panhandle by North Cita Creek and the Prairie Dog Town Fork of the Red River. The High Plains are capped by Pleistocene Blackwater Draw silt, sand, and mud and Pliocene–Miocene Ogallala caliche, sand, silt, and gravel. Inset within these units are ancient lacustrine deposits that compose the undivided Pliocene–Pleistocene Cita Canyon lake beds (Hood, 1977a, b; Gustavson, 1991). Underlying Ogallala deposits are Triassic Dockum units mapped as older, undivided Santa Rosa and Tecovos mudstone, siltstone, and sandstone, and younger, undivided Trujillo and Cooper Canyon sandstone, conglomerate, and mudstone (McGowen and others, 1979; Lehman, 1994). Ogallala and Dockum strata contain the High Plains aquifer. Blackwater Draw deposits, the main surficial unit on the High Plains, support the extensive agricultural development of the High Plains region. Beneath the Dockum units are Permian Quartermaster sandstone, siltstone, and mudstone (Fracasso and Kolker, 1985a, b) and local Whitehorse/Cloud Chief sandstone, siltstone, mudstone, and gypsum beds. Similar to Permian strata in the Lake Theo area, dissolution of subsurface Permian evaporite strata has resulted in the subsidence and collapse of outcropping lower Quartermaster and Whitehorse/Cloud Chief strata. This deformation has caused folds and fractures filled with gypsum. Some of the most distinctive deposits in the canyons consist of relatively young, undivided landslide, slump, and slope-wash debris and blocks (Gustavson and Simpkins, 1989).

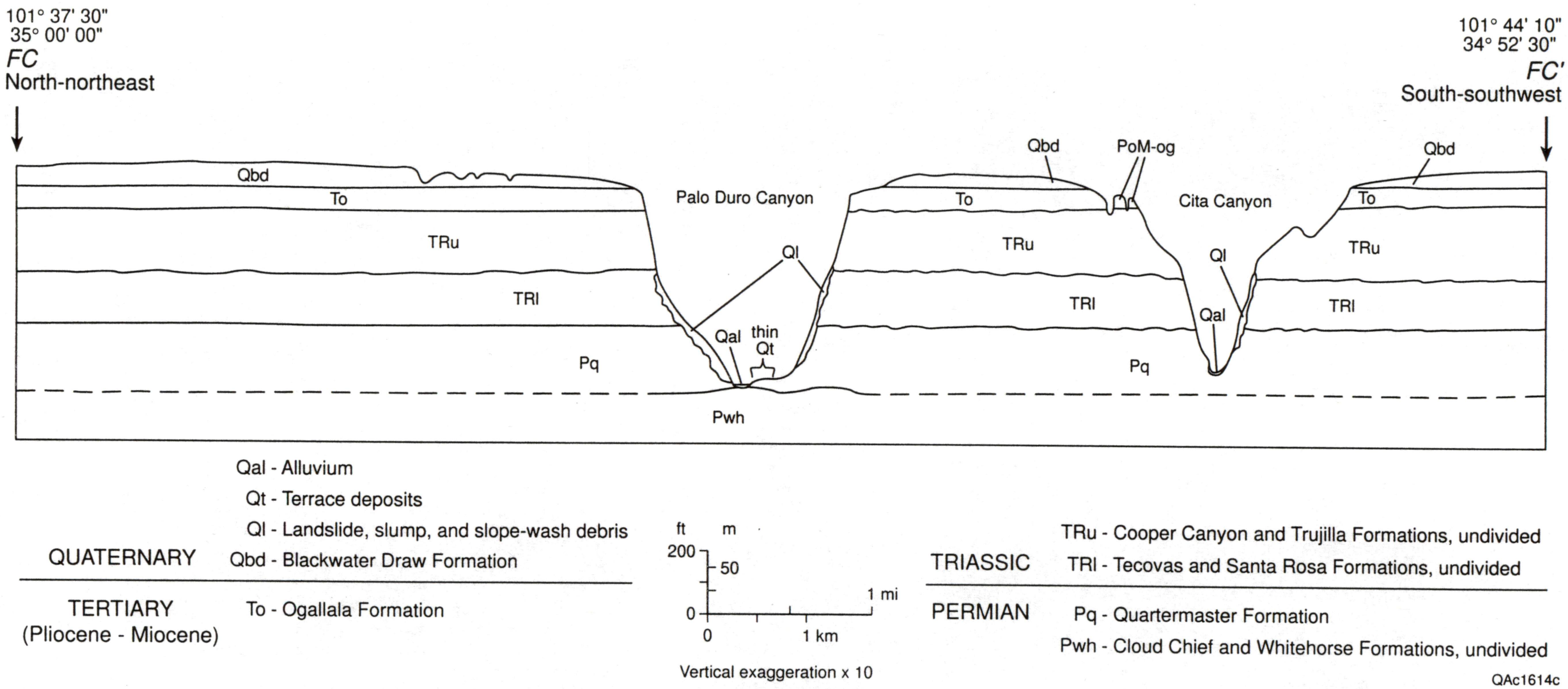

Figure 14. Cross section across the Fortress Cliff quadrangle. Location of cross section is shown on the geologic map of the quadrangle.

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APPENDIX A: EXPLANATION OF GEOLOGIC UNITS

West San Antonio Region

Bandera, Castroville, D'Hanis, Hondo, Murphy School, Mustang Valley, Quihi, Riomedina, Sabinal NE, Tarpley, Tarpley Pass, Texas Mountain, Timber Creek, and Twin Hollow Quadrangles, Texas

(1:24,000 scale)

QUATERNARY

Qal—Alluvium. Unconsolidated gravel, sand, silt, and clay along streams and rivers; inundated regularly. Gravel is mostly limestone and chert. Along minor drainages includes undivided low terrace deposits. Also includes some local bedrock outcrops that are undivided.

Qt—Terrace deposits. Unconsolidated gravel, sand, silt, and clay along streams and rivers. Mostly above flood level.

Qle—Leona Formation. Fine calcareous silt grading down into coarse gravel.

Qt+Qle—Terrace deposits and Leona Formation, undivided.

TERTIARY

QTu—Uvalde gravel (older alluvium). Gravel and sand, some clay; well-rounded pebble to cobble-sized gravel common, few boulders; mostly chert and limestone, commonly cemented by caliche. Deposits typically cap topographically high areas. Precise age unknown; approximately late Tertiary to Quaternary. Thickness ranges from several feet of gravel lag to more than 10 ft.

Eocene to Paleocene

PAEw+PAm—Wilcox (Paleocene to Eocene) and Midway (Paleocene) Groups, undivided. Outcrops are not common. Wilcox Group is sandstone and mudstone; some shale and lignite.

Thickness ranges between 440 and 700 ft. Midway Group is mudstone, silt/siltstone, sand/sandstone, and sandy fossiliferous limestone. Thickness of as much as ~75 ft.

TERTIARY TO UPPER CRETACEOUS

PAm+Kes—Midway Group (Paleocene) and Escondido (Upper Cretaceous) Formation, undivided. Midway Group is mudstone, silt/siltstone, sand/sandstone, and sandy fossiliferous limestone. Outcrops are not common. Thickness of as much as ~75 ft. Escondido Formation is mudstone, siltstone, sandstone, and silty limestone. Includes thin (up to ~30 ft), lower marl and mudstone unit, Corsicana marl. Outcrops are not common. Escondido thickness ranges between 550 and 900 ft.

CRETACEOUS

Upper Cretaceous

Kes—Escondido Formation. Mudstone, siltstone, sandstone, and silty limestone. Includes thin (up to ~30 ft), lower marl and mudstone unit, Corsicana marl. Outcrops are not common. Escondido thickness ranges between 550 and 900 ft.

Kan—Anacacho Formation. Limestone and marl. Grain-rich limestone common. Light gray to white, thin to thick bedded, glauconitic, and contains fossil fragments. Thickness ranges from 240 to 500 ft.

Kau—Austin Group. Chalk, marl, and limestone. Light gray to white, thin to thick bedded, massive to slightly nodular. Chalk mostly microgranular calcite with minor foraminifera tests; abundant *Inoceramus* prisms. Chalk forms ledges and alternates with marl and locally bentonitic seams. Sparsely glauconitic, pyrite nodules partly weathered to limonite are common. Thick caliche on most outcrops. Thick black soil with juniper and live oak in low-relief areas. Locally highly fossiliferous with pelecypods, echinoids, ostracodes, and forams. Thickness of 135 to 200 ft.

Kef—Eagle Ford Formation. Shale, siltstone, and limestone. Upper part limestone and shale. Shale dark gray. Limestone light yellowish brown, flaggy, in beds up to 4 ft thick. Lower part siltstone and very fine grained sandstone, light yellow to gray, laminated, flaggy, some limestone, silty, medium brown, and laminated. Flat to gently rolling topography. Covered with dark brown soil on slopes; outcrops are rare. Strata at slope break of Eagle Ford/Buda contact commonly fossiliferous with oysters, ostracodes, forams, fish bones and teeth, and *Inoceramus*. Thickness of 15 to 30 ft.

Kbu—Buda Limestone. Limestone. Hard and dense to chalky, poorly bedded to nodular, glauconitic, fossiliferous, abundant broken shell fragments locally. Light gray to pale orange; weathers dark gray to brown. Thinner bedded and argillaceous near upper contact. Lower part is soft, chalky limestone. Upper contact is disconformable, sharp, and conspicuous. Forms resistant cap on hills. Weathers to form thin, red-brown soil with rounded cobbles of limestone. Less glauconitic and less iron-oxide-stained than Georgetown Formation. More fossil gastropods than Austin Group. Burrows filled with chalky marl. Abundant pelecypods, forams, ostracodes, serpulids, echinoid spines, and bryozoans. Locally, solitary corals and green algae. Thickness of 40 to 65 ft.

Kdr—Del Rio Formation. Clay. Gypsiferous, calcareous, pyrite common, poorly indurated, plastic, dark gray to olive brown; abundant *Ilymatogyra arietina* (formerly *Exogyra arietina*). Becomes less calcareous and more gypsiferous upward; blocky, medium gray, weathers light gray to yellowish gray. Some thin lenticular beds of highly calcareous siltstone. Slope forming or underhanging where slumped below overlying Buda. Forms highly expansive soil. Water tanks for livestock commonly excavated on outcrops. Upper and lower contacts gradational. Marine megafossils include abundant *Ilymatogyra arietina* (formerly *Exogyra arietina*) and other pelecypods. Thickness of 15 to 50 ft.

Lower Cretaceous

Kgt—Georgetown Formation. Limestone and some marl. Nodular to bedded, gray to tan; abundant fossils include *Waconell wacoensis* (formerly *Kingena wacoensis*)and *Gryphaea washitaensis*. Few interbeds of marl 2 to 3 inches thick. Upper contact is conformable and gradational where exposed, and commonly obscured by slumping of the overlying Del Rio Formation. Lower contact is disconformable. Diverse assemblage of fossils includes ammonoids, forams, echinoids, and pelecypods. Unit poorly exposed and mostly inferred on maps; may be absent locally. As much as 30 ft thick.

Kp—Person Formation. The Person Formation is the upper unit of the Edwards Group in the Balcones Fault Zone outcrop belt of the San Marcos Platform. It is approximately equivalent to the upper Devils River Formation (platform margin facies) and the Segovia Formation of the Edwards Plateau. Limestone and dolomitic limestone. Shallow subtidal to tidal-flat cycles. Honeycombed limestone interbedded with chalky to marly limestone and recrystallized limestone, bedded to massive, and leached and collapsed intervals. Locally, pockets of red clay (terra rosa) in karst collapse features. Thin, dark-red soil and residual chert regolith covered with sparse vegetation. Lower 20 to 30 ft comprises regional dense member, a dense argillaceous limestone; commonly thin, flaggy beds. Mappable bench (regional dense member) at contact with underlying Kainer Formation. Mud cracks preserved near lower contact. Upper contact is burrowed, disconformable. Fossils include pelecypods, gastropods, rudistids. Thickness of ~130 to 150 ft.

Kk—Kainer Formation. The Kainer Formation is the lower unit of the Edwards Group in the Balcones Fault Zone outcrop belt on the San Marcos Platform. It is approximately equivalent to the lower Devils River Formation (platform margin facies) and the Fort Terrett Formation of the Edwards Plateau. Limestone and dolomitic limestone. Shallow subtidal to tidal-flat cycles. Upper part contains common hard grainstone interbedded with marly mudstone and wackestone, honeycomb porosity common; middle to lower part contains limestone, dolomitic limestone, and some leached evaporitic rocks and breccias in middle part. Some researchers include strata composing Walnut Formation, **Kw** with lower part of Kainer Formation (**Kk**). Residual chert mantles uplands underlain by Kainer. Horizontal current laminations or low-angle cross-stratification present. Lower part is locally clayey, coarsely crystalline limestone. Fossiliferous; rudistids, caprinids, miliolids, oysters, and gastropods. Thickness of ~250 ft.

Ks—Segovia Formation. The Segovia Formation is the upper unit of the Edwards Group in the eastern Edwards Plateau and is approximately equivalent to the Person Formation of the Balcones Fault Zone area of the San Marcos Platform and upper Devils River Formation of the platform margin. Limestone, dolomitic limestone, and marl. Only minor outcrop areas in northwest part of map area. West of map area as much as 360 ft thick.

Kft—Fort Terrett Formation. The Fort Terrett Formation is the lower unit of the Edwards Group in the eastern Edwards Plateau and is approximately equivalent to the Kainer Formation and Walnut Formation of the Balcones Fault Zone area of the San Marcos Platform and the lower Devils River Formation of the platform margin. Lateral lithologic changes between Kainer and Fort Terrett deposits are gradational related to minor facies changes. Limestone, dolomitic limestone, and marl. Shallow subtidal to tidal-flat cycles. Upper part contains some leached evaporitic rocks and breccias. Lower 20 to 40 ft are subtidal limestone that are approximately equivalent to the Walnut Formation (Kw) of the Balcones Fault Zone area.

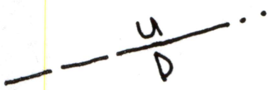
Kdvru—upper Devils River Formation. The upper Devils River Formation is the upper part of the Edwards Group along the San Marcos Platform margin. It is approximately equivalent to the Person Formation of the Balcones Fault Zone outcrop belt of the San Marcos Platform and the Segovia Formation of the Edwards Plateau. Limestone and dolomitic limestone. Shallow subtidal to tidal-flat cycles. Some rudistid mounds. Thickness of ~200 to ~250 ft.

Kdvrl—lower Devils River Formation. The lower Devils River Formation is the upper part of the Edwards Group at the San Marcos Platform margin. It is approximately equivalent to the Kainer Formation of the Balcones Fault Zone outcrop belt of the San Marcos Platform and the Fort Terrett Formation of the Edwards Plateau. Limestone and dolomitic limestone. Shallow subtidal to tidal-flat cycles. Upper part contains some leached evaporitic rocks and breccias. Lower 20 to 50 ft is nodular limestone. Thickness of ~350 to ~400 ft.

Kw—Walnut Formation. Limestone, marl, and dolomitic limestone; undifferentiated Bull Creek and Bee Cave Members; upper Bee Cave Member consists of fossiliferous marl, *Exogyra texana* common; Bee Cave Member thins and may pinch out toward the southwest; along steep slopes the marly Bee Cave Member commonly supports denser vegetation than does the overlying Kainer Formation; lower Bull Creek Member comprises limestone and dolomite interbedded with some marl; gastropods common; *Exogyra texana*; gradational contact with underlying Glen Rose Formation. Cream to light yellowish brown. Karst locally; some honeycomb porosity. Some researchers include **Kw** as lower part of Kainer Formation (**Kk**) southwest of Hays County. Formation of as much as 30 to 50 ft thick.

Kgru and Kgrl—Glen Rose Formation. *Corbula* interval divides the formation into upper and lower parts. **C** on map indicates locality of *Corbula* observed in outcrop. Limestone, dolomitic limestone, and marl. Shallow subtidal to tidal-flat cycles. Alternating resistant and recessive beds forming stairstep topography; limestone, wackestone, packstone, grainstone, hard to soft and marly, 3- to 10-ft-thick, shoaling-upward cycles common, light gray to yellowish gray; dolomite, fine grained, porous, yellowish brown; locally burrowed; local honeycomb porosity; marine megafossils include molluscan steinkerns, rudistids, oysters, and echinoids; local dinosaur tracks. Upper part, **Kgru**, relatively thinner bedded, more dolomitic, and less fossiliferous; some intervals of disturbed bedding and collapse breccia possibly caused by evaporite solution; thickness of about 400 ft. Lower part, **Kgrl**, commonly more massive, contains some rudistid reefs and mounds. *Corbula* interval at top with abundant steinkerns of *Corbula harveyi* (Hill) in one to three thin, resistant, 1- to 3-ft-thick beds composing an interval of as much as 15 ft thick; thickness of about 200 to 270 ft. Thickness of entire formation about 650 ft.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered. Question marks (?) indicate where uncertain.

Karst-related collapse or subsidence of bedrock.

Strike and dip of beds dipping between 2 and 6°.

Georgetown Region

Cobbs Cavern, Ding Dong, Florence, Georgetown, Hutto,

Jarrell, Leander, Leander NE, Round Rock, Salado,

Weir, and Youngsport quadrangles, Texas

(1:24,000 scale)

QUATERNARY

Qal—Alluvium. Gravel, sand, silt, and clay along streams and rivers; inundated regularly. Gravel is mostly limestone and chert. Along minor drainages, includes undivided low terrace deposits. Includes some local bedrock outcrops that are undivided.

Qt—Terrace deposits. Gravel, sand, silt, and clay along streams and rivers. Mostly above flood level along entrenched streams and rivers. Larger deposits along San Gabriel River, Berry Creek, and Brushy Creek are as thick as 36 ft and locally may be thicker.

Qu—Undivided alluvium. Sand, silt, clay, and some gravel. Includes terrace alluvium local drainageway alluvium and slope-wash alluvium.

Qt+Ktl—Undivided terrace deposits (Quaternary) and lower Taylor Group.

QUATERNARY TO TERTIARY

QTa—Older alluvium. Gravel, sand, clay; well-rounded pebble- to cobble-sized gravel, few boulders; mostly chert and limestone, some quartz and igneous and metamorphic rock detritus. Some deposits mostly sand and clay. Deposits typically cap topographically high areas. Precise age unknown; deposits probably of different ages; possibly equivalent to Quaternary Leona Formation and to late Tertiary or Quaternary Uvalde gravel.

QTa+Qu—Older alluvium and terrace, drainageway, and slope-wash alluvium, undivided.

CRETACEOUS

Upper Cretaceous

Ktl—Lower Taylor Group, undivided, Includes Pecan Gap and Ozan Formations. Also includes local Sprinkle Formation that is equivalent to part of the Ozan Formation. Marl, calcareous clay, chalk. Outcrops are rare.

Kau—Austin Group. Chalk, marl, and limestone. Thin- to thick-bedded, bentonitic seems, pyrite or marcasite nodules common and weather to limonite. Fossils include inoceramus; inoceramus prisms common. In Austin–Georgetown region the Austin Group includes six formations (oldest to youngest): the Atco, Vinson, Jonah, Dessau, Burditt, and Pflugerville Formations (Young, 1985). Only Atco through Dessau Formations occur north of Brushy Creek. Thickness is about 360 to 425 ft.

Kef—Eagle Ford Formation. Shale and silty limestone to calcareous siltstone. Unit consists of three lithologic intervals: a lower calcareous shale, a middle flaggy, silty limestone to calcareous siltstone, and an upper shale. Montmorillonitic clay. Thin (0.4 to 3 inches) bentonite beds may occur in the middle part of the unit (Garner and Young, 1976). About 65 ft thick in Williamson County and about 23 ft thick to the south in Travis County.

Kbu—Buda Formation. Limestone. Lower part is slightly glauconitic and fossiliferous; upper part is hard, resistant, burrowed, fossiliferous, and contains shell fragments. Thickness is mostly between 3 and 30 ft; may be absent locally.

Kdr—Del Rio Formation. Clay. Calcareous, fossiliferous, poorly indurated, plastic, dark gray to olive brown; contains *Ilymatogyra arietina* (formerly *Exogyra arietina*). Slope forming or underhanging where slumped below overlying Buda. Weathers light gray to yellowish gray. Forms highly expansive soil. Water tanks for livestock commonly excavated on outcrops. Thickness is ~65 ft.

Lower Cretaceous

Kgt—Georgetown Formation. Limestone and marl. Nodular, very fossiliferous; diagnostic marine megafossils include *Waconell wacoensis* (formerly *Kingena wacoensis*) and *Gryphaea washitaensis*. Rare small vugs. Uppermost Edwards aquifer strata. Thickness increases northward from ~65 ft to 110 ft.

Ked—Edwards Limestone. Limestone, dolomitic limestone, and marl. Massive to thin beds, chert, and fossiliferous; fossils include rudistids. Shallow subtidal to tidal-flat cycles. Honeycomb textures, voids in collapse breccias, and cavern systems. Accounts for most of the Edwards aquifer strata. Thickness is between 100 and 300 ft; thins northward.

Kc—Comanche Peak Formation. Limestone and marl. Nodular, fossiliferous. Lower part of Edwards aquifer strata. Thickness thickens northward from about 40 to 70 ft.

Kwkv—Keys Valley Member of Walnut Formation. Marl, argillaceous limestone, and some limestone. Thickness up to ~50 ft. Walnut Formation consists of six members that include, from oldest to youngest, the Bull Creek, Bee Cave, Cedar Park, Whitestone, Keys Valley, and the upper marl members (Moore, 1964). The upper marl member occurs north of southern Bell County and is not mapped in the study area.

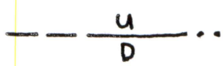
Kwcpbc—Cedar Park, Bee Cave, and Bull Creek Members, undivided, of Walnut Formation. Limestone, argillaceous limestone, and marl. Individual members are about 30 to 50 ft thick. Walnut Formation consists of six members that include, from oldest to youngest, the Bull Creek , Bee Cave, Cedar Park, Whitestone, Keys Valley, and the upper marl members (Moore, 1964). The upper marl member occurs north of southern Bell County and is not mapped in the study area.

Kwkv+Kwwh+Kwcpbc+Ked—Keys Valley, Whitestone, Cedar Park, Bee Cave, and Bull Creek Members, undivided, of the Walnut Formation and Edwards Formation, undivided. Limestone, argillaceous limestone, and marl. Area of Edwards interfingering with Walnut Member, and Whitestone Member interfingering with Keys Valley Member.

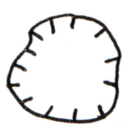
Kwwh+Kwcpbc+Ked—Whitestone, Cedar Park, Bee Cave, and Bull Creek Members, undivided, of the Walnut Formation and Edwards Formation, undivided. Limestone, argillaceous limestone, and marl. Area of Edwards interfingering with Walnut Formation.

Kgru—upper Glen Rose Formation. Limestone, dolomitic limestone, and marl. Shallow subtidal to tidal-flat cycles. Alternating resistant and recessive beds forming stairstep topography. Marine megafossils include molluscan steinkerns, rudistids, oysters, and echinoids; local dinosaur tracks. Dolomitic limestones contain water. *Corbula* interval, usually one to three thin beds containing the bivalve, informally divides the lower and upper Glen Rose Formation. Only upper Glen Rose strata crops out in the map area.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered. Question marks (?) indicate where uncertain.



Karst-related collapse or subsidence of bedrock.

Strike and dip of beds dipping between 2 and 6°.

Approximate axis of gentle monocline.

Del Rio Region

Del Rio NE, Del Rio NW, Del Rio SE, Del Rio SW,

Rough Canyon, and Rough Canyon SE Quadrangles, Texas

(1:24,000)

QUATERNARY

Qal—Alluvium. Unconsolidated gravel, sand, silt, and clay along streams and rivers; inundated regularly. Gravel is mostly limestone and chert. Along minor drainages, includes undivided low terrace deposits. Includes some small bedrock outcrops that are undivided.

Qarg—Alluvium of Rio Grande floodplain. Sand, silt, clay, and gravel; commonly cultivated; urbanized in and near Del Rio.

Qt—Alluvium of terrace deposits. Unconsolidated gravel, sand, silt, and clay along streams and rivers. Mostly above flood level along entrenched streams and rivers.

Qtrg—Alluvium of terraces along the Rio Grande Valley border. Sand, gravel, silt, and clay. Includes undivided terraces of different elevations and probably different ages.

Qavb—Undivided alluvium of drainageways, young fans, and young arroyo terraces located along the Rio Grande Valley border. Sand, gravel, silt, and clay.

Qtrg+Qavb—Undivided Qtrg and Qavb.

QUATERNARY TO TERTIARY

QTa—Older alluvium. Gravel, sand, and clay. Pebble- to cobble-sized gravel is well rounded. Some deposits mostly sand and clay. Precise age unknown. Deposits probably of different ages. Some deposits have well-developed calcic soil horizons (caliche). Older alluvium is probably equivalent to the Quaternary Leona Formation and late Tertiary or Quaternary Uvalde gravel.

QTa+Ksa—Undivided older alluvium (late Tertiary to Quaternary) and Lower Cretaceous Salmon Peak Formation.

UPPER CRETACEOUS

Kef—Eagle Ford Group. Shale, siltstone, and limestone. Upper part is flaggy limestone and shale. Lower part is laminated and flaggy siltstone and very fine-grained sandstone; some silty limestone. Thickness is ~150 to 200 ft..

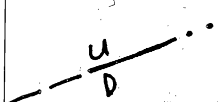
Kbu—Buda Formation. Limestone. Massive, poorly bedded to nodular. Upper part near contact is argillaceous and thin bedded. Glauconitic, pyrite, fossiliferous, abundant pelecypods, burrows. Thickness is ~50 to 70 ft.

Kdr—Del Rio Formation. Clay, some calcareous siltstone. Calcareous, gypsiferous, pyrite common, weathers light-gray to yellowish-gray. Marine megafossils include abundant *Ilymatogyra arietina* (formerly *Exogyra arietina*) and other pelecypods. Thickness is ~20 to ~80 ft.

LOWER CRETACEOUS

Ksa—Salmon Peak Formation. Limestone. Fossiliferous, abundant *caprinid*, chert abundant, crossbeds, grainstone and packstone fabrics common. Lower part is *Globigerina* mudstone. Karst features. Thickness is ~310 ft.

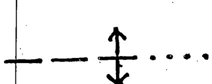
Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered. Question marks (?) indicate where uncertain.

Karst-related collapse or subsidence of bedrock.

Strike and dip of beds dipping between 2 and 6°.



Axis of broad anticline; dotted where covered.

Lake Theo Quadrangle, Caprock Canyons State Park

(1:24,000)

QUATERNARY

Holocene

Qal—Alluvium. Sand, silt, gravel, and mud along drainageways. Includes some undivided low terrace deposits and some local bedrock outcrops.

Qt—Terrace deposits. Sand, silt, gravel, and mud along drainageways. Mostly above flood level along entrenched drainages.

Pleistocene

Qbd—Blackwater Draw Formation. Sand, silt, and sandy mud. Thickness up to ~70 ft.

Qli—Lingos Formation. Sand, silt, mud, and gravel. Thickness locally up to ~180 ft.

TERTIARY

Pliocene and Miocene

To—Ogallala Formation. Sand, silt, gravel, mud, and caliche. Thickness in map area as much as ~120 ft. Upper caliche is massive to laminated and has a stage V morphology.

TRIASSIC

TRd—Dockum Group, undivided. Sandstone, mudstone, and conglomerate. Dockum includes four undivided units (following Lehman, 1994): the older Santa Rosa, Tecovos, Trujillo, and younger Cooper Canyon Formations. Thickness between ~200 and ~300 ft.

PERMIAN

Pq—Quartermaster Formation. Sandstone, siltstone, and mudstone. Gypsum veins common in lower part. Reddish color. Ash beds (Fracasso and Kolker, 1985a, b). Minor folds due to subsurface evaporite dissolution and associated subsidence of lower Quartermaster strata. Thickness is ~300 ft.

Pwh—Whitehorse and Cloud Chief Formations, undivided. Sandstone, siltstone, mudstone, and gypsum beds. Gypsum veins common. Minor folds due to subsurface evaporite dissolution and associated subsidence of strata. Some small-scale folds of gypsum beds due to conversion of anhydrite to gypsum. Only upper part of unit exposed.

Map Symbols

	Strike and dip of beds.
	Horizontal to nearly horizontal beds; beds dipping <2°.
	Minor anticline.
	Minor syncline.
	Ash in Permian Quartermaster Formation.

Fortress Cliff Quadrangle, Palo Duro Canyon State Park

(1:24,000)

QUATERNARY

Holocene

Qal—Alluvium. Sand, silt, gravel, and mud along drainageways. Includes some undivided low terrace deposits and some local bedrock outcrops.

Qp—Playa deposits. Mud, silt, and some fine sand. Local deposits on High Plains.

Ql—Landslide, slump, and slope-wash debris and blocks. Mostly consists of Triassic Dockum strata and lesser amounts of Permian Quartermaster and Tertiary Ogallala rocks that have slid as large rotated blocks and as smaller debris deposits.

Holocene and Pleistocene

Qa—High alluvium. Sand, silt, less common pebbles. Local deposits on flat ridges within canyons. Thickness as much as 5 ft.

Pleistocene

Qbd—Blackwater Draw Formation. Sand, silt, and sandy mud. Thickness up to ~70 ft.

TERTIARY TO QUATERNARY

Pliocene and Pleistocene

QTc—Cita Canyon lake beds, undivided. Mud, silt, and sand. Consists of lower Blancan (Pliocene to early Pleistocene) lacustrine deposits overlain by Pleistocene lacustrine deposits that are interstratified with eolian sand, silt, and mud (Johnston and Savage, 1955; Hood, 1977a). The upper sequence contains Pearlette ash (Johnston and Savage, 1955; Hood, 1977a; Izett and Wilcox, 1982)

TERTIARY

Pliocene and Miocene

To—Ogallala Formation. Sand, silt, gravel, mud, and caliche. Thickness in map area as much as ~70 ft. Upper caliche is massive to laminated and has a stage V morphology.

TRIASSIC

TRdu—Cooper Canyon and Trujillo Formations, undivided, of the Dockum Group. Sandstone, conglomerate, and lesser mudstone. Sandstone is gray and contains common cross-beds. Mudstones are red, maroon, and gray. Thickness is up to ~200 ft.

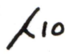
TRdl—Tecovos and Santa Rosa Formations, undivided, undivided of the Dockum Group. Mudstone and lesser siltstone and sandstone. Lavender, gray, maroon, orange, and white. Concretions, geodes, and silicified wood common. Thickness is less than 200 ft.

PERMIAN

Pq—Quartermaster Formation. Sandstone, siltstone, mudstone. Gypsum veins common in lower part. Reddish color. Ash beds (Fracasso and Kolker, 1985a, b). Minor folds due to subsurface evaporite dissolution and associated subsidence of lower Quartermaster strata. Thickness is ~220 ft.

Pwh—Whitehorse and Cloud Chief Formations, undivided. Sandstone, siltstone, mudstone, and gypsum beds. Gypsum veins common. Minor folds due to subsurface evaporite dissolution and associated subsidence of strata. Some small-scale folds of gypsum beds due to conversion of anhydrite to gypsum. Only upper part of unit exposed.

MAP SYMBOLS



Strike and dip of beds.

 Horizontal to nearly horizontal beds; beds dipping <2°.

 Minor anticline.

 Minor syncline.

 Ash in Permian Quartermaster Formation.

 Ash in upper part of Cita Canyon Lake deposits.