Summary Report for the 1998–1999 STATEMAP Project: Geological Mapping to Support Improved Data-Base Development and Understanding of Critical Aquifers of Texas

by

Edward W. Collins, Jeffrey G. Paine, and Jay A. Raney

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Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

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INTRODUCTION

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. For the 1998–1999 work year this project was divided into three subprojects. Work for subproject 1 dealt with the third and final year of mapping within several karst aquifer areas undergoing rapid urban growth along the Edwards aquifer and recharge zone. Three map areas make up 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 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.

Subproject 2 involved digital compilation of existing geologic maps, scale 1:24,000, of the Hueco Bolson–El Paso region that were constructed for previous STATEMAP projects (fig. 2; table 1). The contract product is a color geologic map (digital data set), scale 1:100,000, of the west Hueco Bolson–El Paso region, Texas. This digital map is important because it provides a good geologic base and a crucial data set for part of the Texas–Mexico border area that is undergoing rapid urban growth, diminishing water resources, and environmental stress due to development. The map area also includes large areas of public access lands (Franklin Mountains and Hueco Tanks State Parks) whose management will benefit from having digital geologic data available for planning, development, and improved public awareness of geologic processes and geologic history.

Work for subproject 3, mapping of areas of special environmental concern, addresses the urgent need for geologic maps in specific areas that are environmentally stressed. Two quadrangles that were mapped, Magers Crossing and Sabinal Canyon Quadrangles, encompass public lands of

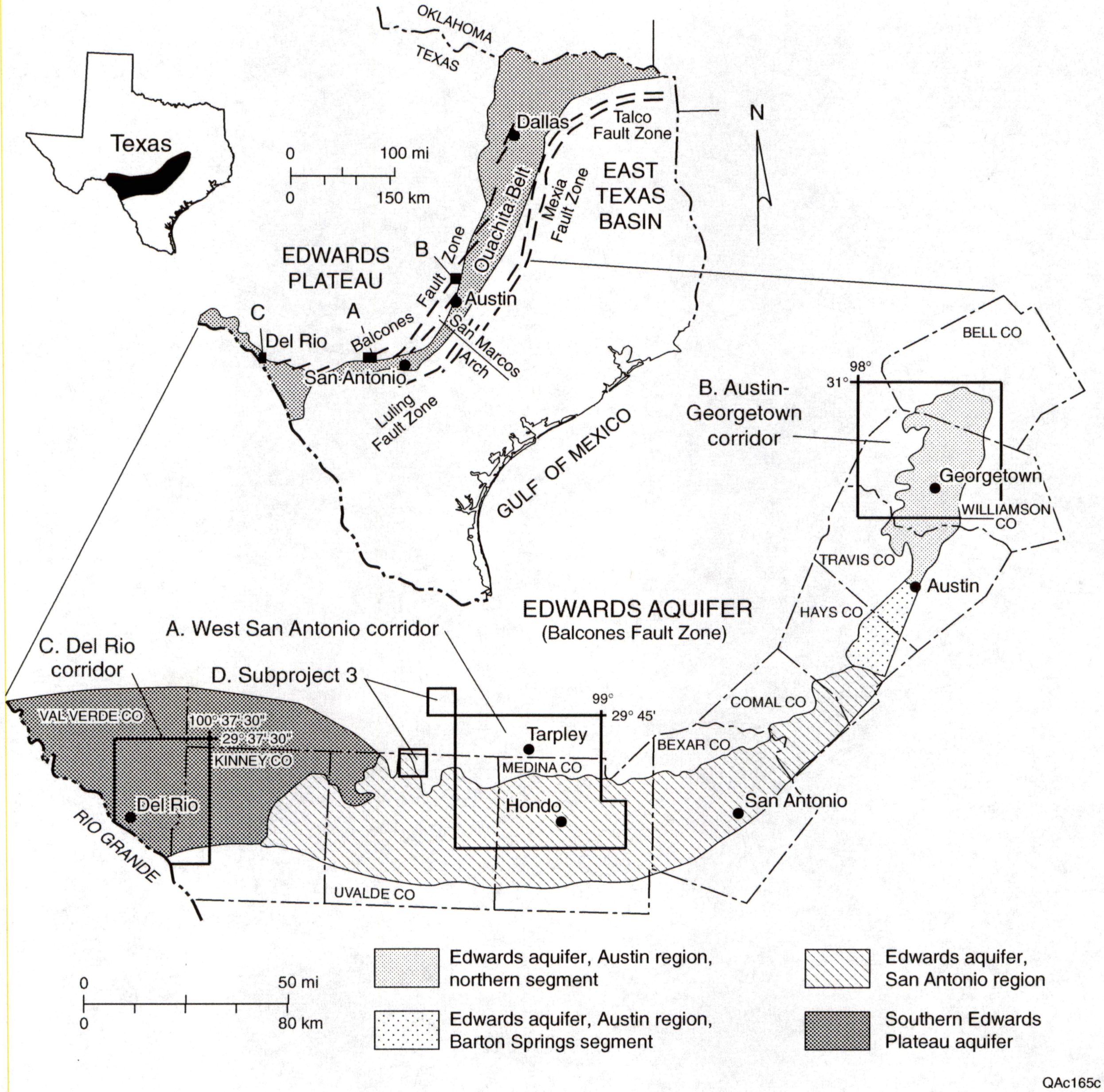

Figure 1. Location of karst aquifer–urban-growth corridor study area, subproject 1, areas A, B, and C. This area includes parts of the Balcones Fault Zone and the Edwards aquifer and Edwards aquifer recharge zone. Also shown is location of two quadrangles (D) for subproject 3, mapping of areas of special environmental concerns.

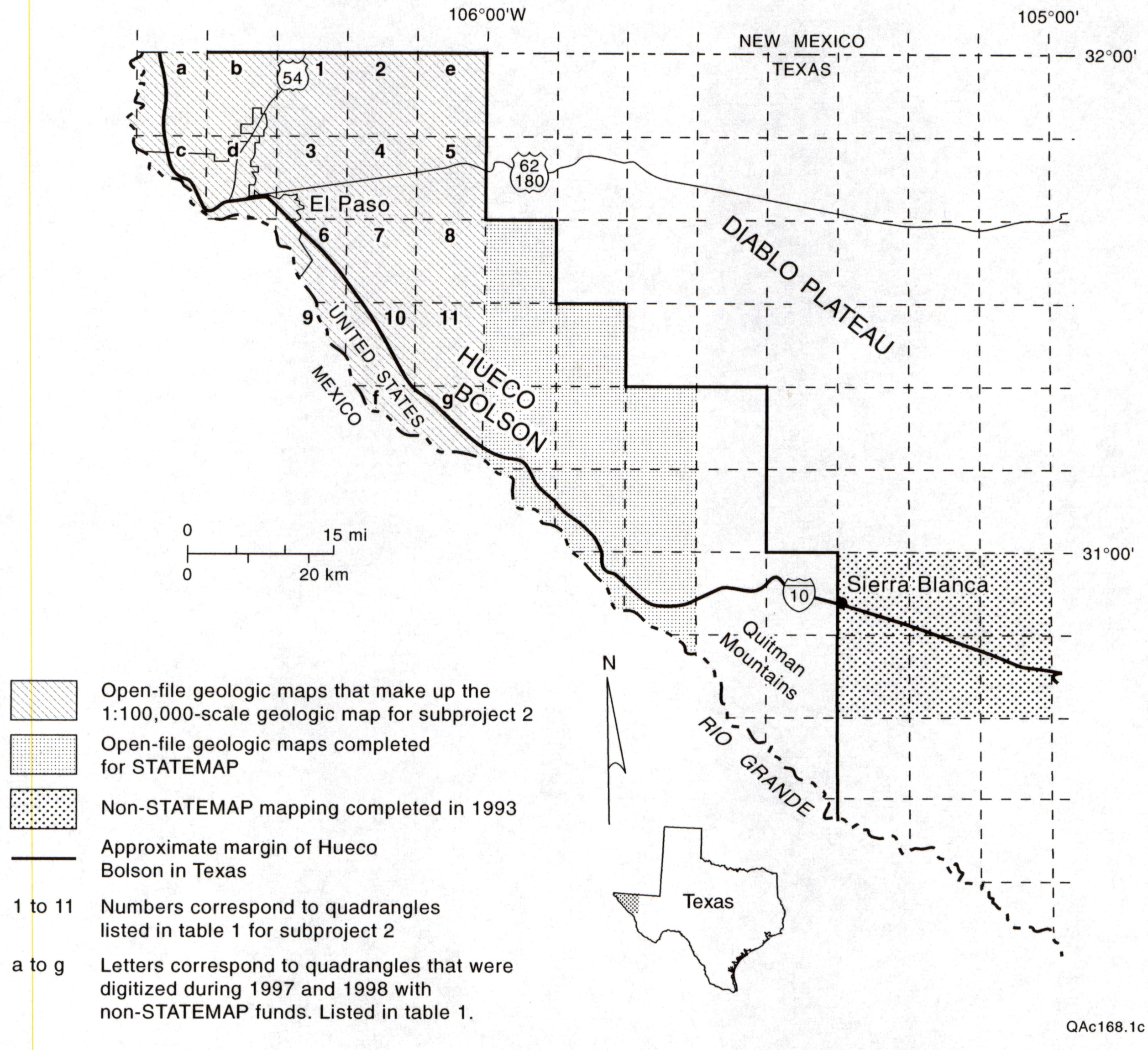

Figure 2. Location of open-file geologic maps (1:24,000 scale) that were digitized to produce the Geologic Map of the West Hueco Bolson, El Paso Region, Texas, 1:100,000 scale. Names of quadrangles on table 1.

Table 1. List of geologic quadrangle maps that were digitized and compiled for subproject 2, Geologic Map of the West Hueco Bolson, El Paso Region, Texas.

Quadrangles digitized for subproject 2:

1. Fort Bliss NE
2. Nations East Well
3. Fort Bliss SE
4. Nations South Well
5. Helms West Well
6. Ysleta
7. Clint NW
8. Clint NE
9. San Elizario
10. Clint
11. Clint SE

Quadrangles digitized through non-STATEMAP funds:

a. Canutillo
b. North Franklin Mountain
c. Smeltertown
d. El Paso
e. Hueco Tanks
f. Isla
g. Tornillo

State parks that are in the recharge and recharge-contributing areas of the Trinity and Edwards aquifers (fig. 1). Within the park areas are some of the better public exposures of units that make up the geologic framework of the aquifers, which are the sole water source for much of the region. Geologic maps will greatly aid public education regarding protection, management, and utilization of the aquifers. These maps will be utilized for improved management of the public lands and for raising awareness of natural hazards of the region, such as flooding. Two other special-topic quadrangles that were mapped for subproject 3, Luling and Prairie Valley School Quadrangles, include areas where previous oil-field activities or possible abandoned oil wells are potentially polluting local aquifers, rivers, or agricultural lands (figs. 3 and 4). Improved geological maps of these areas serve as part of a necessary geological data base for assessing contaminant sources and for implementing effective remediation measures.

For the 1998–1999 contract year, 15 maps, scale 1:24,000, were completed by new mapping and 1 color map (digital data base), scale 1:100,000, was completed by digital compilation of existing maps. Methods used to map the subproject 1 and 3 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 show where faults are covered. Most strata in the study areas, almost flatlying, commonly have very low regional dips of less than 1°. Some exceptions where strata dip 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.

Our methods used in the digital-map compilation of the El Paso region, subproject 2, also followed standard procedures. Geologic maps of the relevant 7.5-minute quadrangles, which are on open file at the Bureau of Economic Geology, were digitized at a scale of 1:24,000 in ARC/INFO. The map area is composed of 18 quadrangles. Whereas 11 quadrangles were digitized

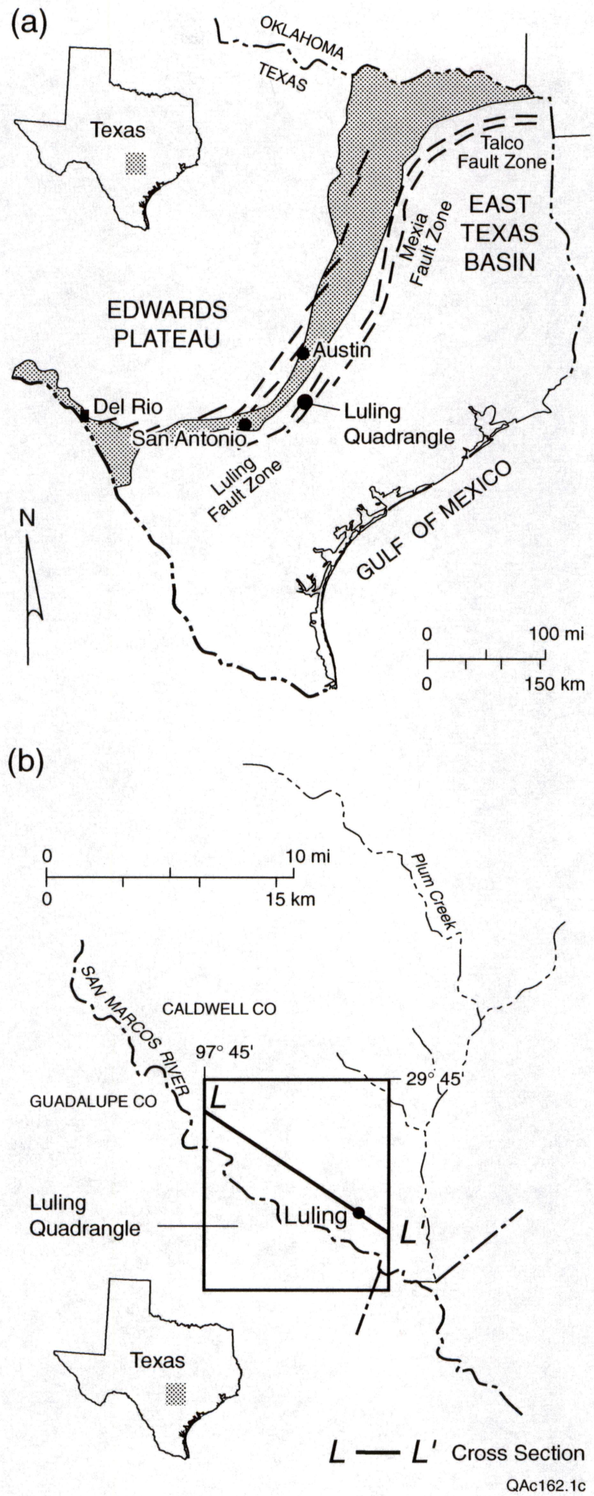

Figure 3. Location of Luling Quadrangle for mapping of an area of special environmental concern, subproject 3.

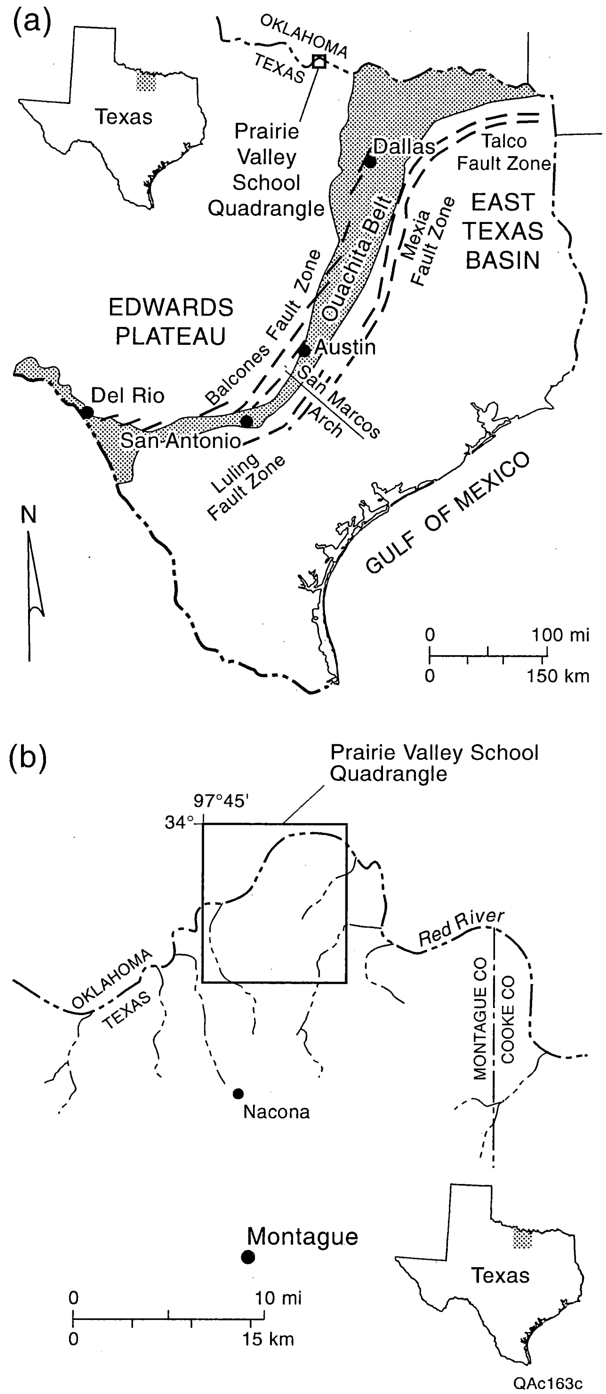

Figure 4. Location of Prairie Valley School Quadrangle for mapping of an area of special environmental concern, subproject 3.

for this STATEMAP project, the other quadrangles had been previously digitized with non-STATEMAP funds (fig. 2; table 1). Digital data of each quadrangle were merged to form a composite data set of the west Hueco Bolson–El Paso area. The plotted color map is at a scale of 1:100,000.

It is our intent that quadrangle maps for the subproject 1 areas will ultimately be combined into seamless data sets. Three composite hard-copy maps, scale 1:100,000, of the three subproject 1 areas 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 when final publication plans are made for the currently open-file 1:100,000-scale maps. Unit descriptions, stratigraphic charts, and correlation diagrams are based on observations made during this study and by many previous geologic investigations by earlier workers.

Several regional geologic maps, scale 1:250,000, illustrate the regional geology surrounding the subproject 1 and 3 map areas (Brown and others, 1974; Proctor and others, 1974a, b; Waechter and others, 1977; McGowen and others, 1991). Previous studies of central and south-central Texas stratigraphy include the Young (1967) discussion of the Lower Cretaceous and his report (Young and Woodruff, 1985) of the Upper Cretaceous Austin Group, the Rodda and others (1966) study of Lower Cretaceous rocks, the Stricklin and others (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. Other more local previous studies are the Holt (1959) report on geology of Medina County, the Welder and Reeves (1964) study of Uvalde County, the Adkins and Arick (1930) investigation of the geology of Bell County, and the Freeman (1968) discussion of the geology west of Del Rio. Also the McFarlan and Menes (1991) summary of the Lower Cretaceous of the Gulf of Mexico Basin and the Sohl and others (1991) discussion of the Upper Cretaceous of the Gulf of Mexico Basin were useful, as was the Sellards and others (1932) volume on the stratigraphy of Texas.

Literature related to study of the Luling Quadrangle of subproject 3, includes the Sellards (1924) and Brucks (1925, 1927) discussion of the history, structure, and stratigraphy of the

Luling oil field. The Rasmussen (1947), Follett (1966), and Shafer (1966) discussions of the ground-water resources and general geology of the region surrounding the Luling Quadrangle were also informative. Relevant previous studies for mapping of the Prairie Valley School Quadrangle of subproject 3 include the Frye and Leonard (1963) report of the Quaternary geology along the Red River and the Hentz (1988) discussion of the Permian bedrock stratigraphy. Previous studies of the structure and stratigraphy of the subproject 2 area, west Hueco Bolson–El Paso region, are listed on the Geologic Map of the West Hueco Bolson, El Paso Region, Texas, which is an attached contract deliverable. A cross section of this area is included as a separate plate.

SUBPROJECT 1: GEOLOGIC MAPPING (1:24,000) OF KARST AQUIFER TERRAINS IN RAPIDLY DEVELOPING AREAS OF CENTRAL TEXAS

Eleven maps were completed this past year for subproject 1 study areas. 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. 5 through 7). Upper Tertiary and Quaternary gravel and sand deposits locally overlie the older strata (fig. 5). Detailed stratigraphy of the map areas is described in appendix A—Explanation of Geologic Units.

In the West San Antonio corridor, the Sabinal, Comanche Waterhole, Flatrock Crossing, and Seco Pass Quadrangles were mapped (fig. 8). Geology at the north part of the area mapped 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 upper 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, Fort Terrett, Segovia, and Devils River Formations,

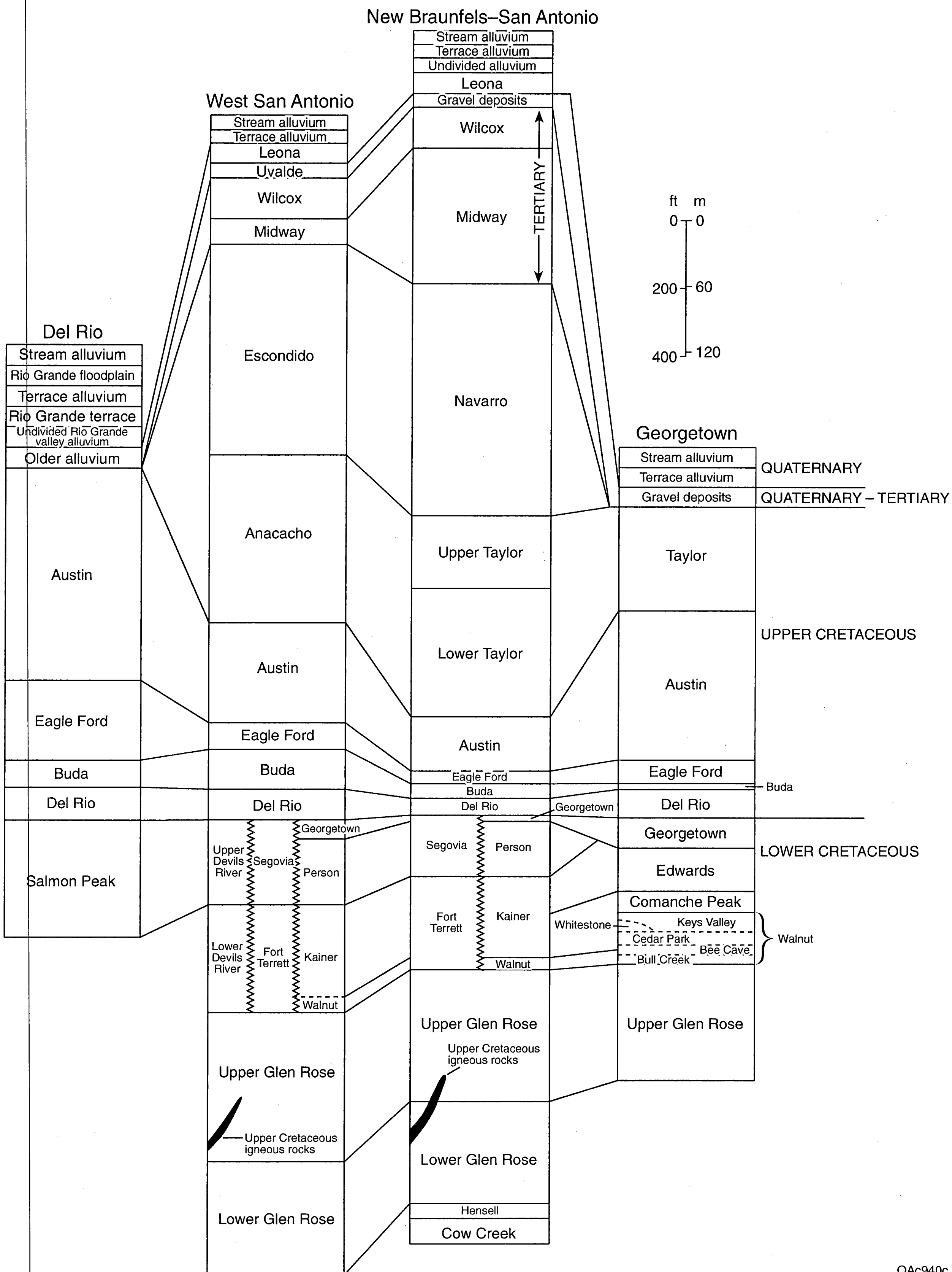

Figure 5. Stratigraphic charts illustrating units for subproject 1 map areas and for previous New Braunfels—San Antonio map area.

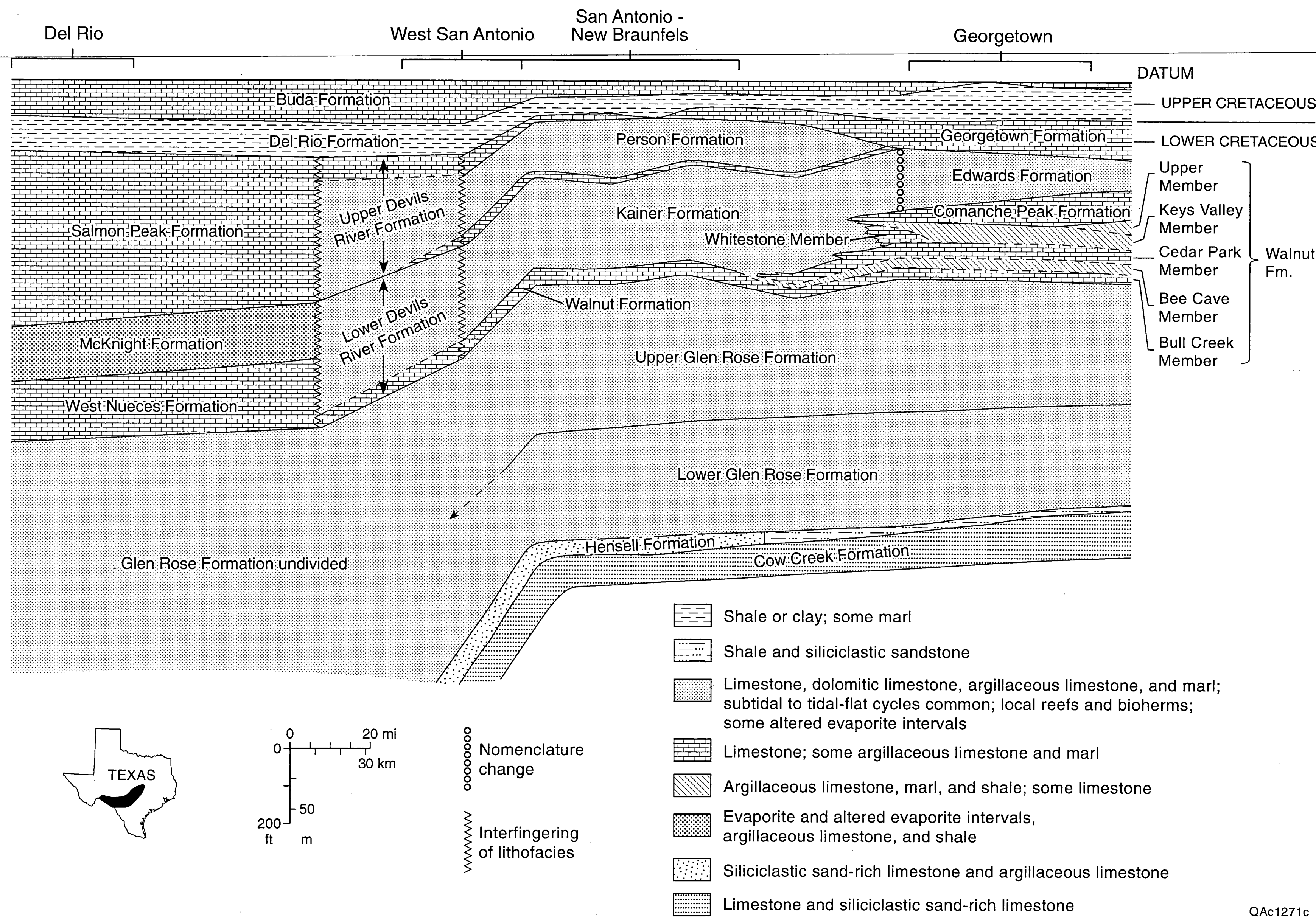

Figure 6. Diagrammatic correlation of Lower Cretaceous units across south-central Texas and subproject 1 map areas.

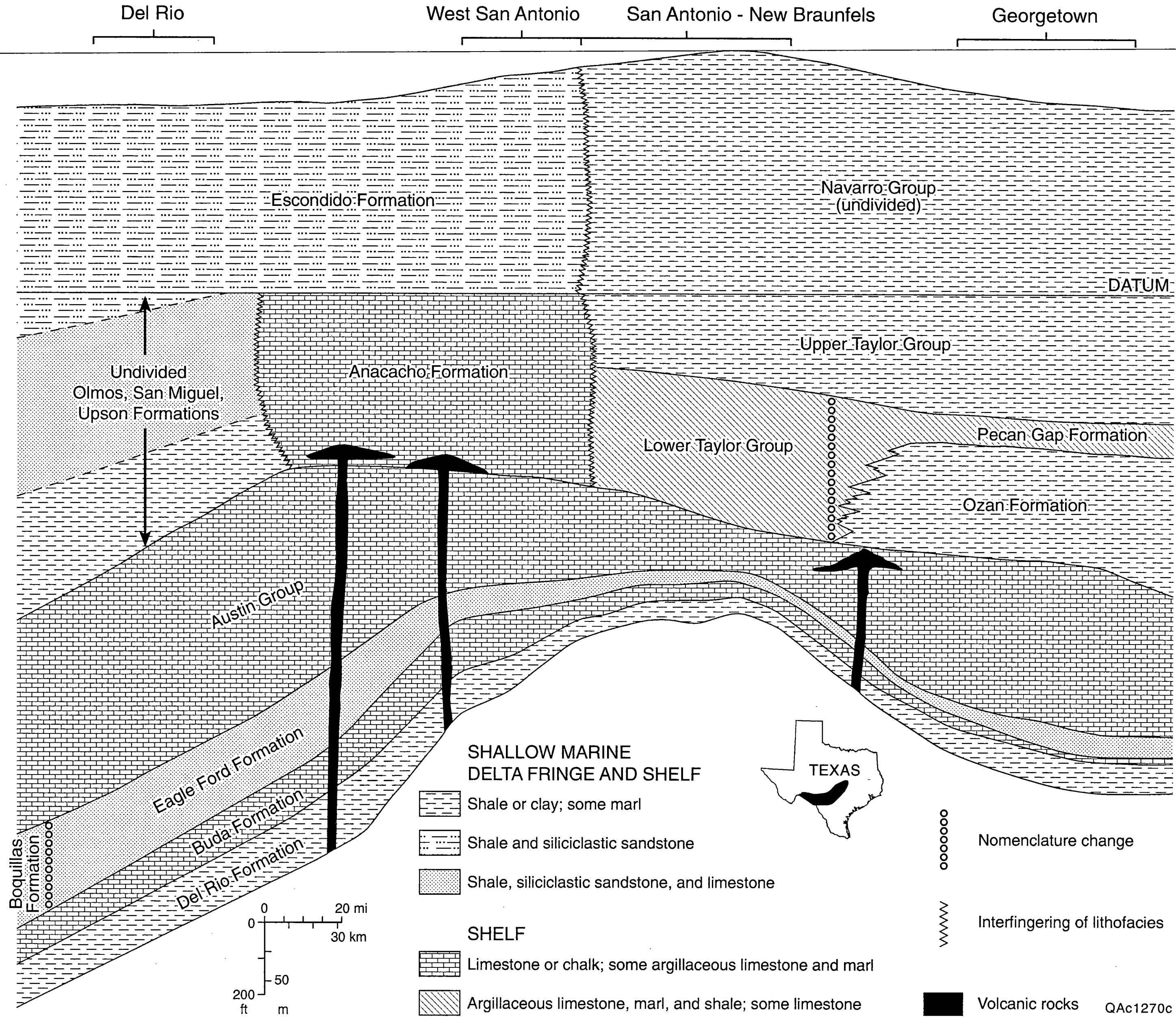

Figure 7. Diagrammatic correlation of Upper Cretaceous units across south-central Texas and subproject 1 map areas.

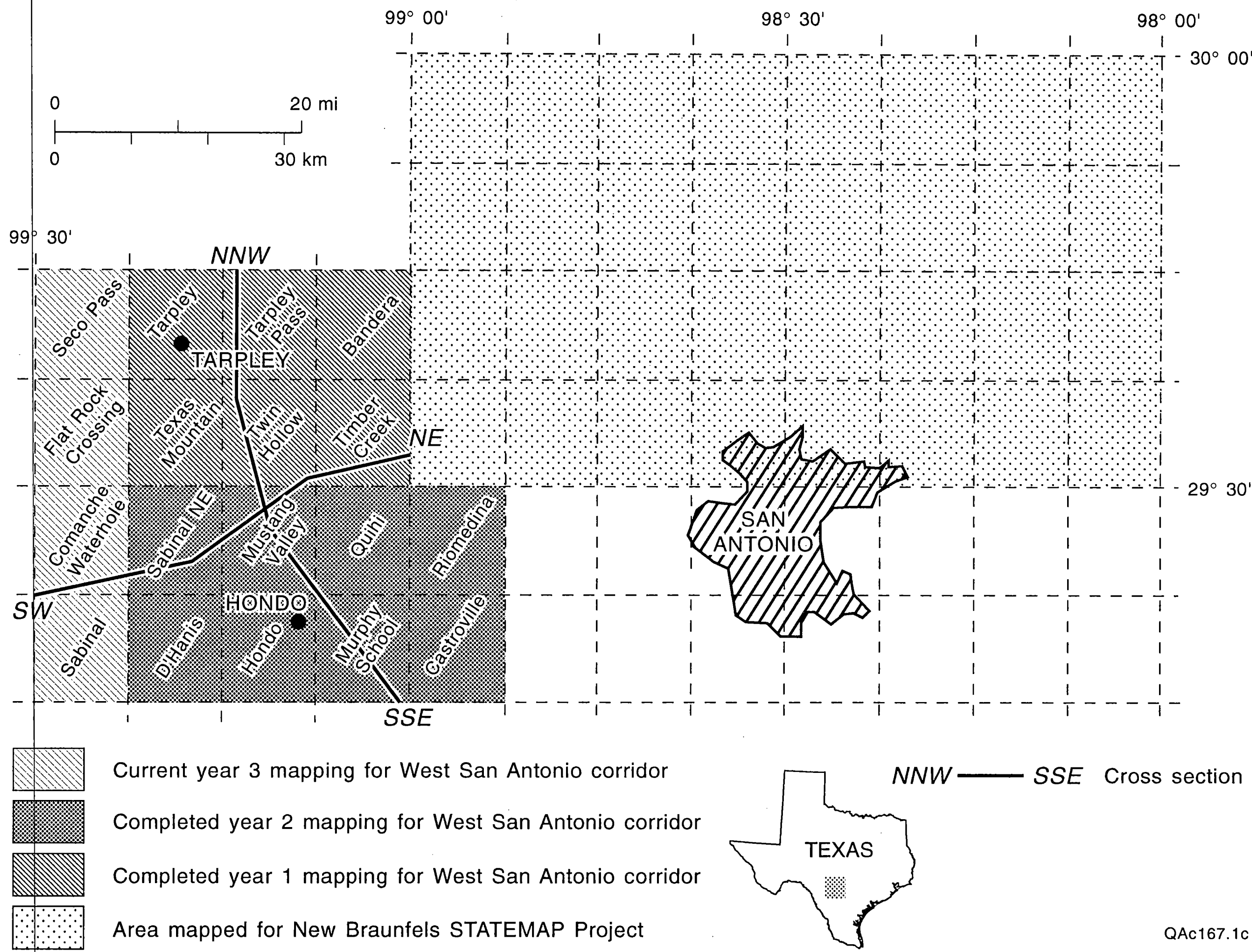

Figure 8. Diagram of 7.5-minute quadrangles that compose the West San Antonio map area. Cross sections illustrated in figures 9 and 10.

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. 9). The area is important to recharge of the Edwards aquifer because within fault blocks of the Balcones Fault Zone the aquifer strata dip very gently west-southwestward into the subsurface, providing good continuity of the aquifer strata from the recharge area to the subsurface (fig. 10).

Mapping in the Austin–Georgetown corridor includes the Nameless, Liberty Hill, Mahomet, and Briggs Quadrangles (fig. 11). Strata mapped on these quadrangles consist mostly of limestone, marl and dolomitic limestone of the Lower Cretaceous Glen Rose, Walnut, Comanche Peak, and Edwards Formations (figs. 5 and 6). Younger Lower and Upper Cretaceous rocks of the Georgetown, Del Rio, Buda, Eagleford, Austin, and Taylor units crop out eastward within the quadrangles mapped previously. Quaternary terrace deposits are associated with Brushy Creek, the San Gabriel and Lampasas Rivers, and local tributaries. Faults strike mostly 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. 12).

In the Del Rio corridor, the Mud Creek South, Mud Creek North, and Flat Rock Creek SW Quadrangles were mapped (fig. 13). 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 upper Tertiary alluvium (figs. 5 through 7). Several northeast-striking faults cut across the east-central part of the study corridor, although faults were not identified within the quadrangles mapped during this year. Part of a broad, east-northeast-trending anticline crosses the mapped area and is illustrated in the north-trending cross section that crosses through the central part of the corridor study area (fig. 14).

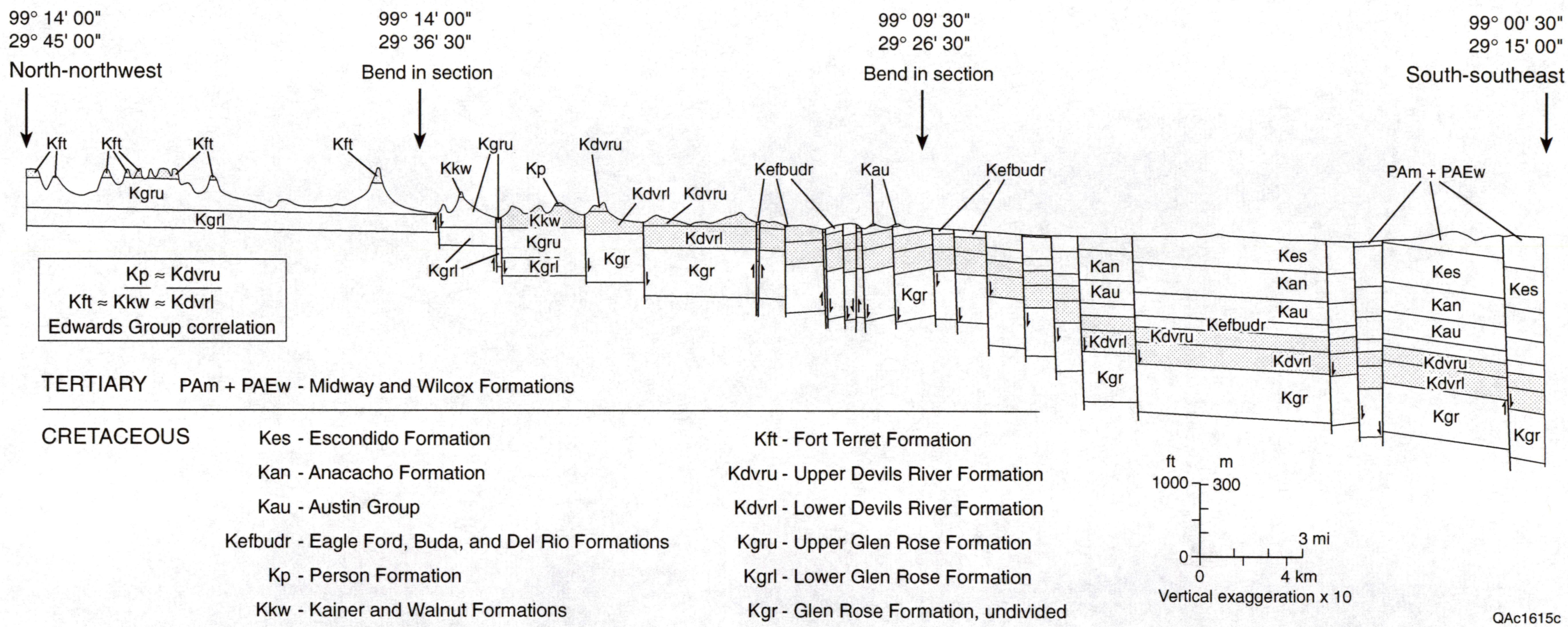

Figure 9. North-trending cross section, NNW–SSE, of West San Antonio map area. Shaded units indicate Edwards aquifer strata. Location of cross section shown in figure 8.

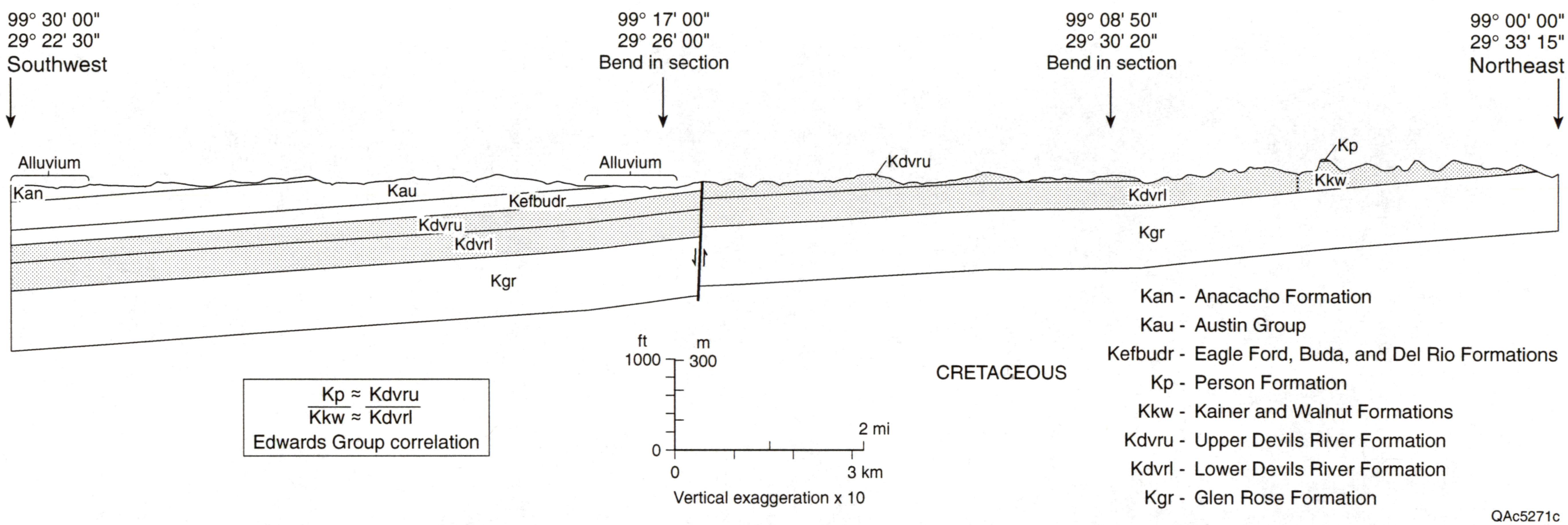

Figure 10. Southwest-trending cross section, SW–NE, of West San Antonio map area. Shaded units indicate Edwards aquifer strata. Location of cross section shown in figure 8.

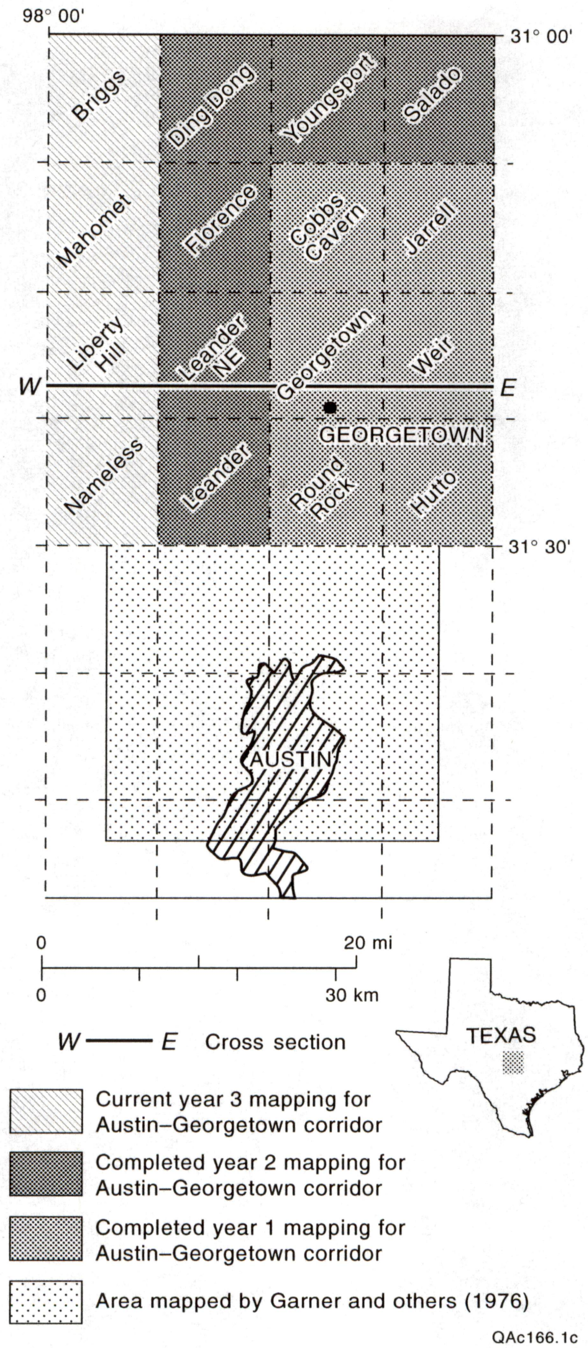

Figure 11. Diagram of 7.5-minute quadrangles that compose the Austin–Georgetown map area. Cross section shown in figure 12.

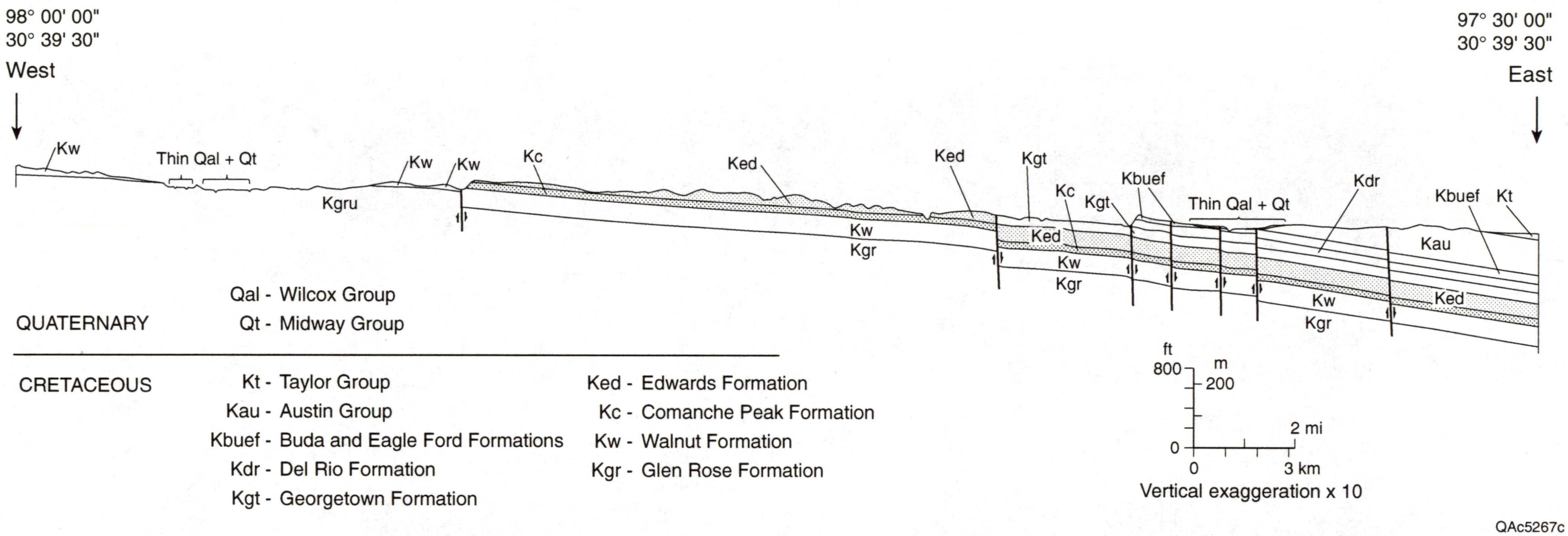

Figure 12. Cross section of Georgetown map area. Shaded units indicate Edwards aquifer strata. Location of cross section shown in figure 11.

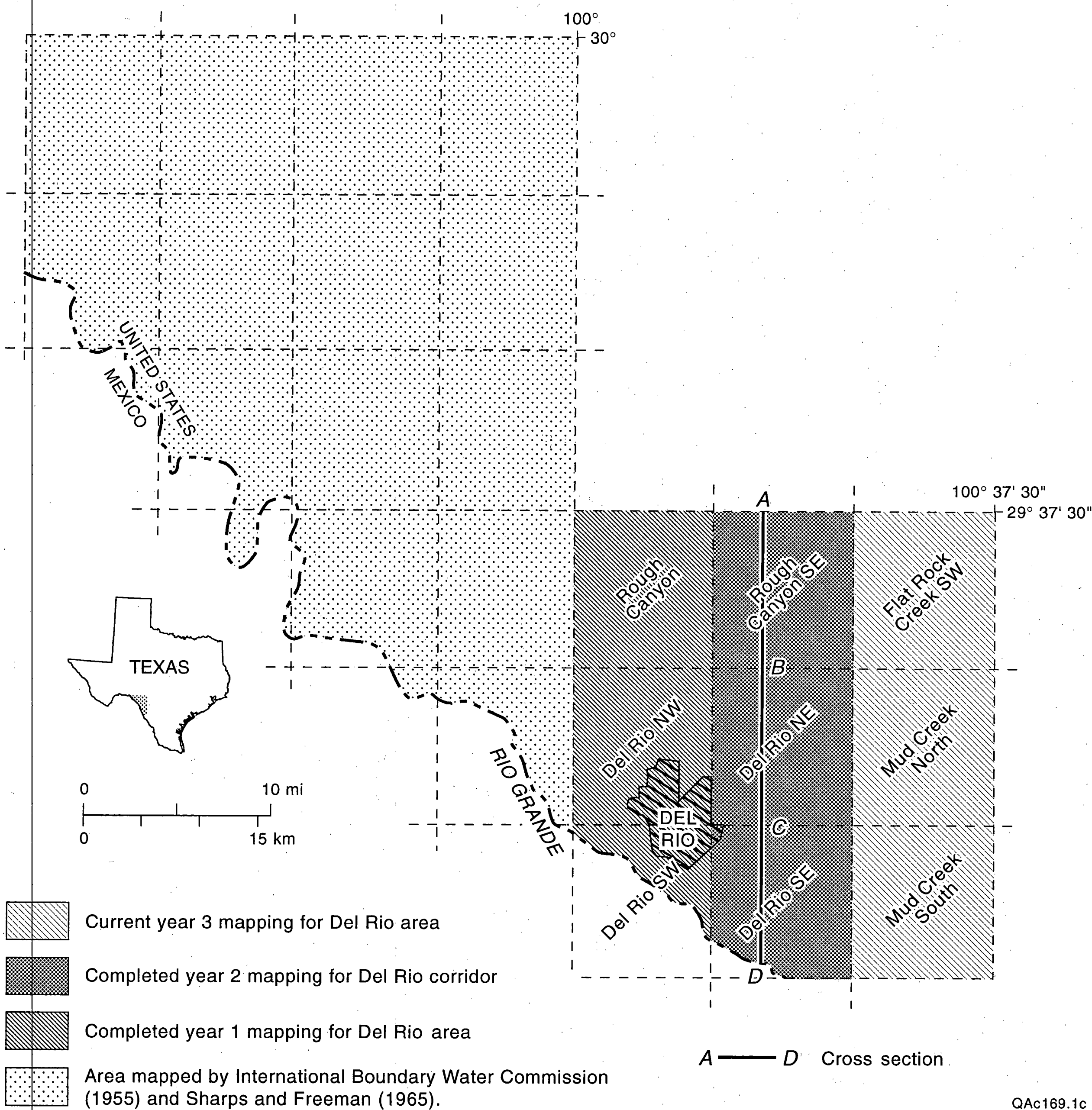

Figure 13. Diagram of 7.5-minute quadrangles that compose the Del Rio map area. This report discusses year-2 mapping. Cross section shown in figure 14.

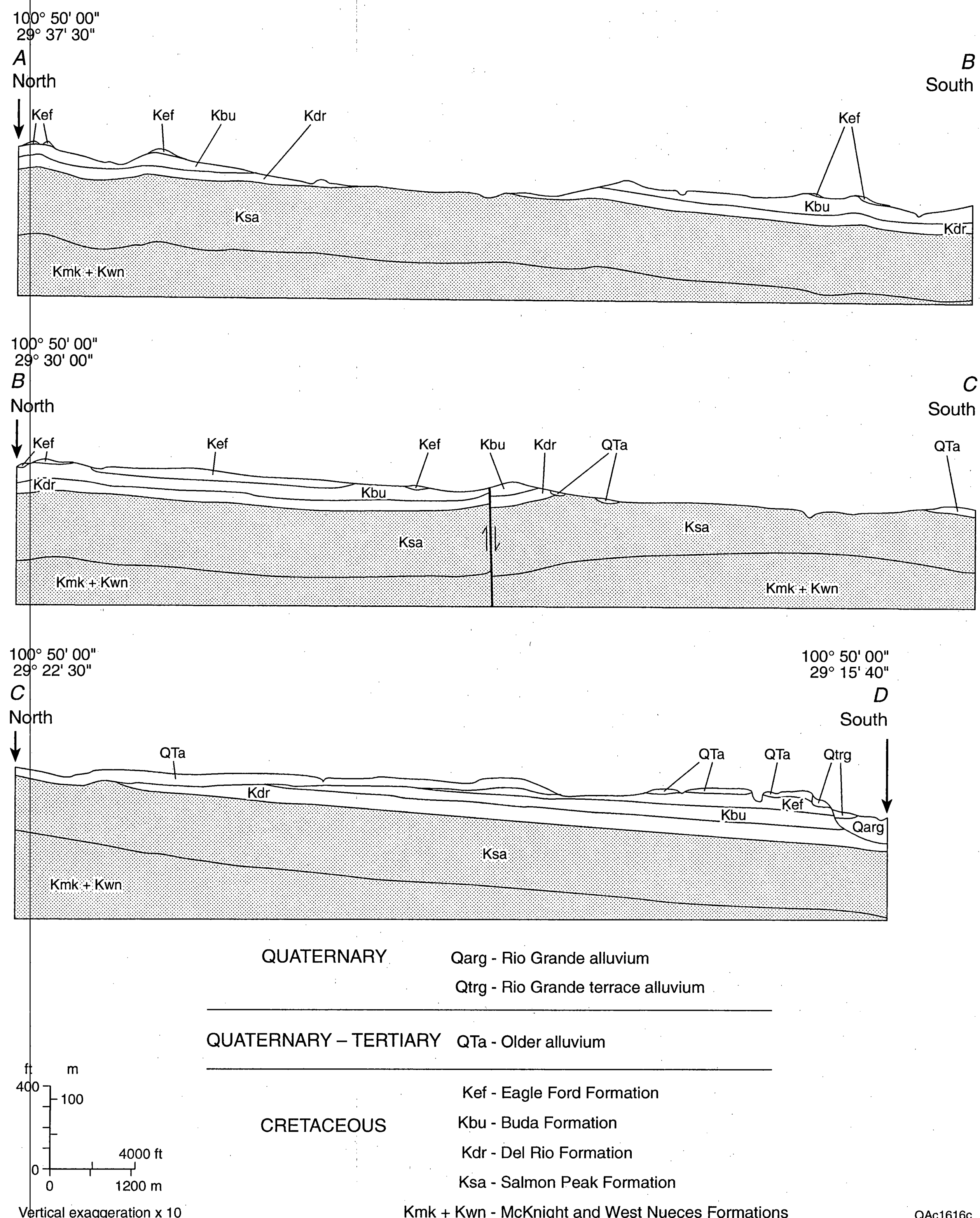

Figure 14. Cross section of Del Rio map area. Shaded units indicate Edwards aquifer strata. Location of cross section shown in figure 13.

SUBPROJECT 2: GEOLOGIC MAP OF THE WEST HUECO BOLSON, EL PASO REGION, TEXAS (1:100,000)

The Geologic Map of the West Hueco Bolson, El Paso Region, Texas, illustrates the geology of the Franklin Mountains, east margin of the Hueco Mountains, Hueco Bolson piedmont and basin floor, and Rio Grande Valley and valley border. The Hueco Bolson is an extensional basin that may be the continuation of the Rio Grande Rift in Texas. Surrounding the basin are mountains and highlands in which Precambrian to Tertiary rocks are exposed. The basin-fill sediments in outcrop are as old as the Pliocene, but they extend to depths of more than 8,200 ft in the subsurface, where they are of unknown age.

The Franklin Mountains (relief as great as 2,700 ft) bound the west edge of the Hueco Bolson. El Paso lies at the south margin of the mountains, and urban growth is expanding rapidly northward along the flanks of the mountains. The mountain range is a west-dipping, tilted fault block that trends northerly. A relatively continuous stratigraphic section of Precambrian through Permian rocks that are locally intruded by Tertiary igneous rocks is present in the Franklin Mountains. Quaternary alluvial-fan deposits have built off the edge of the mountains into the Hueco basin to the east and into the Mesilla basin to the west. Tertiary to Quaternary basin-fill alluvial-fan and fluvial deposits are not commonly well exposed along the east margins of the Franklin Mountains, although they are better exposed in arroyos at the west margin of the range that drain into the Rio Grande. Strata within the range are cut by faults that strike north, northeast, and northwest. These faults may predate the range-bounding faults that represent the latest episode of range uplift and tilting. The range is bounded on the east by a distinct, north-trending Quaternary fault, the East Franklin Mountains fault, which crosses the El Paso and North Franklin Mountain Quadrangles.

The east margins of the Hueco Bolson are bounded by the Hueco Mountains (relief as great as 885 ft) and its foothills. Only the west part of the Hueco Mountains are within the map area. Similar to the Franklin Mountains, the area records a long geologic history. Within the map study area Lower Ordovician–Upper Cambrian(?) Bliss sandstone is overlain by Lower Ordovician El Paso Group limestone, dolomitic limestone, and dolomite. Upper and Middle Ordovician Montoya Group limestone and dolomitic limestone overlie the El Paso Group and are overlain by the Silurian Fusselman Dolomite. Devonian Percha Shale and Canutilo Formation bedded chert, limestone, and marl crop out locally. Mississippian Helms Formation and Rancheria Formation limestone, sandy limestone, and shale are well exposed. Pennsylvanian Magdalena Group limestone, marl, and shale overlie Mississippian deposits and are at angular unconformity with overlying Permian Hueco Group conglomerate, limestone, dolomitic limestone, marl, and shale. Tertiary intrusive rocks in the area, mostly syenite to monzonite of the Hueco Tanks region, were intruded about 35 mya as sills and dikes. Northwest-striking and north-striking normal faults cut bedrock. Broad, northwest-trending folds are expressed within the bedrock strata. Localized folding related to sill emplacement has also occurred. Limestone is actively being quarried for crushed stone and cement along the flanks of the Hueco Mountains. Alluvial fan and drainageway alluvium compose the piedmont deposits shed from the Hueco Mountains. Bedrock foothills surrounded by alluvium are common at the basin margin.

The piedmont area of the basin contains surficial deposits of alluvial fans and incised alluvial fans of the upper piedmont slope near the higher relief bedrock areas and surficial deposits of mostly coalesced alluvial fans of the lower piedmont slope. The older alluvial deposits contain a K soil horizon that is a 2.3- to 5-ft-thick stage IV to V calcrete. The K horizon suggests that these deposits are as old as middle Pleistocene. Calcic soils of younger alluvial deposits exhibit progressively decreased development. The alluvial deposits overlie older basin-fill deposits of the Pliocene–middle Pleistocene Camp Rice Formation and the Pliocene Fort Hancock Formation. Windblown sand commonly covers the piedmont alluvium.

The basin-floor area contains mostly windblown sand deposits that overlie Pliocene–middle Pleistocene Camp Rice sand and gravel and lesser amounts of silt and clay and Fort Hancock lacustrine clay and silt and lesser amounts of alluvial fan and fluvial gravel, sand, silt, and clay. Fort Hancock bedded gypsum is common in outcrops within the southeast part of the Hueco

Bolson, outside of the map area. Fort Hancock deposits represent lacustrine and associated deposition in a bolson setting. Camp Rice deposits represent a system of dominant fluvial and alluvial-fan deposition, along with some floodplain and minor lacustrine deposition. Lower Camp Rice deposits include reworked Fort Hancock sediments. Within the basin-floor area, the top of the Camp Rice is capped by a well-developed stage IV to V pedogenic calcrete. Older alluvial-fan deposits at the basin margins may be nearly time equivalent to the uppermost Camp Rice deposits. Some coalesced alluvial-fan deposits that are shed from the highlands across the piedmont may extend onto the basin-floor area. Windblown sand deposits that overlie basin-fill deposits appear mostly to be less than 6 to 10 ft thick, although at one abandoned sand quarry, the eolian sand was more than 26 ft thick. Coppice dunes, interdune sheet deposits, and deflation areas are common. At the east margin of the Hueco Bolson, local areas of active sand dunes and areas of partly vegetated, stabilized to partly stabilized dunes are present. The basin floor and piedmont contain a series of north-trending, sand-covered scarps that may be fault related.

The Rio Grande valley and valley border consist of the Rio Grande floodplain and remnant terraces that have been incised into the older basin-fill deposits. The older basin-fill deposits and the remnant terraces are commonly covered by windblown sand. Fan deposits at the mouths of arroyos and smaller drainageways that drain into the river valley also exist. Alluvium associated with the remnant terraces and fans along the valley border are thin. Observations of the calcic-soil development and stratigraphic position of these deposits were used to subdivide the Quaternary valley border stratigraphy. Alluvium of the Rio Grande floodplain is commonly cultivated where it is not urbanized. Sand and gravel quarries mining the relatively uncemented Camp Rice deposits and the caliche capping them are common along the valley border rim.

SUBPROJECT 3: GEOLOGIC MAPPING OF AREAS OF SPECIAL ENVIRONMENTAL CONCERN

The mapping areas of special environmental concern include two quadrangles, Magers Crossing and Sabinal Canyon, along the Edwards and Trinity aquifer recharge and contributing zones, and two quadrangles, Luling and Prairie Valley School, where local aquifers and rivers are potentially being polluted by previous oil-production practices, leaking oil wells, pits, or pipelines. Improved geologic maps of these areas will aid professionals and the public in making informed decisions concerning environmental-protection issues. Detailed stratigraphy of the map areas is described in appendix A—Explanation of Geologic Units.

Magers Crossing and Sabinal Canyon Quadrangles

Magers Crossing and Sabinal Canyon Quadrangles are located in south-central Texas along the Edwards aquifer (figs. 1 and 15), and these areas include Garner and Lost Maples State Parks. These two quadrangles lie west and northwest of a larger area that was mapped for subproject 1, at the margin of the Edwards Plateau, immediately north of the Balcones Fault Zone. Rivers and intermittent tributaries have incised into the relatively flat lying strata forming terrain characterized by canyons and hills (figs. 16 through 18). The Frio River crosses the Magers Crossing Quadrangle, and the Sabinal River crosses the Sabinal Canyon Quadrangle. Bedrock of the areas are Lower Cretaceous limestone, dolomitic limestone, dolomite, argillaceous limestone, and marl of the Glen Rose Formation and Edwards Group. Edwards Group units include the Fort Terrett and Segovia Formations (carbonate-platform facies), which are gradational to the Devils River Formation (carbonate-platform-margin facies). Glen Rose strata make up the upper part of the Trinity aquifer, and Fort Terrett, Segovia, and Devils River Formations compose the Edwards aquifer. Quaternary stream and terrace alluvium locally overlie the bedrock in map areas. Intermittent springs and seeps are relatively common in the map areas. The study areas are part of the important contributing zone for the prolific San Antonio segment of the Edwards aquifer and

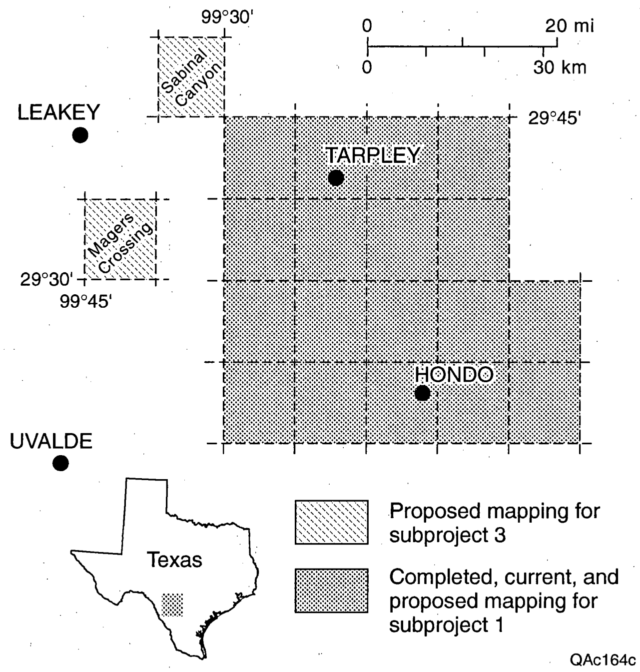

Figure 15. Location of Sabinal Canyon and Magers Crossing Quadrangles, two areas of special environmental concern for subproject 3. These quadrangles lie near subproject 1 mapping.

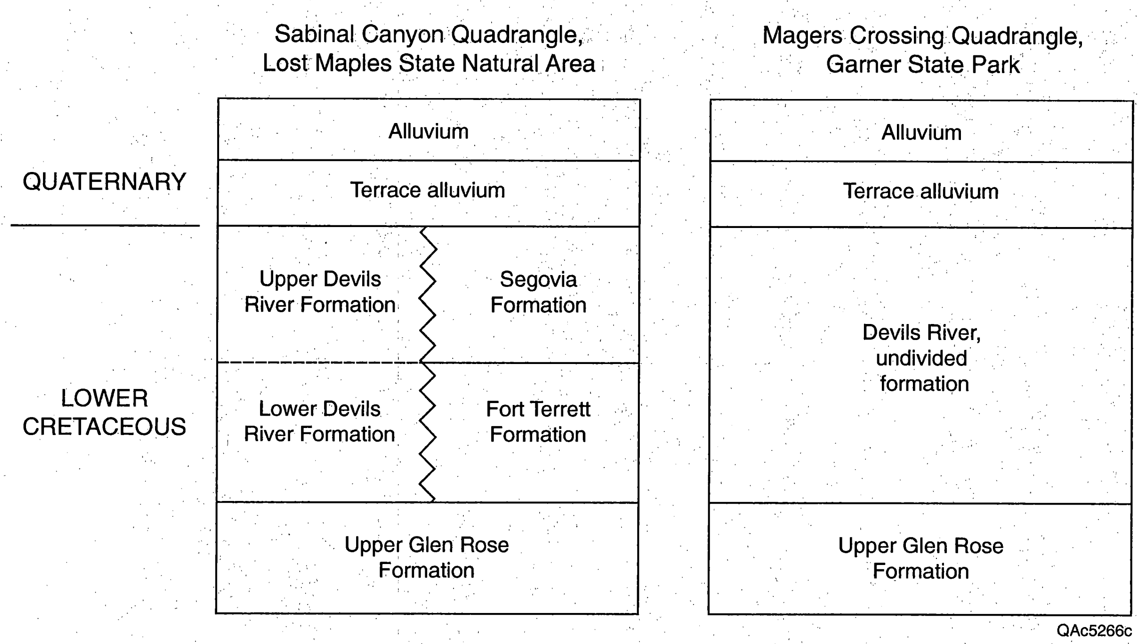

Figure 16. Stratigraphic charts illustrating units of Magers Crossing and Sabinal Canyon Quadrangles of subproject 3.

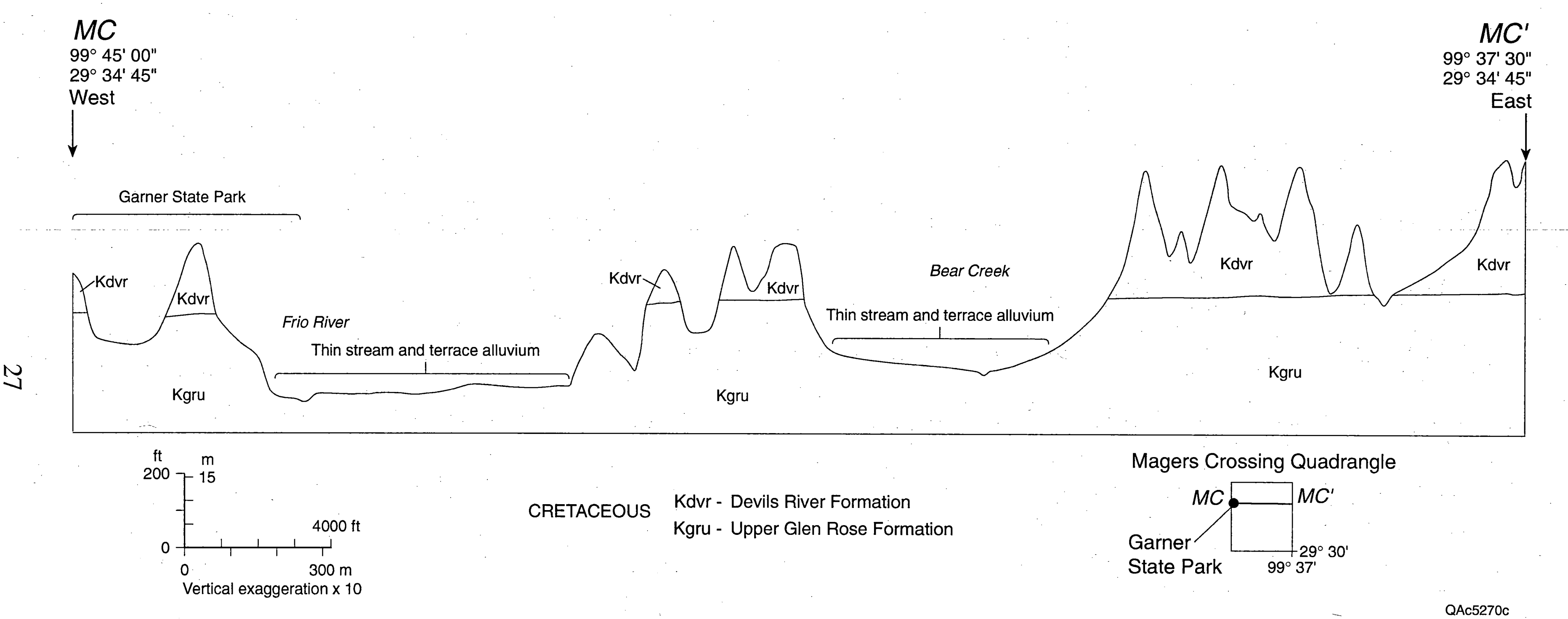

Figure 17. Cross section of Magers Crossing Quadrangle.

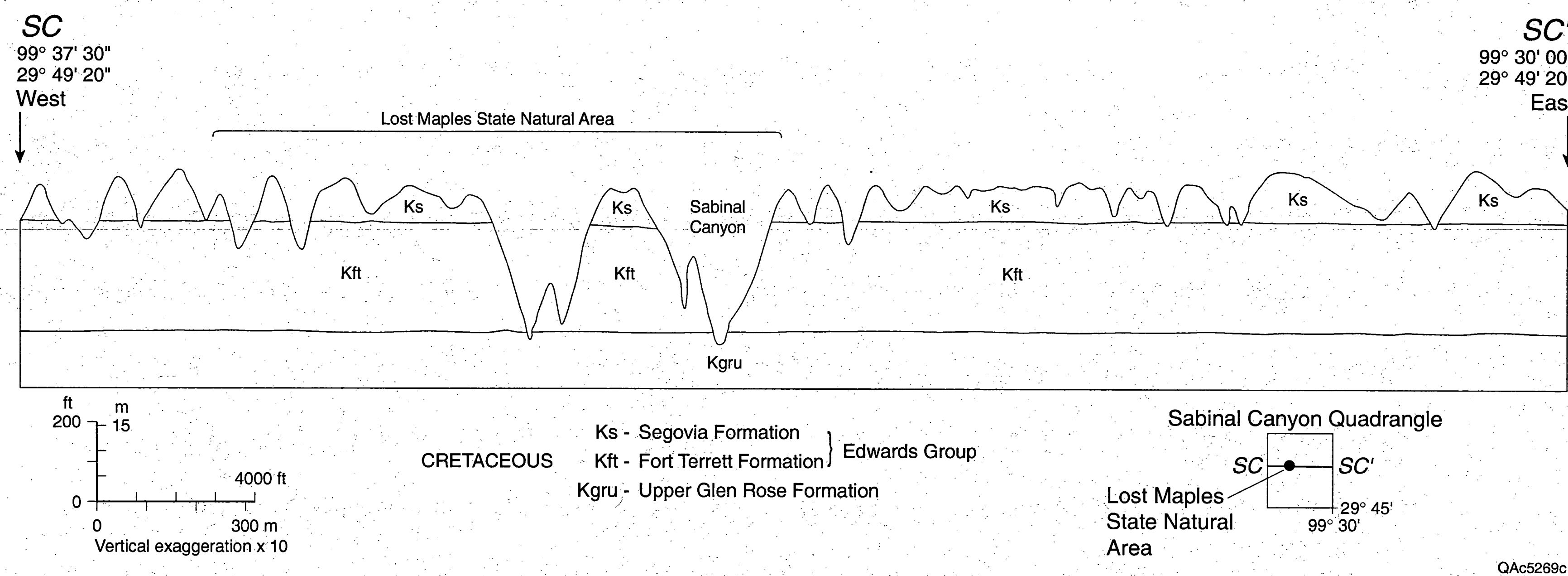

Figure 18. Cross section of Sabinal Canyon Quadrangle.

recharge zone. The Frio and Sabinal Rivers and tributaries within the map areas flow into the primary Edwards recharge zone.

Luling Quadrangle

The Luling Quadrangle is located in south-central Texas along the San Marcos River (fig. 3). Oil-field activities in this area have occurred since the early 1920's, and many wells, pipelines, and abandoned disposal pits exist within the quadrangle. Parts of the Luling, Spiller, Dunlap, and Salt Flat oil fields are in the study area. The geologic map of this area provides a base to aid professionals in evaluating environmental-protection issues such as reported crude-oil discharge into the San Marcos River from a seep along the river bank. Surface geology of the area includes the Paleocene–Eocene Wilcox Formation, and Quaternary terrace and river alluvium (appendix A—Explanation of Geologic Units). Wilcox deposits consist of a lower interval composed of mudstone and lesser sandstone and an upper interval of sandstone with some mudstone. Quaternary terrace deposits are extensive along the San Marcos River, and some of the larger terraces may be greater than 20 ft thick. The Wilcox outcrop belt acts as part of the recharge area for the regional Carrizo–Wilcox. Terrace deposits make up smaller, more local water-bearing units. Cross section L–L′ illustrates the stratigraphic section and structure across the map area (fig. 19). Normal faults crossing the area form structural traps for hydrocarbons. Hydrocarbon production is from Lower Cretaceous Edwards limestone and Upper Cretaceous Austin Group chalk and limestone. The surface geologic map of the Luling Quadrangle illustrates the location of Wilcox and Quaternary alluvium, inferred locations of normal faults, and areas where oil-field practices, including the drilling of wells and construction of pits, pipelines, and roads, have been most abundant.

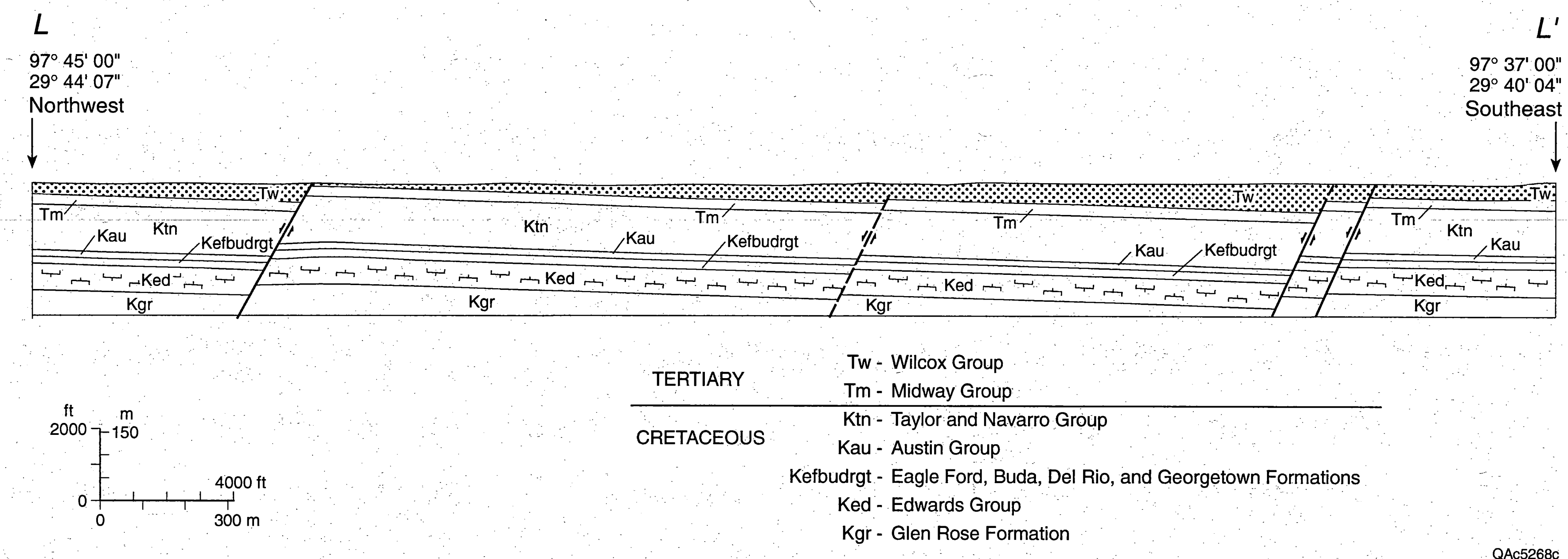

Figure 19. Cross section L–L′ of Luling Quadrangle, illustrating stratigraphic section and structure of the area.

Prairie Valley School Quadrangle

This quadrangle is located in North-Central Texas on the south flank of the Red River valley. Extensive oil and gas discoveries in what eventually became the prolific Nocona North and Spanish Fort oil fields began in the 1920's (McBee and Vaughan, 1956), some four decades before saltwater discharge related to oil-field production was regulated in Texas. Consequently, millions of barrels of co-produced saltwater have been discharged onto the ground and into pits and creeks. Near-surface salinization of soil and water has killed vegetation, contaminated shallow-water wells, enhanced surface erosion, and increased the salinity of the Red River (Hovorka and others, 1999). Most sources of salinity are located in the oil fields on Permian bedrock; the most significant impacts of salinization occur on cultivated alluvial terrace deposits of the Red River.

Structurally, the Prairie Valley Quadrangle is situated at the crest of the Muenster–Waurika Arch, an extensive Paleozoic structure that trends northwest-southeast (McBee and Vaughan, 1956). Outcropping units in the quadrangle include fluvial sandstones and mudstones of the Permian Nocona Formation (Hentz, 1988; McGowen and others, 1991) and a complex series of Tertiary and Quaternary alluvial and eolian sediments (Frye and Leonard, 1963) (fig. 20). Permian sandstones, commonly displaying prominent jointing, crossbedding, and some soft-sediment deformation, are exposed on upland areas, hill crests, road cuts, and in stream banks, particularly in the south part of the quadrangle. Farther north and closer to the Red River, Permian units are blanketed by as much as several meters of more recent windblown and river-borne sediments.

The post-Permian deposits consist of unlithified gravel, sand, silt, and clay deposited by the ancestral Red River and its tributaries or silt and sand blown across the valley and deposited on river terraces and Permian outcrops. At least three episodes of Red River alluvial activity are represented in the quadrangle, including (1) sandy, modern channel and muddy floodplain deposits in the modern terrace; (2) an extensive and well-preserved, older, intermediate terrace that is as much as 2 mi wide and more than 50 ft higher than the modern floodplain; and (3) gravel lag and

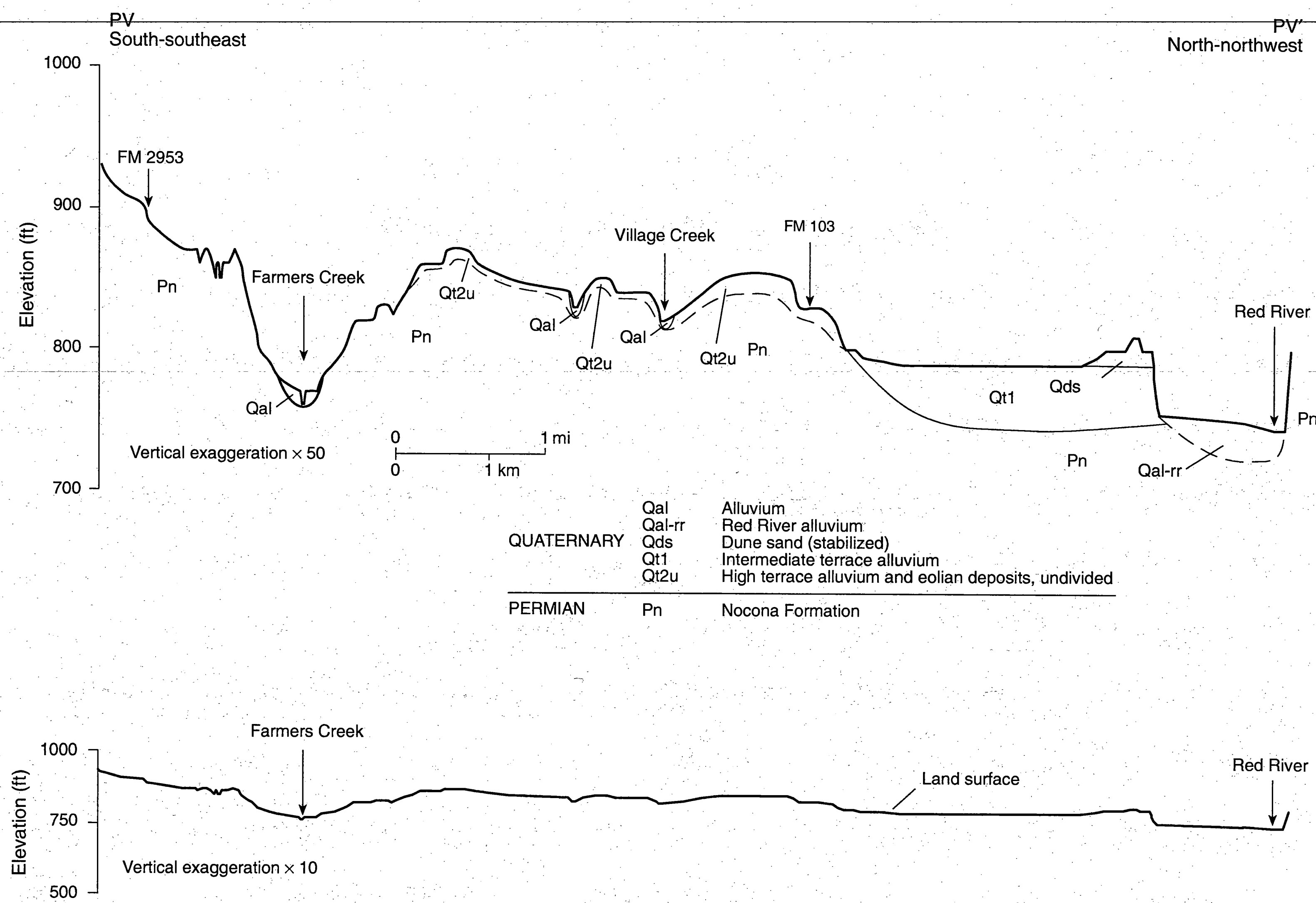

Figure 20. South–north cross section PV–PV′, illustrating stratigraphic and topographic relationships among Quaternary and Permian geologic units mapped in Prairie Valley School Quadrangle, Montague County, Texas.

finer grained alluvial deposits that are exposed at higher elevations and generally thicken toward the river valley. Inset into these older alluvial deposits on the upland are much younger and less extensive alluvial sediments transported by small streams that drain the upland. Despite similar lithology, these two alluvial units can be distinguished by differences in their degree of soil development.

Eolian silts and sands are found as vegetated and stabilized dunes where the modern and intermediate terraces meet and as blanket deposits overlying older terrace alluvium on the uplands. Like the alluvial deposits, the age of the windblown deposits generally increases southward from the river.

Areas barren of vegetation that are likely to be caused by oil-field salinization are mapped separately. This map unit includes both source areas, where saltwater has been discharged at the surface, and sink areas, where saltwater has reached the surface through ground-water flow or overland transport.

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APPENDIX A: EXPLANATION OF GEOLOGIC UNITS

West San Antonio Region

Bandera, Castroville, Comanche Waterhole, D'Hanis, Flatrock Crossing, Hondo, Murphy School, Mustang Valley, Quihi, Riomedina, Sabinal, Sabinal NE, Seco Pass, 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. 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. Deposits of adjacent terraces at different elevations are mapped separately.

Ql—Landslide deposits. Local deposits of Little Creek canyon area within Seco Pass Quadrangle.

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 upper 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 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 as much as ~75 ft. Escondido Formation is mudstone, siltstone, sandstone, and silty limestone. Includes thin (as much as ~30 ft), lower marl and mudstone unit, Corsicana marl. Outcrops are not common. Escondido thickness ranges between 550 and 900 ft.

CRETACEOUS

Upper Cretaceous

Ki—Intrusive igneous rocks. Basalt (field term). Generally not well exposed. Locations from Welder and Reeves (1964). Some very small outcrops noted by Holt (1959) in Medina County are not shown.

Kes—Escondido Formation. Mudstone, siltstone, sandstone, and silty limestone. Includes thin (as much as ~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.

Kan+QTu—Undivided Cretaceous Anacacho Formation and Quaternary to Tertiary Uvalde gravel.

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 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 as much as 4 ft thick. Lower part siltstone and very fine grained sandstone, light yellow to gray, laminated, flaggy, some limestone, silty, medium brown, 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, teeth, and *Inoceramus*. Thickness 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 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 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, 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; locally may be absent. 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, 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 composes 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 ~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 ~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 the 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

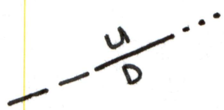
Segovia Formation of the Edwards Plateau. Limestone and dolomitic limestone. Shallow subtidal to tidal-flat cycles. Some rudistid mounds. Thickness ~200 to ~250 ft.

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 ~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 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 stair-step topography; limestone, wackestone, packstone, grainstone, hard to soft and marly, 3- to 10-ft-thick, upward-shoaling 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 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 as much as 15 ft thick; thickness ~200 to ~270 ft. Thickness of entire formation ~650 ft.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered.

Doline. Probable karst-related collapse or subsidence of bedrock.

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

Georgetown Region

Briggs, Cobbs Cavern, Ding Dong, Florence,
Georgetown, Hutto, Jarrell, Leander, Leander NE,
Liberty Hill, Mahomet, Nameless, 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. Deposits of adjacent terraces at different elevations are mapped separately.

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 upper 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 seams, 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 ~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 mostly between 3 and 30 ft; locally may be absent.

Kdr—Del Rio Formation. Clay. Calcareous, fossiliferous, poorly indurated, plastic, dark gray to olive brown; contains *Ilymatogyra arientina* (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 ~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. Thickens northward from ~40 to 70 ft.

Kwkv—Keys Valley Member of Walnut Formation. Marl, argillaceous limestone, and some limestone. Thickness as much as ~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 member (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 ~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 member (Moore, 1964). The upper marl member occurs north of southern Bell County and is not mapped in the study area.

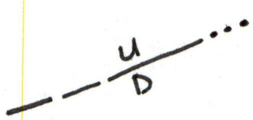
Kwkv+Kwwh+Kwcpbc+Ked—Keys Valley, Whitestone, Cedar Park, Bee Cave, and Bull Creek Members, undivided, of the Walnut Formation and Edwards Formation, undivided. Limestone, argillaceous limestone, and marl. Area of Edwards interfingering with Walnut members, and Whitestone Member interfingering with Keys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

Kpa—Paluxy Formation. Quartz sandstone. Calcareous; interbedded with limestone. Occurs only in northwest part of study area. Thickness less than 10 ft in map area.

Kgru—upper Glen Rose Formation. Limestone, dolomitic limestone, and marl. Shallow subtidal to tidal-flat cycles. Alternating resistant and recessive beds forming stair-step topography. Marine megafossils include molluscan steinkerns, rudistids, oysters, and echinoids; local dinosaur tracks. Dolomitic limestones contain water. *Corbula* interval, commonly 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.

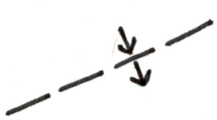
Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered.

Doline. Probable 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,

Flat Rock Creek SW, Mud Creek North, Mud Creek South,

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. Includes some slope-wash deposits. 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. Deposits of adjacent terraces at different elevations are mapped separately.

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, 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 to the upper Tertiary or Quaternary Uvalde Gravel.

QTa+Qal—Undivided older alluvium and alluvium of drainageways and slopes.

QTa+Qt—Undivided older alluvium and terrace alluvium.

QTa+Ksa—Undivided older alluvium (upper 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 ~150 to 200 ft.

Kef+QTa—Undivided Eagle Ford Group and older alluvium.

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 ~50 to 70 ft.

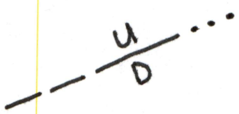
Kdr—Del Rio Formation. Clay, some calcareous siltstone. Calcareous, gypsiferous, pyrite common, weathers light gray to yellowish gray. Marine megafossils include abundant *Ilymatogyra arietina* (formerly *Exogyra arietina*) and other pelecypods. Thickness ~20 to ~80 ft.

Kdr+Qal—Undivided Del Rio Formation and slope wash and drainage alluvium.

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 ~310 ft.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered.

Doline; Probable karst-related collapse or subsidence of bedrock.

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

Axis of broad anticline; dotted where covered.

Magers Crossing Quadrangle, Garner State Park

(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 local bedrock outcrops that are undivided.

Qt—Terrace deposits. Gravel, sand, silt, and clay along streams and rivers. Mostly above flood level. Deposits of adjacent terraces at different elevations are mapped separately.

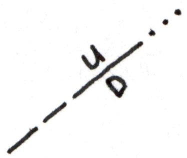
Qu—Undivided older terrace deposits and slope-wash alluvium. Gravel, sand, silt, and clay.

LOWER CRETACEOUS

Kdvr—Devils River Formation. The Devils River Formation is approximately equivalent to the Kainer and Person Formations (Edwards Group) of the Balcones Fault Zone outcrop belt of the San Marcos Platform and the Fort Terrett and Segovia Formations (Edwards Group) of the Edwards Plateau outcrop belt of the San Marcos Platform. Limestone and dolomitic limestone. Shallow subtidal to tidal-flat cycles. Some rudistid mounds. Some leached evaporitic rocks and breccias. Lower 20 to 50 ft is nodular limestone. Thickness ~550 to ~650 ft.

Kgru—Upper Glen Rose Formation. Limestone, dolomitic limestone, argillaceous limestone and some marl. Shallow subtidal to tidal-flat cycles. Alternating resistant and recessive beds forming stair-step topography; limestone, wackestone, packstone, grainstone, hard to soft and marly, 3- to 10-ft-thick, upward-shoaling 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. Thickness ~200 to ~270 ft. Thickness of entire formation ~650 ft.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered.

Doline. Probable karst-related collapse or subsidence of bedrock.

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

Sabinal Canyon Quadrangle, Lost Maples State Park

(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 local bedrock outcrops that are undivided.

Qt—Terrace deposits. Gravel, sand, silt, and clay along streams and rivers. Mostly above flood level. Deposits of adjacent terraces at different elevations are mapped separately.

CRETACEOUS

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 the upper Devils River Formation of the platform margin. Limestone, dolomitic limestone, and marl. Total thickness of unit 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.

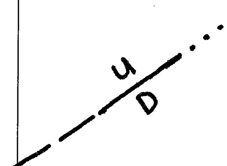
Kdvru—upper Devils River Formation. The upper Devils River Formation is the upper part of the Edwards Group along the San Marcos Platform margin. It is approximately equivalent to the

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 ~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 ~350 to ~400 ft.

Kgru—Upper Glen Rose Formation. Limestone, dolomitic limestone, argillaceous limestone and some marl. Shallow subtidal to tidal-flat cycles. Alternating resistant and recessive beds forming stair-step topography; limestone, wackestone, packstone, grainstone, hard to soft and marly, 3- to 10-ft-thick, upward-shoaling 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. Thickness ~200 to ~270 ft. Thickness of entire formation ~650 ft.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered.

Doline. Probable karst-related collapse or subsidence of bedrock.

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

Approximate boundary of interfingering platform and platform-margin facies. Nomenclature boundary.

Luling Quadrangle, Texas

(1:24,000)

QUATERNARY

Qal—Alluvium. Unconsolidated gravel, sand, silt, and clay along streams and rivers; inundated regularly. Along minor drainages includes undivided low terrace deposits. Includes some local bedrock outcrops along stream banks that are undivided.

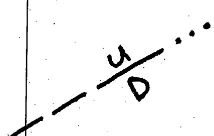
Qt—Terrace deposits. Gravel, sand, silt, and clay along streams and rivers. Deposits of adjacent terraces at different elevations are mapped separately.

TERTIARY

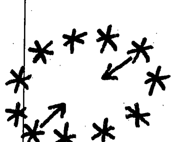
Paleocene–Eocene

PaEwi—Wilcox Group. Mudstone and sandstone. Ironstone concretions common, variable amounts of lignite exist regionally, glauconitic near base and top of unit, crossbedded, locally burrowed. Lower part of unit is dominantly mudstone with lesser sandstone. Sandstone commonly interbedded with mudstone in upper part. Thickness about 1,200 to 1,300 ft.

Map Symbols



Fault; **U**, upthrown side; **D**, downthrown side; dashed where relatively less distinct than solid; dotted where covered.



Area where oil-field practices, including the drilling of wells and construction of pits, pipelines, and roads, have been most abundant.

HS

Reported location of hydrocarbon seep along San Marcos River (A. R. Dutton, personal communication, 1999).

Prairie Valley School Quadrangle, Montague County, Texas

(1:24,000)

QUATERNARY

Qal—Alluvium. Unconsolidated sand, silt, clay, and gravel along minor ephemeral streams and drainages. Inset into compositionally similar but older Red River alluvial terrace and eolian deposits in places, particularly near the Red River. Distinguished from older deposits by lesser degree of soil formation. Includes some local outcrops of Nocona Formation sandstone or mudstone. Deposits are generally less than a few feet thick and are confined to a zone within a few tens of feet of the drainages.

Qal-rr—Red River alluvium. Sand, gravel, silt, and clay deposited in broad channel and floodplain environments of the modern Red River. Includes vegetated and unvegetated deposits and the actively migrating Red River. Found at the lowest elevations within the Red River valley (generally 730 to 770 ft above sea level). Deposits generally less than 20 ft thick within a topographic low that is as much as 1 mi across. May include local outcrops of Nocona Formation.

Qds—Vegetated and stabilized dunes. Unconsolidated sand and silt deposited in dunes on Qt1 at its boundary with Qal-rr. Dunes have been stabilized by vegetation and form low rolling hills 10 to 20 ft high.

Qt1—Intermediate Red River terrace alluvium. Sand, silt, clay, and gravel deposited in channel and floodplain environments by ancestral Red River. Broad, well-preserved terrace as much as 2 mi wide and about 40 ft above modern floodplain at elevations of 785 to 800 ft above sea level. Deposits as much as 50 ft thick; channel gravel and sand common in lower part, overbank silt and clay common in upper part. May be blanketed in places by veneer of windblown sand and silt.

Qt2u—Undivided high Red River terrace alluvium and eolian deposits. Unconsolidated sand, silt, gravel, and clay deposited in channel and floodplain environments by ancestral Red River at elevations more than 800 ft above sea level. Unit includes underlying gravel lag and overlying eolian sand and silt sheet. Terrace shape modified by later drainage development and eolian activity. Above 830 ft, unit consists of thin, basal gravel lag and overlying eolian sand and silt. Unit ranges from less than 1 ft to several feet thick, generally thickening toward the river. Includes some local outcrops of Nocona Formation.

PERMIAN

Pn—Nocona Formation. Undivided sandstone, mudstone, siltstone, and conglomerate. Sandstones and conglomerates in broad channel-fill bodies, tan to dark reddish brown, fine grained to very coarse grained, thin to thick bedded. Soft-sediment deformation typical in thicker beds, large-scale crossbeds common. Friable to moderately well cemented with silica, limonite, and hematite. Chert-pebble conglomerate mostly near base of thicker sandstone units. Thickness of individual sandstone members 5 to 40 ft. Mudstone, reddish-brown, yellowish-brown, locally gray and olive, unstratified and thick-bedded, calcareous nodules and ferruginous concretions locally common; sandstone and siltstone in lentils and platy thin beds throughout, laminated, cross-laminated, crossbedded. Total thickness of Nocona Formation 330 to 350 ft (McGowen and others, 1991).

MAP SYMBOL

d — Area disturbed by oil-field-related activity, including excavations, saltwater discharge pits, and barren areas caused by near-surface salinization.