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Integrated Surface-Subsurface Mapping of the Balcones Fault Zone in the San Antonio Area, Texas; Upper Cretaceous Stratigraphy, Faulting, and Quaternary Terracing

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ABSTRACT

Remapping at 1:48,000 scale of the north half of the San Antonio 1:100,000 quadrangle is being undertaken as a contribution to supporting urban development, conservation of historical and natural resources, and understanding the geologic and geomorphic history of the urban area. Mapping is essentially complete from the east side of San Antonio westward to Castroville.

The area includes exposed formations from Austin Limestone through Lower Wilcox Group sandstone and shale; however, most of the surface consists of very poorly exposed Upper Cretaceous mudstones and Quaternary alluvium, which conceal the underlying structures. Therefore, subsurface mapping on base of the Del Rio Clay, using the abundant water well and some oil well control in the region, has been used to interpret the pattern of Balcones faulting and extrapolate it to the surface. Mudstone contacts are projected based on thicknesses from logged wells. Such integrated surface-subsurface techniques should be applied to other poorly-exposed areas of Texas, wherever the subsurface information is sufficient.

The Upper Cretaceous section changes significantly across the area. The Campanian Pecan Gap marl is overlain westward by a thickening tongue of the Anacacho Limestone, which is a fine-grained micrite that is hydrocarbon-productive in a number of significant fields. Overlying Taylor mudstone is assigned to the Bergstrom Formation; the Bigfoot Unconformity truncates it at its top. Overlying shales in the east (Navarro-Kemp) pass westward into a varied unit of calcareous mudstone containing thin sandstones and limestones (Escondido Formation). These changes can be seen on a log cross-section through the area as well as surface exposures.

Paleogene strata of the Midway and lower Wilcox are exposed in the southern part of the area. Marginal marine sandstone and siltstone of the

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Poth member of the Midway are exposed, forming the northwest limit of sandy soils mapped as Wilcox.

Major Balcones faults can be traced across the mapped area, trending N60°E. Significant antithetic faults are present and form grabens and major upthrown fault blocks; irregular anticlinal structures are also present (most famously the Culebra Anticline).

A complex series of three or more terrace deposits form the dominant geomorphology of much of the area. The highest preserved deposits (generally called the 'Uvalde gravels') form fairly narrow ridges across the landscape that are capped by calichified gravels. They are loosely correlative to present streams. A series of middle terraces occur at lower levels, including the 'Leon Creek Fan' and fans sourced from the Culebra Anticline. Lower terraces are found near the major drainages, including the Applewhite terrace of Holocene age along the Medina River; still lower surfaces form part of the present floodplain.

INTRODUCTION AND PREVIOUS WORK

The San Antonio area is the second largest major metropolitan area in Texas, having a population of over 2.3 million in 2020 (1.58 million in the city limits). Growth has been steady at about 19% per decade since 1980. The downtown and southside areas along the San Antonio River were the site of the original Spanish settlement of Texas including a chain of five missions and associated structures that were established in the 18th century. The four downstream missions and associated structures became a National Historical Park in 1983, and the entire chain of missions became a UNESCO World Heritage Site in 2015. Development in the 20th century has spread northward and northwestward into the fringes of the Hill Country and is now also extending westward toward Castroville and in a lesser degree southward.

The San Antonio area has a complex geology that is significant for both historical context, present-day and future development, and urban hazards (Ewing, 2008). The area lies within the Balcones Fault Zone (Fig. 1), a belt of normal faulting that extends through southwest and central Texas. Surface bedrock exposures in the area range from Glen Rose and Edwards limestones (Lower Cretaceous) to the north, to Wilcox sandstones (Paleocene and Eocene) to the south. Abundant terrace and fan deposits of Quaternary age mantle the bedrock, particularly in the outcrop belt of Upper Cretaceous and Paleocene claystones. The various units affect soil and foundation stability and have provided different resources for historical development. In the subsurface, the Edwards Group carbonates host the prolific Edwards (Balcones Fault Zone) Aquifer, the principal water source for San Antonio (Ewing, 2004).

Despite the complexity and importance of San Antonio geology, detailed mapping has been limited, especially in the southern part of the urban area (the San Antonio 1:100,000 sheet; Fig. 1). The first comprehensive geologic report was by Hill and Vaughan (1898), focusing on the groundwater resource of the Edwards Aquifer. The Texas Bureau of Economic Geology published a full report on the geology of Bexar County (Sellards, 1919), containing valuable reports of surface outcrops now vanished or inaccessible. An updated countywide geologic map and report was completed by Arnow (1959) as part of groundwater resource studies. Regional mapping was used for the 1:250,000 compilation of Brown et al. (1983), but is generalized and inaccurate in the San Antonio area. In the 1990s, the Bureau of Economic Geology completed open-file geologic mapping of quadrangles to the north in the New Braunfels 1:100,000 sheet, resulting in a published map at that scale (Collins, 2000). Collins also mapped the Castroville and Riomedina quadrangles in the northwest edge of the San Antonio sheet (Collins, 1998a, 1998b). In recent years, Elliott has completed six quadrangles south of the present study within the Carrizo outcrop belt in support of sand resource development (Elliott, 2013–2019; quadrangle locations on Figure 1A). However, no quadrangle-scale mapping has been completed in the part of the San Antonio urban area lying in the San Antonio sheet, despite the great importance to histori-

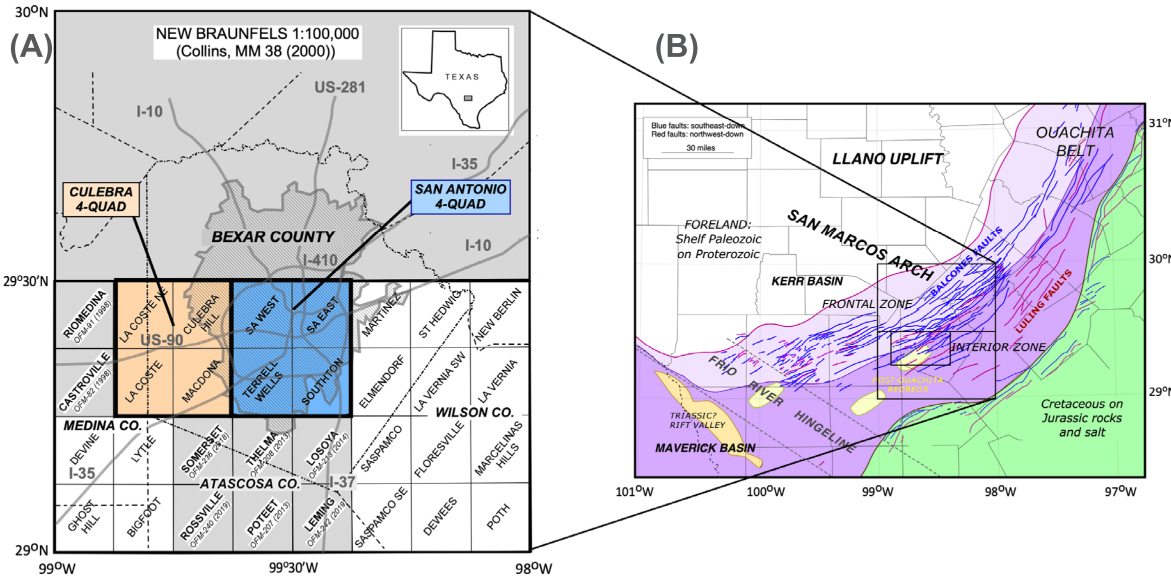

Figure 1. (A) Location map of the San Antonio 1:100,000 sheet within the Balcones Fault Zone, and the location of past and present quadrangle mapping (Culebra and San Antonio 4–Quad sheets) within that sheet. (B) Balcones map as modified from Ewing (2016).

cal conservation and urban development. In large part this is due to the extremely poor exposure of most units, particularly the Upper Cretaceous mudstones.

Subsurface geology has been studied intensively over the years to understand the Edwards aquifer and its resources. Important regional maps include that of Maclay (1995) based on much previous work by the U.S. Geological Survey, and that of Collins and Hovorka (1997). However, published mapping is on a regional scale and is not easily relatable to local features. Most importantly, surface and subsurface mapping have been carried out in separate projects and have not been integrated.

The present project proposes an integrated approach of surface and subsurface mapping to provide useful maps of the San Antonio sheet. Two four-quadrangle areas have been mapped at 1:48,000: the 'San Antonio 4–Quad' to the east and the 'Culebra 4–Quad' to the west (Fig. 1).

OVERVIEW OF STRATIGRAPHY

Overlying Paleozoic 'basement' (deformed Ouachita facies rocks and overlying red beds) is a series of Cretaceous and Paleogene sedimentary rocks, thickening to the southeast by addition of younger strata (Figs. 2 and 3). A basal clastic unit (Hosston or Travis Peak) grades upward to a thick sequence of carbonates with thinner interbedded shales and marls (Sligo through Austin). The carbonate sequence is overlain by a thick sequence of mudstone, marlstone and thin sandstones and greensands (Pecan Gap through Midway), which in turn is overlain by the sandstone-rich Wilcox Group.

Of particular importance in the carbonate sequence are the porous Edwards Group carbonates (Albian). Northwest of a sharp line through the mapping area, the Edwards contains fresh water, and yields water at high rates from hundreds of wells drilled. To the southeast the unit contains brackish to saline, warm and sulfur-rich water that has been produced at a few wells. The Edwards is overlain by the calcareous claystone of the Del Rio Clay, which forms a consistent mapping horizon, easily recognized on most drillers' logs and on geophysical well

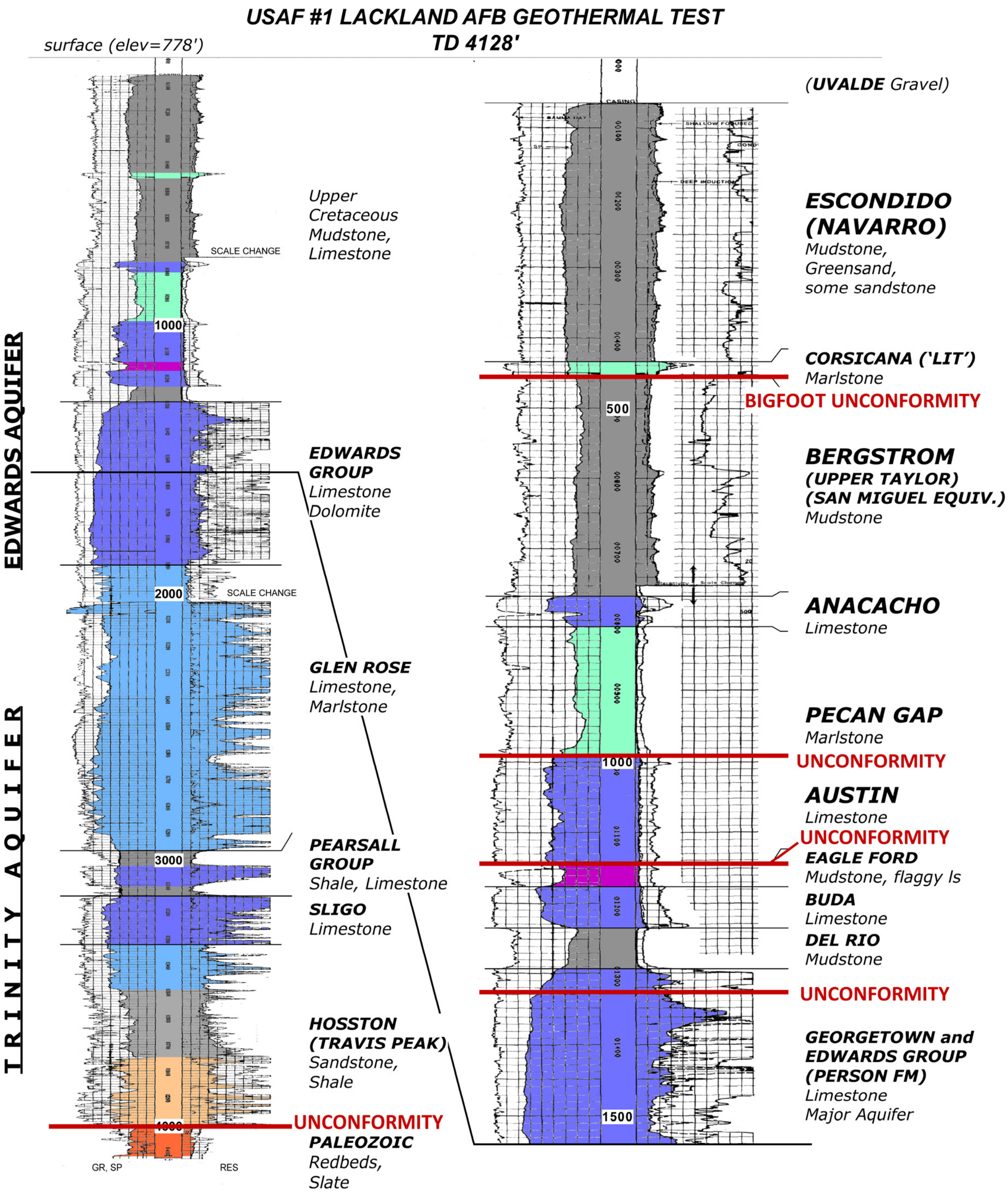

Figure 2. Type log, Paleozoic to Cretaceous units: Lackland #1 Geothermal Test Well (northwest corner, Terrell Wells quadrangle). Units exposed in the map area are indicated by larger font size.

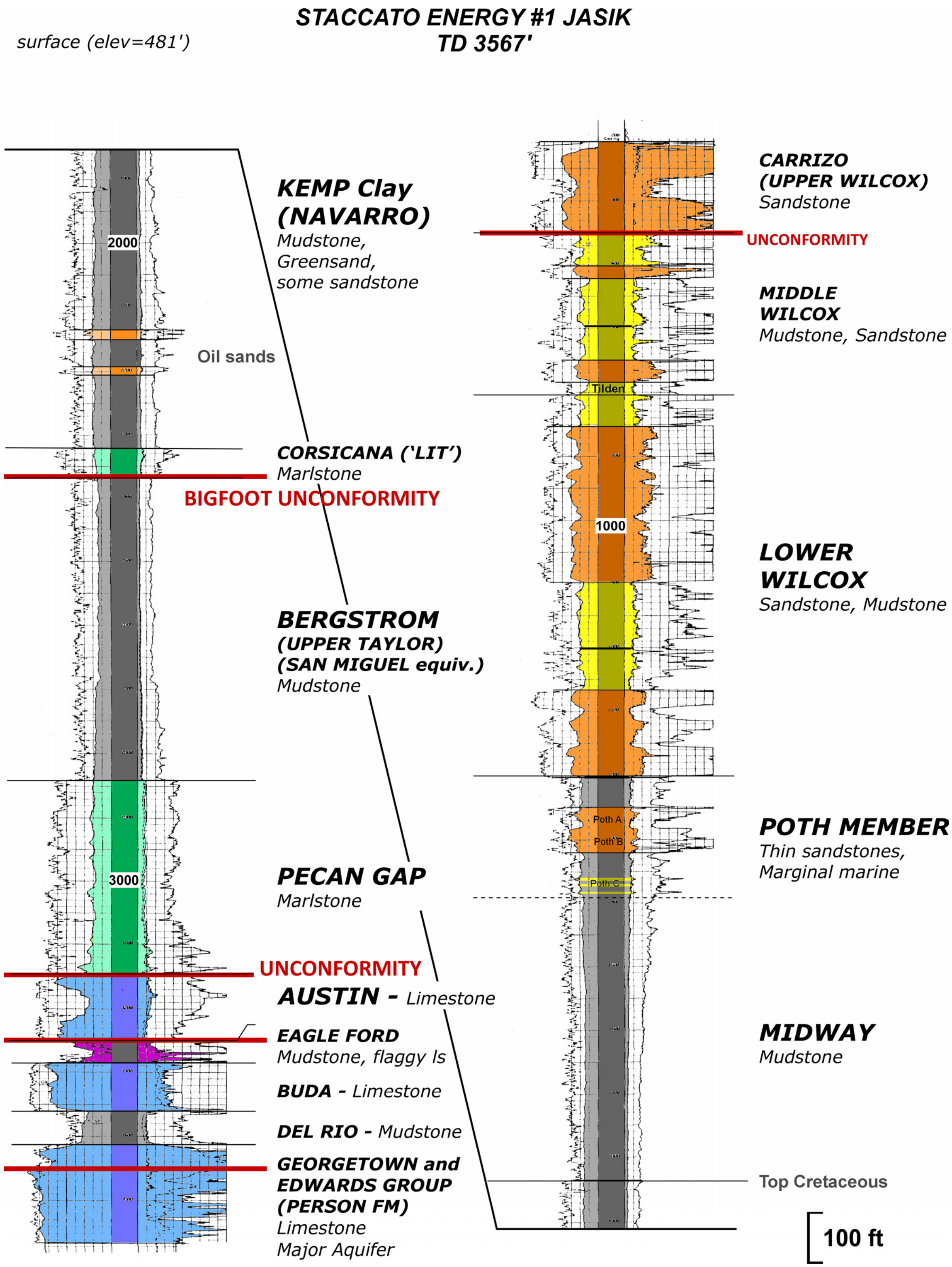

Figure 3. Type log, Edwards to Carrizo units: Staccato #1 Jasik (western Saspamco quadrangle, southern tip of Bexar County).

logs, and has been penetrated by most water wells and many oil and gas wells.

Except for a small area of Edwards outcrop in the northwest, the oldest exposed unit in the San Antonio sheet is the Austin Group limestone. The Austin is fairly hard and fractured, and contains significant groundwater that is linked to the underlying Edwards by Balcones faulting. Overlying marlstone (Pecan Gap) is overlain by slightly calcareous mudstone (Bergstrom) and younger mudstone units. The youngest bedrock unit in the mapped quadrangles is the lower part of the Wilcox Group, but younger units are preserved farther south in Bexar County.

METHODS: INTEGRATED SURFACE AND SUBSURFACE GEOLOGY

Because most units in the map area are exposed very poorly, it was necessary to use subsurface information to create acceptable maps. There is abundant subsurface information from water wells and oil and gas tests in the area. Water wells were compiled using Pettit and George (1956) along with all data posted on the website of the Texas Water Development Board (the groundwater data viewer; https://ww3.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer#). Structure was mapped at the base of the Del Rio Clay. This horizon and the immediately overlying units (Austin–Eagle Ford–Buda–Del Rio) are reliably picked on most drillers' logs due to profound changes in color and drill rate, which indicate the casing point for Edwards water wells. Some water wells also have geophysical logs; and in the southern part of the area, various oil and gas tests have geophysical logs that allow the mudstone and marlstone units to be differentiated. In the San Antonio 4–Quad, 383 wells yielded Base Del Rio data; in Culebra 4–Quad, 252 wells provided data. A subsurface structure map was compiled; faults were estimated from offsets in well depths (Fig. 4).

Using the structure map, faults have been projected up to the surface (or to subcrop below terrace gravels), assuming that the faults are Neogene and cut all bedrock units. Significant contacts in outcrop are estimated and mapped from unit thicknesses observed in wells with geophysical logs.

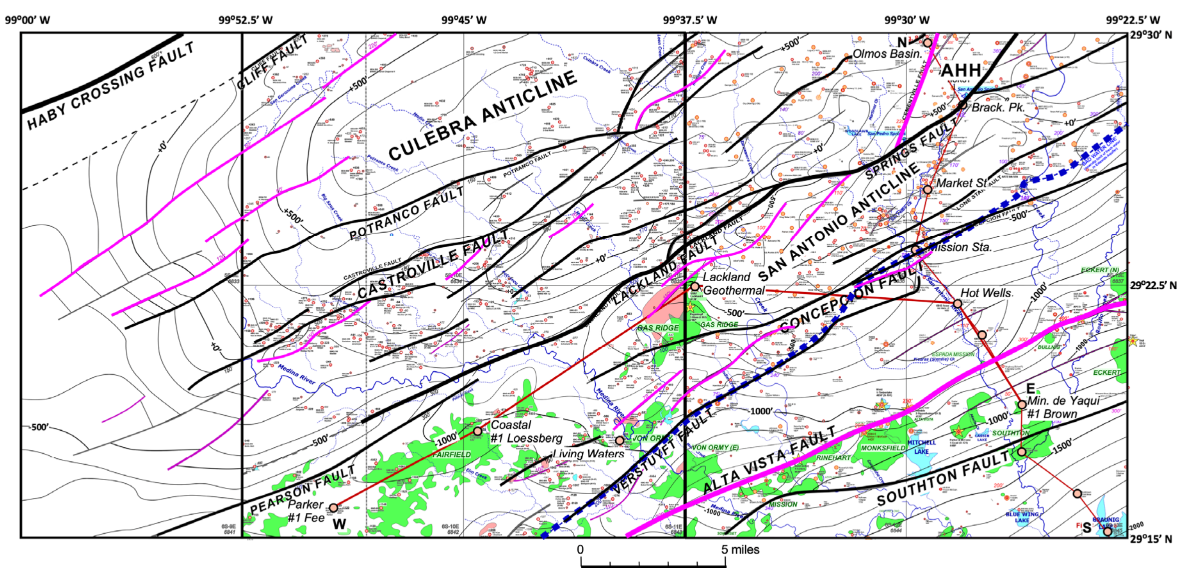

Figure 4. Structure map, Base Del Rio, showing location of well data. The downdip limit of fresh water in the Edwards Group is shown by a blue dashed line; oil fields are shown in green, and gas fields in red. Southeast-down faults in black and northwest-down faults in magenta. Deep wells (sub-Edwards) are starred. Structure is continued westward into Castroville and Riomedina quadrangles. AHH, Alamo Heights horst.

Surface mapping proceeded with field traverses, focusing on streamside exposures where accessible. Soils provide much information, and the county soil survey maps were consulted. Field observations required alterations to the subsurface mapping in several areas. Observations were plotted on standard topographic quadrangle maps, assisted by aerial imagery. A bedrock geologic map is the product (Fig. 5).

Quaternary terraces and alluvial deposits were identified from high-resolution (1 ft) LIDAR imagery acquired by the San Antonio River Authority. Contacts were field-checked where possible.

KEY OBSERVATIONS IN EXPOSED STRATIGRAPHY

Full descriptions of the mapped units are not given here; they will be presented in the text accompanying the final published maps (Ewing, 2021 submitted). Key observations on stratigraphic units are presented here, based on exposures in the map area and subsurface sections.

The Austin Limestone thickens gradually to the west and south (Fig. 6) from 120 ft in the Southton quadrangle (Minerales de Yaqui #1 Brown) to 150 ft at the Lackland geothermal well and 211 ft in the Lacoste quadrangle (Parker #1 Fee; Fig. 6). This thickening is consistent with the location of the area on the southwestern flank of the San Marcos Arch, which experienced less sedimentation and more frequent erosion throughout Late Cretaceous time. The detailed Austin subdivisions of Cooper (2017) have not been used for mapping; but in the field, differentiation can be made of a lower Austin lime micrite with wispy bedding, and an upper Austin unit with diverse shelly micrite-packstone lithologies and several biostromes. These correspond approximately to Cooper's Atco Formation (lower) and the combined Vinson-Jonah-Dessau formations (upper).

The Taylor Group in the San Antonio area shows complex relationships that are important for proper mapping and regional interpretation. In the eastern part of the map area (the San

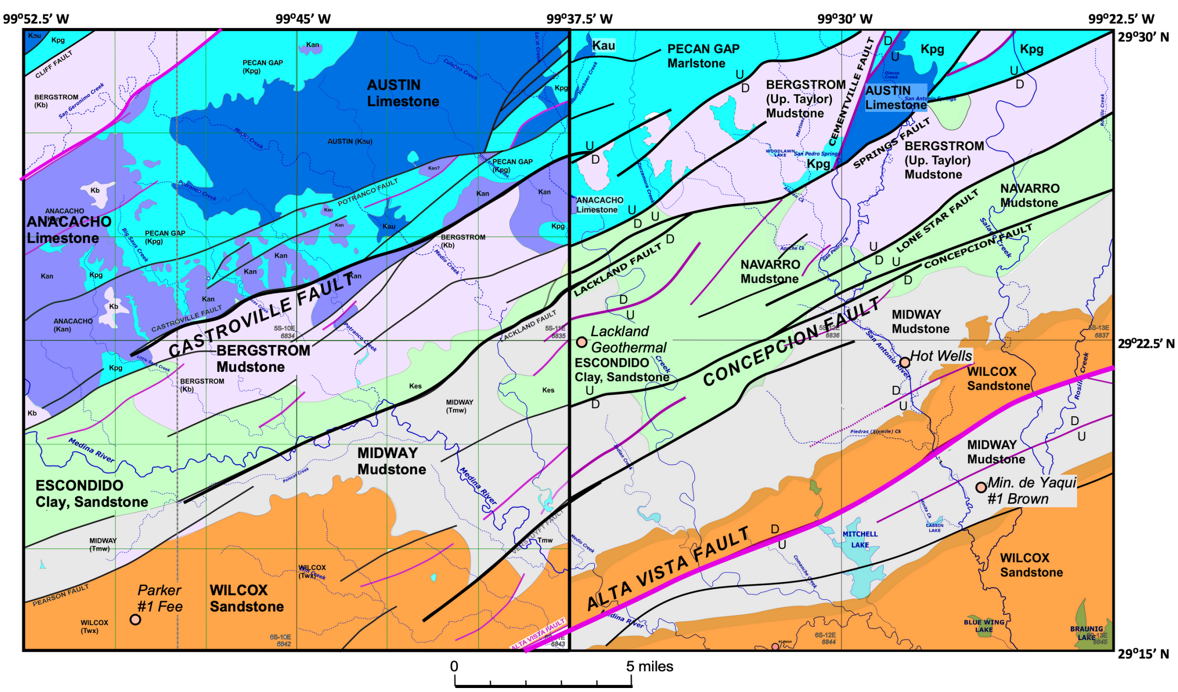

Figure 5. Bedrock map. Southeast-down faults in black and northwest-down faults in magenta.

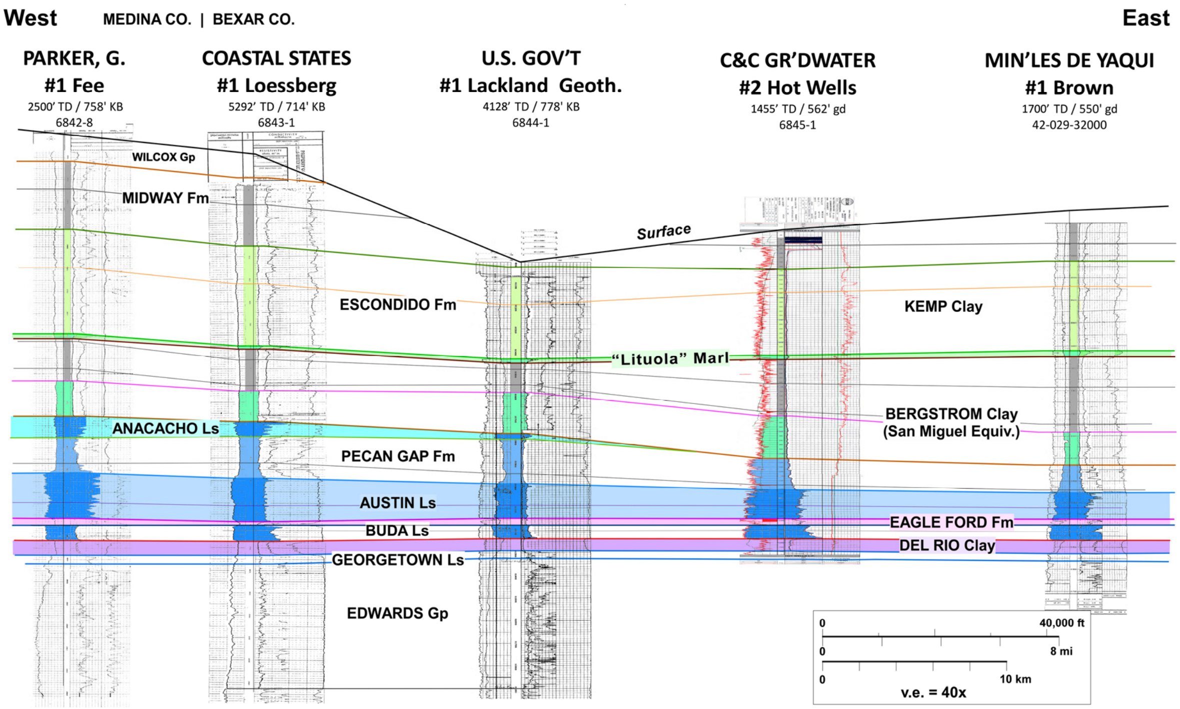

Figure 6. W–E stratigraphic section through the southern part of the mapped area, showing changes in Upper Cretaceous stratigraphy. Location of section on Figure 4.

Antonio River and Salado Creek valleys), the lower part of the Taylor is a soft, white-gray marlstone some 120–140 ft thick. This unit was identified as Pecan Gap Formation by Ellisor and Teagle (1934) and Brown et al. (1983); Arnow (1959) mapped it as Anacacho. To the west, in the Leon Creek valley, this unit has a chalky lower section and a marl-rich upper section and is 140–180 ft thick. There, it is overlain gradationally by a hard chalky micrite similar to the Austin; this is mapped as the Anacacho Limestone. This unit thickens westward, partly by facies change from surrounding units; it is 40 ft thick near its eastern edge at the Lackland geothermal well but up to 90 ft thick in eastern Medina County (Fig. 6). The Anacacho is a significant reservoir for oil and gas in southwestern Bexar County.

Overlying the Anacacho (or the Pecan Gap where the Anacacho is not developed) is a slightly calcareous marine claystone that is mapped in this study as the Bergstrom Formation (replacing 'Taylor clay/marl'). It is correlative with the Upson Clay and possibly some of the San Miguel Formation of southwestern Texas, but the Austin-derived nomenclature is preferable here from lithology and stratigraphic relationships. The top of the Bergstrom is a regional erosional unconformity, the Bigfoot Unconformity. In the map area, the Bergstrom is as little as 200 ft thick in the north but increases to 340 ft thick in the south due to northward removal of beds at the unconformity (Fig. 7). Southwest of the area, San Miguel and Olmos sandstones are preserved and are significant oil reservoirs.

Overlying the unconformity is a section 500 ft thick of mudstone and siltstone resting on a thin basal marlstone ('Corsicana equivalent', or '*Lituola*' zone). This unit is generally muddy in the east but develops more siltstone and sandstone to the west; thicker sandstones are exposed near Castroville. The sand-bearing sections are generally mapped as Escondido, the eastern muds as 'Navarro mudstone' (Kemp Formation of East Texas). Several thin sandstones in the mudstone section form oil reservoirs in the southern part of the area.

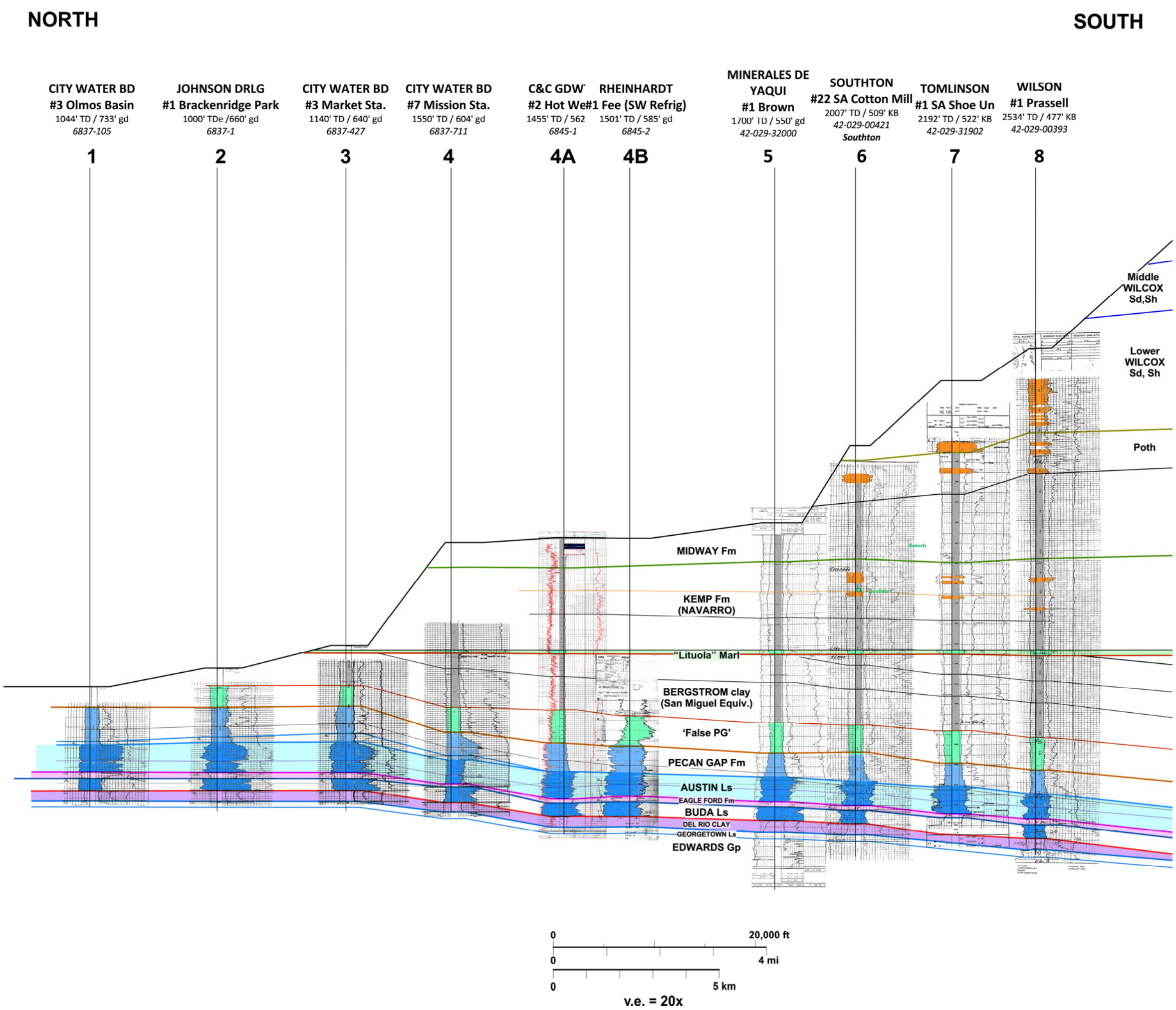

Figure 7. N–S stratigraphic section along the San Antonio River valley, showing erosion on the Bigfoot Unconformity; datum top of *Lituola* zone. Location of section on Figure 4.

Navarro mudstone is overlain by about 500 ft of Midway (Paleocene) mudstone, both formations being seldom exposed. Distinctive concretions are present at a few horizons in the Midway. The upper part of the Midway is gradational upward to thin, marginal marine sandstones of the Poth member, which are oil-productive in the subsurface. In outcrop, the soils become sandy at this horizon and remain sandy into the overlying Wilcox units; hence the base of Wilcox is picked in outcrop at a slightly deeper point than would be done in well logs. The Wilcox is sand-rich and variably cemented, as observed in several outcrops, notably at the Espada Aqueduct site west of San Juan mission.

BALCONES FAULTING

Faults of the Balcones Fault System are prominent across the area, trending N60–65°E. The faults are defined using subsurface data, but the faults that offset Austin and Anacacho resistant units have strong geomorphic and photogeologic expression, especially on the Culebra Anticline. Most major faults are southeast-down; however, significant northwest-down (antithetic) faults are also present, particularly on the northwest flank of the Culebra Anticline, at Cementville, in the Lackland Air Force Base area, and the Alta Vista fault in the southeast part of the area. Faults have 100–500 ft of displacement; faults with less than 100 ft displacement are not generally resolvable but are abundant. Major fault trends include the Potranco and Castroville faults; the Pearson-Lackland-Springs fault trend; the Verstuyft-Concepcion trend; and the antithetic Alta Mesa Fault.

The variation in regional dips and tilting is remarkable. The Culebra Anticline is well expressed in the northwest part of the area, and excellently shown by air photos. A more subtle anticlinal structure trends southwest from downtown towards Lackland, which Sellards (1919) called the 'San Antonio structure.' In general, fault blocks northwest of the Concepcion Fault System tend to be nearly flat-lying, and dip as often northwest as southeast (Fig. 8). The Fairfield area (south of the Medina River in the southwest part of the area) is nearly flat; surface outcrops of the basal Wilcox mantle a broad area but are very thin. Southeast of the Concepcion fault, dips are steadily southeast at 120–150 ft/mi; dips of 135 ft/mi are observed in Poth strata northwest of the Alta Vista Fault.

The downdip limit of fresh water in the Edwards Aquifer runs along the Verstuyft-Concepcion Fault Zone across the area. The prolific water wells of the 'Living Waters Catfish farm' and the Mission well field lie just northwest of this line; warm sulphur water is produced just to the south at Hot Wells.

QUATERNARY DEPOSITS

Quaternary terraces and other alluvial deposits form the principal geomorphic elements in the belt of mudstones south and east of the Culebra Anticline; they are more abundant than shown on the surficial map (Fig. 9). The highest terraces are underlain by highly calichified chert gravel with uncommon pisolitic sand and finer-grained deposits; these are correlated with the Uvalde gravels to the west and the Lockhart gravels to the northeast, and could be either Pliocene or early Pleistocene in age. They are preserved in discontinuous linear belts, probably representing the oldest river systems known in the area. A major belt occurs east of the San Antonio River beneath Fort Sam Houston and the Cemetery district, another near Lackland, and a third paralleling Medio Creek across the Culebra Anticline.

Very extensive terraces of gravel, sand and silt lie at somewhat lower elevations and cover much of the outcrop area. These include flat terrace surfaces loosely associated with present streams, and low-gradient alluvial fans; they are probably Pleistocene in age. An extensive, nearly flat surface lies east of Salado Creek. On the San Antonio River, the Alamo terrace includes an old spring deposit, the Concepcion tufa, at Mission Concepcion; that mission and San Jose were constructed of rock quarried from the tufa. West of the river, a broad low-gradient fan is present, extending southeast from Leon Creek and underlying much of west San Antonio; its eastern end contains pisolitic gravels and other calcareous rocks that were used in construction of some missions. Smaller fans are present south of the Culebra Anticline highlands west to Castroville. An enigmatic intermediate surface occurs in the southwest part of the area; this flat 'Natalia surface' has clay soils but is underlain by sandy basal Wilcox.

Lower terraces are closely related to present river systems. An extensive sand-rich terrace occurs along the Medina River and is up to 65 ft thick; the materials of this 'Applewhite terrace' were deposited mainly during early and middle Holocene time (13,000 to 4000 ^{14}C years before present; Thoms and Mandel, 2007). It is trenched by the present course of the Medina River and its active floodplain.

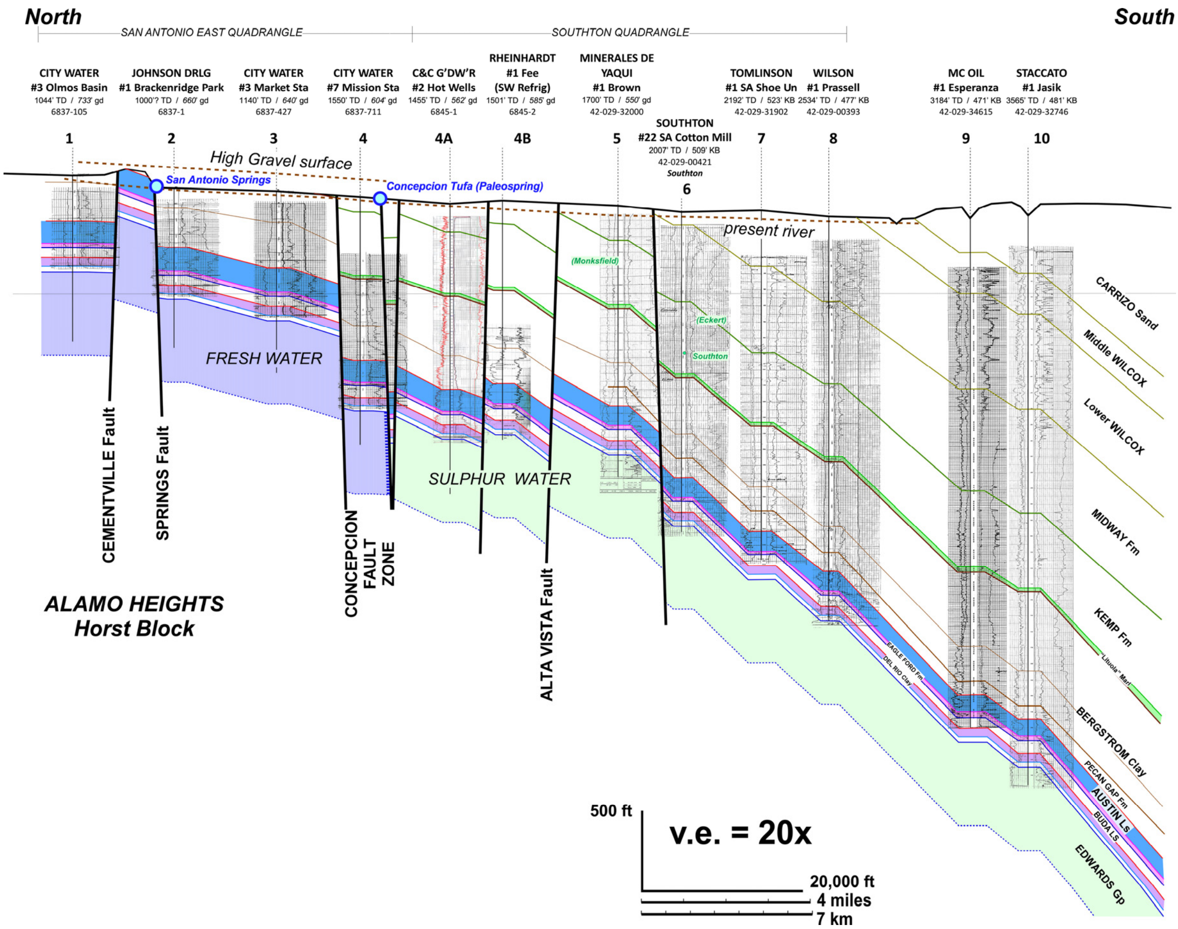

Figure 8. N–S structural section along the San Antonio River valley, showing Balcones faults, southeast dip, and location of San Antonio springs and Concepcion paleospring. Location of section on Figure 4.

CONCLUSIONS

Integrated surface and subsurface mapping was successful at creating detailed and useful maps of the San Antonio area. Similar techniques should be used wherever subsurface data is sufficient to allow it. Subsurface data allow recognition of faulting and estimation of contacts; lateral stratigraphic variations can be observed with both surface and subsurface observations.

The mapping advances our understanding of the human history of the San Antonio area. The Spanish missions, as well as military and civil settlements, were entirely dependent on their local environment. The building materials were locally derived: the Austin limestone used for fine carving at the upper missions came from quarries near San Antonio Springs, while tufa from Concepcion was used for building in the middle missions, and the lower (southern) missions used Wilcox sandstone and pisolitic gravel from the Leon Creek fan. Austin building stone continued to be used until the arrival of the railroad in 1877.

Resources of groundwater are greatly affected by the outlined fault trends. In particular, the role of hypogene dissolution near the downdip limit of fresh water has been debated; the associ-

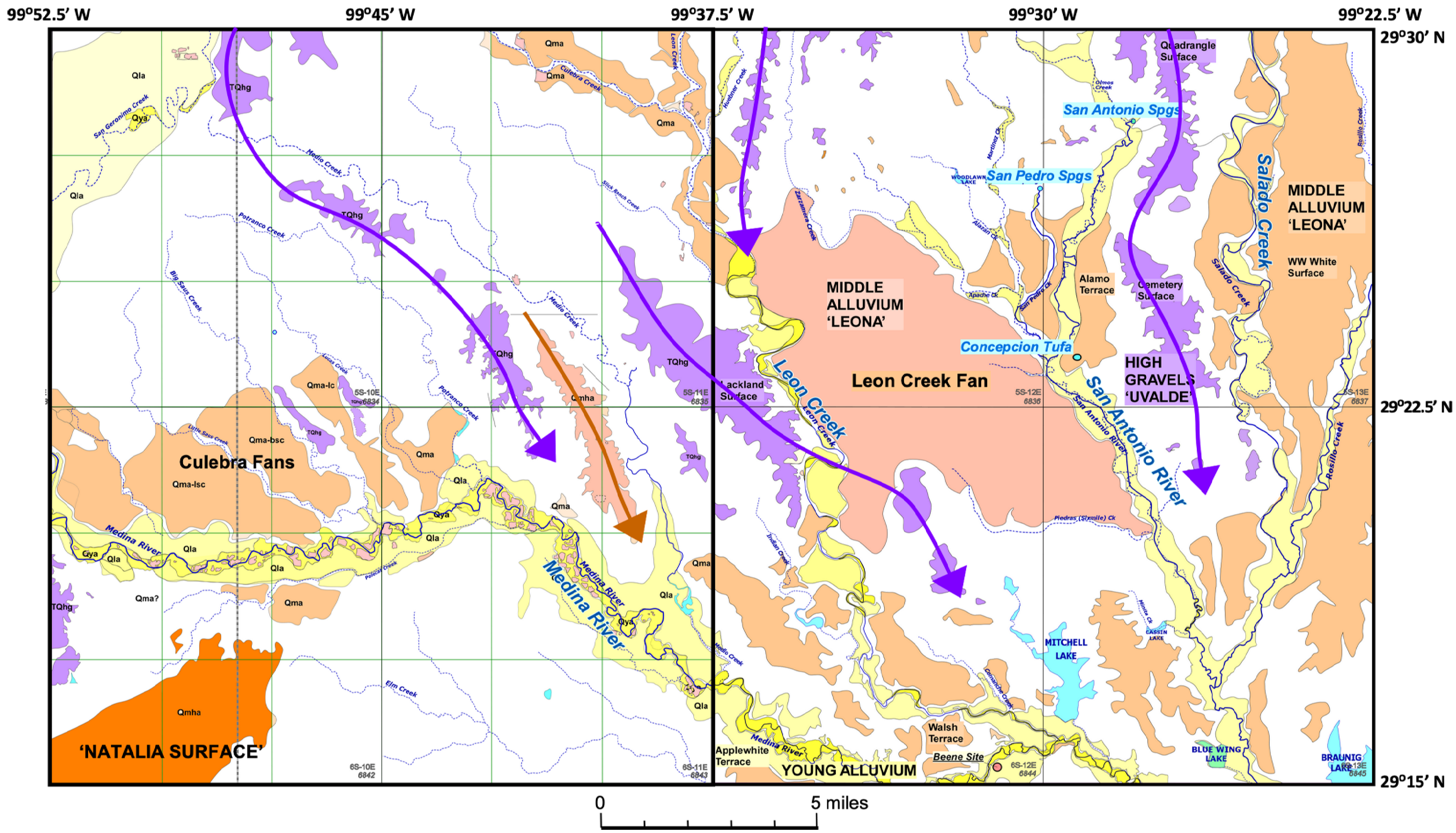

Figure 9. Map of Quaternary geology, showing high gravels (purple), middle alluvium (orange), and lower alluvium (yellow). Some inferred fluvial axes shown; springs in blue.

ation with the Concepcion fault system may bear on this. Resources of oil and gas can also be placed in context.

Continued urban and industrial development is affected by geological and geotechnical considerations. The abundant clay soils derived from the mudstone and marlstone units provide poor foundations for buildings and roads, with profound shrink/swell behavior, buckling and settlement. Where Quaternary terrace materials mantle the mudstone, better shallow foundations can be laid. Areas of Wilcox sandstone and hard limestone (Austin, Anacacho) yield firmer soils that are better for permanent foundations.

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