

Preliminary Geologic Map of the San Antonio SE Quadrangle, Socorro County, New Mexico (Year 1 of 1-Year)

By

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Open-file Digital Geologic Map OF-GM 228

Scale 1:24,000

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PRELIMINARY GEOLOGY OF THE SAN ANTONIO SE QUADRANGLE, SOCORRO COUNTY, NEW MEXICO

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INTRODUCTION

The San Antonio SE quadrangle lay along the Rio Grande in Socorro County, New Mexico, 4.5 km south of the town of San Antonio. It includes much of the current Rio Grande (RG) floodplain, much of the western piedmont of the Cerro de la Campana (CdIC) hills to the east, and an intervening escarpment exposing ancestral Rio Grande sediments of the Plio-Pleistocene upper Santa Fe Group. The land is mainly Bosque del Apache National Wildlife Refuge (BdA NWR, or simply the Refuge) land, with lesser Antelope Wells Wilderness Study Area (AW WSA) land and BLM land. As a result, land use and access are both highly restricted, with research permits necessary to work on the BdA NWR, and few roads through both the Refuge and the AW WSA. In addition, the White Sands Missile Range (WSMR) lay immediately east of the southern half of the quadrangle, further impeding access. Improved dirt county roads run along the eastern and southern perimeter of most of the quadrangle, as well as along the eastern side of the floodplain on the BdA NWR, and a few unimproved dirt roads reach into the quadrangle from these.

Geologically, the San Antonio SE quadrangle lay within the Rio Grande rift geologic province, an area of late Cenozoic east-west extension. The rift is composed of several roughly north-south extensional basins that filled with sediment derived from adjacent highlands, termed the Santa Fe Group (Baldwin, 1963; Hawley et al., 1969). The quadrangle lay at the south end of the Plio-Pleistocene Socorro basin, and the only geologic units exposed on the quadrangle itself are sediments of the Plio-Pleistocene upper Santa Fe Group and post-Santa Fe Group alluvium and eolian sand sheets.

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UPPER SANTA FE GROUP SEDIMENTS

Volumetrically, sediments of the Plio-Pleistocene upper Santa Fe Group (uSFG) are the dominant sediments exposed on the quadrangle. These consist of pebbly sands and muds of the ancestral Rio Grande (ARG, unit QTsf) and sandy gravels of the Plio-Pleistocene piedmont of the CdIC hills (QTsp). These sediments are correlative to the Sierra Ladrones Formation to the north (Machette, 1978) and to the Palomas Formation to the south (Lozinsky and Hawley, 1986).

The pebbly sands and muds of the Plio-Pleistocene ARG (QTsf) dominate the uSFG of the quadrangle. These deposits are distinguished by the presence and abundance of 'exotic' clasts such as granite, chert, quartzite, and obsidian, which are only locally exposed in the nearby highlands. Such clasts are mostly derived from mountains far to the north, such as the Jemez and Taos Mountains, and carried into the quadrangle by the ARG. These pebbles are often associated with light gray quartz and chert-rich cross-bedded sandstones, interpreted as ARG channel deposits. Greenish-gray, clay-rich mud deposits also distinguish ARG deposits, but are rarely exposed. This unit also includes beige or pale brown sandy siltstones. Where ARG sediments are not exposed at the surface, the trend of the ARG can be inferred from the presence of exotic clasts at the surface, as these lithologies are found only in ARG sediments on the quadrangle, and their presence at the surface indicates that the ARG flowed through that area at some point in the past.

Also of the uSFG on the quadrangle are sandy gravels exposed in the northeast corner derived from the CdIC area in the Pleistocene (QTsp; Figure 1). The old age of these gravels is indicated by the extremely well-developed soil present at the top of the deposit, characterized by a Stage V carbonate horizon (Gile et al., 1965; Machette, 1985). Such a well-developed soil is common to the top of the uSFG in the southern portion of the rift (cf., Gile et al., 1981; Chamberlin et al., 2002; Cather, 2002), and indicates that the underlying sediments belong to the uSFG. These gravels are dominated by clasts of andesitic lava of various textures, including aphanitic and plagioclase \pm pyroxene \pm amphibole porphyries. Lesser amounts of Paleozoic limestone and red siltstone clasts and Mesozoic quartz sandstone clasts are also present, possibly reworked from the Baca Formation exposed locally in the CdIC area. These sediments are only locally exposed, but are inferred to underlie the highest ridges in the CdIC piedmont.



Figure 1 - Exposure of the cobble conglomerate QTsp cemented by pedogenic carbonate. A trench nearby exposes the top of the carbonate horizon, revealing the laminar top and fracturing associated with a Stage V carbonate horizon.

The trend of exotic clasts preserved at the surface shows that the eastern margin of the ARG swings eastward in the southern half of the quadrangle. This is consistent with the presence of ARG sediments in the northern Jornada del Muerto basin to the southeast, and observations by R. Myers (pers. comm.) that ARG sediments can be found all around Sand Mountain, which lay immediately east of the southeastern corner of the quadrangle. The importance of this observation is that while the ARG is largely constrained to a single basin to the north in the Albuquerque and Española basins, to the south the ARG can be seen to spillover into several basins (cf., Mack, 2004), and the transition in styles may start within this quadrangle.

POST-SANTA FE SEDIMENTS

Pleistocene to recent Rio Grande sediments

All along the current RG are late Pleistocene to recent sediments of the RG, heavily modified by farming and land management associated with the Refuge. Based on surface textures, vegetation densities, and repeat aerial imagery, these sediments can be delineated into several different aged units; here, I distinguish six, based on imagery from 2005 and 2009; previous workers have delineated more based on imagery from 1935 and 2001 (Pearce and Kelson, 2003).

Older middle Pleistocene ARG sediments (Qfo) are locally present as isolated high terrace deposits along the escarpment that traverses the quadrangle from the north central of the quad to the southwest corner. Unfortunately, the similarity of the post-Santa Fe ARG sediments to the uSFG ARG sediments precludes distinguishing the two through much of the quadrangle, especially where the eolian sand sheets have blanketed the escarpment. But in areas of good exposure, unconsolidated sandy pebbles and pebbly sands overlying moderately to well consolidated muds and sandstones are interpreted as middle Pleistocene terraces (Figure 2), and occur at heights of about 24-30 m and 38-41 m above the current RG channel, possibly correlating to the 27-m and 38-m terraces of McCraw et al. (2006), although the 24-30 m terrace here is not nearly as thick as their 27-m terrace.



Figure 2 - Exposure of Qfo deposits overlying QTsf siltstones and sandstones. Qfo underlies the light gray slopes above the beige siltstones.

I suggest that, based on the parallel trend of the escarpment to the trend of the current RG, the escarpment is principally an erosional feature, cut by meandering of the middle to upper Pleistocene ARG. Alternatively, the escarpment may be fault controlled. No deformation is apparent in the sandstones exposed along the escarpment, however, as might be expected if they lay along a substantial fault.

Non-Rio Grande alluvium

Two categories of alluvium are distinguished here: tributary alluvium derived from the escarpment (Qa_) and tributary alluvium from the CdIC hills (Qp_). These are kept separate as poor exposure inhibits accurately correlating units by age. The escarpment alluvium is composed of pebbly silty sands with compositions comparable to the underlying ARG sediments. Most of this alluvium is mapped as an undivided Holocene bajada (Qayb), but locally an older unit is distinguished based on topography (Qay1) and a younger unit distinguished by being inset upon the bajada (Qay2). Each of these units has similar sediments and relatively weak soils (up to Stage I carbonate horizons in Qay2 and Qayb, up to Stage II in Qay1).

Alluvium from the CdIC hills to the east of the quadrangle is divided into younger (Qpy) and older (Qpo) alluvium based on topography and soil development. The younger alluvium typically has lighter colors and only up to Stage I carbonate horizon development, while the older has browner colors and up to Stage II carbonate horizon development (Figure 3). Both are variably buried by eolian sand sheets, particularly the alluvium along the southernmost drainage, which interacts directly with the younger sand sheet. These eastern drainages typically end in silt-dominated surfaces that are sparsely vegetated (Qpm). As mapped here, they are treated as distal alluvium, where very thin flows carry and accumulate very fine sediment. Alternatively, however, these silts may be local exposures of the underlying uSFG, as pale silt deposits are found interbedded with the ARG deposits. These deposits do not exhibit any signs of a strongly developed soil, however, as is seen in the uSFG piedmont deposits in the northeast corner of the quadrangle.

Eolian sediments

The aerially most significant units on the quadrangle are the two Holocene sand sheets burying both uSFG sediments and some post-SFG alluvial units. Two ages of sand sheet are identified, based on color and small-scale topography. The older sand sheet (Qes1) has a light brown to light reddish brown color at least at the top of the unit from weak soil development (Figure 4). It also has very subdued small-scale topography, which I interpret to reflect smoothing of the surface through time since stabilization of the sand sheet. The younger sand sheet (Qes2) has a very pale brown color, suggestive of no soil development, and greater small-scale topography as blowouts (Qeb) and blowout sand dunes (Qebs), broad ridges of eolian sand oriented transverse to the prevalent wind direction (Qesr), and low narrow ridges of eolian sand oriented parallel to the prevalent wind direction, which are mapped as lines. The younger sand sheet dominates in the south, and I suggest it is prograding over the older sand sheet. This is supported by the local presence of light brown sands at the base of hollows in the very pale brown younger sand sheet, suggesting the older sand sheet underlies the younger sand sheet in the south.

Very pale brown sands also appear to be prograding over alluvium associated with the southernmost drainage from the east.

Mineralogically, both sand sheets contain abundant quartz, suggesting derivation from ARG or younger RG sediments.



Figure 3 - Arroyo cut exposing a thin section of Qpy over Qpo. Qpy is the very pale brown sediment at the top of the outcrop, extending down to about mid-handle. Browner sediments with Stage II carbonate horizon development is Qpo



Figure 4 - Exposure of older sand sheet, Qes2, in arroyo cut. Note strong reddening, that grades downward into beige colors, indicating coloration is related to soil development. Here, Qes2 is capped by Qpy.

STRUCTURE

Structure is very poorly exposed on the San Antonio SE quadrangle. In fact, only the Cemetery fault is truly exposed on the quadrangle; all other faults are projected from neighboring quadrangles or inferred from topography.

The largest fault with known offset is the Fite fault of Cather (2002), which must cut through the very northeast corner of the quadrangle to connect exposures of the fault to the north and east. This fault juxtaposes Mesozoic sediments against Plio-Plietocene uSFG sediments, and serves as the eastern boundary for the southern Socorro basin. The Mike Well fault at the south end of the quadrangle may have comparable or even greater offset, but its offset is uncertain. The fault underlies a tall (10 to 30+ m) north-facing scarp at the south end of the quadrangle (Figure 5), which itself appears to be offset by north-trending faults. The Mike well, which lay immediately south of the quadrangle on the footwall of the Mike Well fault, may terminate in the Permian Yeso Formation (Roybal, 1991), but this does not appear to be certain (Weir, 1965). It is certain that the Yeso Formation rises to the surface across a parallel fault ~2.5 km to the south of the Mike Well fault (Geddes, 1963), however, and it is possible that the two faults are a part of a zone across which the Paleozoic system gradually rises. If the Mike well does terminate in the Yeso, then the Plio-Pleistocene in the footwall of the fault is only ~90 m thick.



Figure 5 - Scarp of the Mike Well fault, with Little San Pascual Mountain in the background. Picture looks southwestward. The scarp may uplift the Permian Yeso Formation to within 90 m of the surface, while another fault lying along the north side of Little San Pascual Mountain uplifts the Yeso as well as underlying Abo Formation and Madera Limestones to the surface (Geddes, 1963).

Locally, in the area of the Cemetery fault, contorted bedding is found in uSFG ARG sandstones, suggestive of soft sediment deformation (Figure 6). This contorted bedding is found nowhere else on the quadrangle, although admittedly the exposure is so poor that it could be more common than is observed. That the contorted bedding is clustered around the Cemetery fault suggests that the soft sediment deformation is a product of liquefaction from earthquakes along the fault, which would indicate that slip was syn-depositional.

Other faults are suggested from low but continuous scarps, and by a pattern of narrow ridges in uSFG ARG sediments at the southwestern end of the quadrangle. The north-northeast trending fault at the southwestern corner of the quad is projected into this quadrangle from the Little San Pascual Mountain quadrangle to the south.



Figure 6 - Cross-bedded sandstones of the upper Santa Fe Group ancestral Rio Grande facies, contorted by soft-sediment deformation. Picture taken near the Cemetary fault.

UNIT DESCRIPTIONS

Post-Santa Fe Group units

Artificial units

af **Artificial fill** (Historic, 0-100 yrs BP): Compacted gravel, sand, silt, and clay composing artificial channels and dams. Only used for larger channels. 0-3 m thick.

Rio Grande fluvial alluvium

Rw **Water** (Active, as per 2009 aerial imagery): Active channel of the Rio Grande. Composed of water, sand, silt, and rare gravels. Includes small sand bars. 0-2 m thick.

Rsb **Sand bar** (Active, as per 2009 aerial imagery): Active sand bars of the Rio Grande. Composed of sand, silt, and rare gravels. 0-2 m thick.

Rf **Recent fluvial deposits** (Recent, 2005 to 2009): Recent sand, silt, and rare gravels of the Rio Grande. Water and unvegetated alluvium in 2005 imagery, poorly vegetated in 2009 imagery. 0-2 m thick.

Hmf **Modern fluvial deposits** (Modern, 2001 to 2005): Sand, silt, and rare gravels of the Rio Grande. Poorly vegetated in 2005 imagery, generally well vegetated in 2009 imagery. Maps by Pearce and Kelson (2003) suggest this was active alluvium in 2001. 0-2 m thick.

Hf **Historic fluvial deposits** (Historic-modern, 1935-2001): Sand, silt, and rare gravels of the Rio Grande. Generally well vegetated in 2005 and 2009 imagery, with scroll bar textures apparent in vegetation banding. Maps by Pearce and Kelson (2003) suggest this was active alluvium in 1935. 0-2 m thick.

- Qfy** **Young fluvial deposits** (Holocene to Historic): Sand, silt, and lesser gravels of the Rio Grande underlying the present floodplain level. Surface generally modified by agricultural or conservational land management, inhibiting further reliable division. Where undisturbed, bears weak scroll bar textures. No significant soil development. 0-2 m thick.
- Qfi** **Intermediate fluvial deposits** (upper Pleistocene?): Sand, silt, and lesser gravels underlying a continuous terrace with tread 3 to 6 m above the active channel. Moderately vegetated in 2005 and 2009 imagery, with weak scroll bar textures. 0-6? m thick.
- Qfay** **Intermediate fluvial deposits, overlain by tributary bajada sediments** (upper Pleistocene to Holocene): Intermediate fluvial deposits overlain by thin tributary alluvium and lesser eolian sands. Generally looks like **Qayb** at the surface, but with weak meander scroll textures apparent on aerial imagery suggesting a fluvial component to the underlying deposit. See descriptions of **Qayb** and **Qfi** for more details.
- Qfo** **Older fluvial deposits** (middle Pleistocene): Pale brown silty fine to coarse sands and gravels of isolated terrace remnants with straths 24 to 41 m above the current Rio Grande channel. Poorly preserved and exposed, likely more common than mapped but obscured by sand sheets and similarity to underlying **QTsf**. 10YR 8/3 color measured, clots of sand cemented by K fabric at surface of higher deposits may be the remains of a Stage III or greater carbonate horizon. 2-10 m thick.

Tributary alluvium

- Qa_** **Tributary alluvium** (upper Pleistocene to Holocene): Sand, silt, and rare gravels of streams that reach the Rio Grande floodplain. Divided into units based on grain size, morphology, and age inferred from landscape position and relative soil development. Most **Qa_** derived from a SSW-trending escarpment that spans the quadrangle; in the northwest corner, some alluvium is derived from the Chupadera Mountains to the west, and this alluvium is significantly more gravel-rich than the escarpment-derived alluvium. Surface sediments of all **Qa_** units are significantly reworked or partially buried by eolian processes.
- Qah** **Historic tributary alluvium** (upper Holocene? to Historic): Pale brown silty, pebbly fine to medium sand with rare pebble channels. Includes alluvium that is inset upon by up to 1 m by active channels. 10YR 7/4 to 6/4 colors measured, no carbonate accumulation. 0-1 m thick.
- Qaf** **Historic tributary gully-mouth fans** (upper Holocene? to Historic): Pale brown silty, pebbly fine to medium sands. Map unit applies to small fans at the terminal mouths of current channels. No significant soil development. 0-1 m thick.
- Qam** **Mud-rich tributary alluvium** (Holocene to Historic?): Pale brown sandy silts. Found locally at the terminus of some streams. May be the top of an older unit, locally exposed by erosion. No evidence of significant soil development. 0-1? m thick.
- Qay2** **Younger tributary alluvium** (Holocene): Light brown silty pebbly fine to medium sands with rare coarse sand channels. Alluvium composes terraces with treads 1.5 to 2 m above local active channels, inset upon the top of **Qayb**. Typical

color 10YR 6/4, with 7.5YR 7/4 Bw horizons, and up to Stage I Bk horizons. 0-3 m thick.

Qayb Bajada of young tributary alluvium (upper Pleistocene? to Holocene): Pale brown silty fine sands with sparse pebbles. Alluvium composes a bajada of small fans emanating from the escarpment, with a surface that is inset upon by **Qay2** and is overlain by that of **Qay1**. Sparse outcrop, but soil development appears comparable to **Qay2** (up to Stage I Bk, slightly reddened Bw). Color of 10YR 6/4 measured. 0-3 m thick.

Qay1 Older tributary alluvium (upper Pleistocene): Pink muddy fine to medium sands with sparse pebbles. Very poorly exposed, but appears to be thin alluvial deposits that are inset upon by **Qayb** and **Qay2**, with surface treads 3 to 7 m above local active channels. Small gullies reveal muddy fine to medium sands with color of 10YR 7/3, up to Stage II carbonate morphology, and up to Stage I gypsic morphology. 0-3? m thick.

Piedmont alluvium

Qp_ Piedmont alluvium (upper Pleistocene to Holocene): Sand, silt, and gravels of streams that do not reach the Rio Grande floodplain. Generally divided into units based on grain size, morphology, and age inferred from landscape position and relative soil development. Alluvium is mainly derived from the Cerro de la Campana-area to the immediate east of the quadrangle. Surface sediments of all **Qp_** units are reworked by or variably buried by eolian processes.

Qph Historic piedmont alluvium (upper Holocene? to Historic): Very pale brown sand, silt, and gravels of active stream channels, including low terrace levels with treads up to 1 m above the channel. Generally moderately to strongly bedded with no soil development. Channel sediment is poorly sorted and gravel-rich, dominantly of various andesitic lithologies, with a medium to coarse sand matrix. Extra-channel sediment is silty fine to medium sands with sparse pebbles. Colors of 10YR 7/3 to 8/2. 0-1.5 m thick.

Qpf Piedmont gully-mouth fans (Holocene to Historic): Pale brown silty, pebbly fine to coarse sand associated with the terminations of current channels and gullies. Unexposed, but surfaces suggest the deposit is mainly silty sand with up to 30% pebbles of mainly andesitic lithologies. Sand is lithic- and plagioclase-rich. Colors of 10YR 6/4 to 7/3 measured. No evidence of significant soil development. 0-1 m thick.

Qpm Mud-rich piedmont alluvium (Holocene to Historic): Pale gray to light reddish brown sandy clayey silts at the terminations of eastern streams. Finely laminated deposits with up to Stage I carbonate horizon development, with carbonate restricted to rhizoconcretions. Redder (5YR 5/4 to 6/4) in the north, grayer (10YR 7/2) in the south. May be the top of an older unit, locally exposed by erosion. 0-1 m thick.

Qpy Younger piedmont alluvium (Holocene): Pale to light brown silty sands and local pebbly paleochannels. Moderately laminated bedding to massive, with up to Stage I carbonate horizon development. Gravels are almost exclusively andesitic lithologies, and sands are lithic- and plagioclase-rich. Alluvium underlies terrace treads 1 to 3 m above local channels. As mapped, **Qpy** includes an erosional

surface with indistinguishable tread height and comparable underlying sediments that are 0.25-0.5 m thick that cannot be reliably mapped separately due to poor exposure. Colors of 10YR 5/3 to 8/3 measured. 0-2 m thick.

- Qpyh** **Younger and historic piedmont alluvium, undivided** (Holocene to Historic): Deposits of **Qpy** and **Qph** combined to fit the map scale. See individual descriptions of these units for details.
- Qpye** **Younger piedmont alluvium overlain by thin younger sand sheet** (Holocene to Historic): Younger piedmont deposits overlain by variable thicknesses (up to 2 m) of **Qes2**-like eolian sand. See description of **Qpy** and **Qes2** for more details.
- Qpo** **Older piedmont alluvium** (upper Pleistocene?): Light brown silty clayey pebbly fine to medium sands with carbonate and gypsum accumulation. Very poorly exposed, but appears to be massive with 5-15% fine pebbles with common carbonate coats, with a light brown color mottled white and pale yellow by carbonate and gypsum. Up to Stage II carbonate horizon morphology, Stage I gypsum horizon morphology. Alluvium underlies surfaces that are inset upon by **Qpi** and **Qpy** and are 3 to 5 m above the local channels. 0-5? m thick.
- Qpe** **Piedmont alluvium, undivided, overlain by thin younger sand sheet** (upper Pleistocene to Holocene): Older and intermediate piedmont alluvium overlain by variable thicknesses (up to 2 m) of **Qes**-like eolian sand. See descriptions of **Qp** units and **Qes2** for details.

Eolian and slopewash units

- Qsa** **Slopewash alluvium** (Holocene): Light reddish brown fine sandy silts to silty sands filling broad shallow swales. Very poorly exposed, but surface sands are lithic- and plagioclase-rich, with rare potassium feldspar and rare to common quartz, and bear rare fine to medium pebbles of andesitic composition. 5YR 6/3 to 7.5YR 6/4 colors measured. 0-1? m thick.
- Qebs** **Eolian blowout sands** (upper Holocene): Light yellow clean fine sands at the downwind sides of blowouts. Blowout sands occur as low, commonly poorly vegetated, parabolic. Sands are moderately sorted and subrounded to rounded, with roughly subequal proportions of quartz, potassium feldspar, plagioclase, and lithics. 7.5YR 7/4 to 10YR 7/4 colors common, with a redder 7.5YR 5/4 color in the southwest corner, immediately downwind of a large outcrop of red sandstones (off quad to south). 0-4 m thick.
- Qeb** **Eolian blowouts** (upper Holocene): Deflationary hollows, included on map to show upper Holocene prevailing wind direction, in conjunction with downwind blowout sands. Only map-scale blowouts are shown. No thickness, as these are mainly erosional features.
- Qesr** **Eolian broad sand ridges** (upper Holocene): Pale brown clean fine sands composing map-scale topographically high bands. Sands are moderately sorted, subrounded to rounded, with abundant grains of quartz, common lithics and potassium feldspar, and lesser plagioclase. Colors of 10YR 6/4 to 7/4 measured. Appears to be local preferential accumulations of the **Qes2** sand sheet. 0-4? m thick.
- Qec** **Eolian coppice dunes** (upper Holocene): Very pale brown clean fine sands composing low dunes accumulating around bushes. Sands are moderately sorted,

- subangular to rounded, with common grains of lithics, plagioclase, potassium feldspar, and quartz. Coppice dunes are 0.5 up to 1.5 m tall relative to barren interdunal areas. No soil development. 0-1.5 m thick.
- Qes2 Younger eolian sand sheet** (upper Holocene): Very pale brown silty to clean, fine to medium sands. Moderately to poorly sorted, subangular to rounded sand grains of abundant quartz and lithics, and rare to common potassium and plagioclase feldspars. No evidence of soil development. Colors of 10YR 6/4 to 7/4 common, with local colors of 7.5YR 6/4 to 7/3. Common relatively low relief eolian surface textures, including small (4 to 10 m diameter) to map-scale (map unit **Qeb**) blowouts, linear ridges and scarps that parallel the prevailing wind direction, and small coppice dunes. Locally, browner, **Qes1**-like sands can be found just below the surface in topographic lows, suggesting **Qes2** is burying **Qes1**. 0-6? m thick.
- Qes1 Older eolian sand sheet** (upper Pleistocene? to lower Holocene): Light brown to brown to locally light reddish brown silty fine to medium sands. Moderately to poorly sorted, subangular to rounded sand grains of abundant quartz, common lithics, and rare to common potassium and plagioclase feldspars. Up to Stage I+ carbonate horizon development with a reddened (5YR 5/4 to 5/6) Bw horizon. Colors of 7.5YR 5/4 to 7.5YR 6/6 measured at the surface. Generally only minor eolian surface textures, including some coppice development and vague prevailing wind-parallel lineations on aerial imagery. 0-1 m thick.
- Qes/_ Sand sheet, undivided, over older sediments:** Used to delineate areas where an older unit is suspected to be found <0.5 m below a surface cover of eolian sands. Evidence used to support this include common thick carbonate coats on gravels at the surface or in animal burrows, common fragments of white carbonate horizon at the surface or in burrows, exposure of the older sediments nearby, and relative landscape position of the sand sheet-buried surface. The burying sand sheet can fit the description of either the older or younger sand sheet.

Upper Santa Fe Group units

Equivalent to the Sierra Ladrones Fm to the north and Palomas Fm to the south

QTsf Upper Santa Fe Group, fluvial facies (Pliocene to lower Pleistocene): Light gray pebbly sandstones, pale brown siltstones, and light greenish gray mudstones of the ancestral Rio Grande. Sands are moderately to poorly sorted, silty to clean, subrounded to rounded, with abundant quartz, common lithics, rare potassium feldspar, and sparse plagioclase. Rare fine pebbles are mainly chert, with lesser granite, intermediate to felsic volcanics, and quartzite. Thickness unknown, but at least 60 m of sediments are exposed; a water well by Socorro penetrated 340 m of QTsf (Chamberlin, pers. comm.).

QTsp Upper Santa Fe Group, piedmont facies (Pliocene to lower Pleistocene): Pale brown to white conglomerates. Poorly exposed, but typically a cobble conglomerate along the east edge grading to a pebble conglomerate to the west. Gravels are poorly sorted, angular to subrounded, and mainly of andesitic porphyry compositions, with sparse red siltstones and limestones. The top is marked by a Stage IV or V carbonate horizon that is exposed along the east edge of the quadrangle. Thickness unknown, but likely comparable to **QTsf**.

Pre-Santa Fe Group units

Cross-section only. Mesozoic strata projected from Cather (2002, 2007); Presence of Permian Yeso Group at depth suggested by Weir (1965) and Roybal (1991).

Kgc **Cretaceous Gallup Sandstone and Crevasse Canyon Formation** (lower Coniacian to Santonian?)

Kmd **Cretaceous D-Cross Tongue of the Mancos Shale** (upper middle Turonian to lower Coniacian)

Kth **Cretaceous Tres Hermanos Formation** (middle Turonian)

Kml **Cretaceous lower part of the Mancos Shale** (middle Cenomanian to lower Turonian)

Kd **Cretaceous Dakota Sandstone** (middle Cenomanian)

Ru **Triassic rocks, undivided**

Gap in rocks presented in cross-sections; gap is not necessarily present in deep subsurface across the quadrangle.

Py **Permian Yeso Group** (Leonardian)

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