Geologic Map of the Abeytas Quadrangle, Socorro County, New Mexico

By

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Open-file Digital Geologic Map OF-GM 121

Scale 1:24,000

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ABSTRACT

The Abeytas Quadrangle covers the junction between the Rio Puerco and Rio Grande at the south end of the Albuquerque Basin. Rift-related Plio-Pleistocene basin fill of the Santa Fe Group exposed in the Abeytas Quadrangle came from four sources: the Rio Grande from the north, Abo Pass and Los Pinos uplift to the southeast, Rio Puerco and Rio San Jose from the northwest, and Rio Salado from the southwest. Quaternary post-basin-fill episodic entrenchment of the Rio Grande is shown by three major fluvial terraces preserved on the eastern side of the Rio Grande valley and by a correlative high terrace along the Rio Puerco. Local tributaries formed several inset levels of alluvial terraces in response to climate change and episodic downcutting and lateral planation by the Rio Grande. Thick valley fills of the Rio Grande and Rio Puerco are the hallmark of both major streams in this area. Several north-trending Quaternary faults displace deposits from less than one to more than 10 m. The Sabinal fault dies out southward in a monoclinal structure. The West Ceja fault dies out southward as the hanging wall becomes a ramp and joins the footwall at the same elevation. The newly-discovered Contreras Cemetery fault offsets the lowest Rio Grande terrace by 2 to more than 4 m and was active at the time of terrace deposition.

INTRODUCTION

The Abeytas Quadrangle lies in central New Mexico about 50 miles south of Albuquerque along the Rio Grande and Interstate 25. The area covered by the quadrangle, which extends from 34°22’30”N to 34°30’N and 106°45’W to 106°52’ 30”W, is approximately 158 km^2 (61 mi^2). Elevations range from approximately 1,436 m

(4,710 ft) where the Rio Grande flows out of the quadrangle to the south to the highest point on the southern Llano de Albuquerque, 1,564 m (5,132 ft). Villages located in the quadrangle are Abeytas, Bernardo, Contreras, Las Nutrias, Sabinal, and San Francisco.

The southeastern and southwestern map areas fall within the largely roadless Sevilleta National Wildlife Refuge and Long-Term Ecological Research area (Sevilleta LTER), which is closed to the public and requires a research permit for access. Access to the southeastern quadrant of the map is gained through a locked gate east of the town cemetery of Contreras on N.M. Route 304 (formerly N.M. 47 as depicted on the quadrangle's base), but there are no maintained roads beyond the gate. Access to the southwestern part of the area is gained by a gated, unpaved road that heads southwest from a county road southwest of Bernardo, approximately 1 km southwest of the old decommissioned U.S.Highway 85 bridge over the Rio Puerco. Accessibility for the remainder of the quadrangle is quite good via paved roads (Interstate 25, U.S. Highway 60, and N.M. Route 304) and numerous unpaved county roads.

Notable geomorphic features include the Rio Grande and Rio Puerco valleys which meet in southern part of the quadrangle at the confluence of the Rio Puerco and Rio Grande, the southern tip of the Llano de Albuquerque at Picho Hill, the southwestern edge of the extension of the Llano de Manzano, and the northeast edge of the Llano de Salado/Ladrones piedmont (Cliff Surface). The Rio Grande valley is about 4 to 6.4 km (2.5 to 4 mi) wide and 105 to 125 m (roughly 350 to 400 feet) deep with broad, gently sloping valley borders. The Rio Puerco valley is about 3.2 km (2 mi) wide and 90 to 105 m (roughly 300 to 340 ft) deep with broad valley borders.

The Abeytas Quadrangle is in the southern part of the Albuquerque basin, a large structural basin of the Rio Grande rift. The basin narrows to the south into the Socorro constriction of the Rio Grande rift (Kelley, 1977). The quadrangle is above the northeastern margin of the Socorro Magma Body (Sanford and Long, 1965; Balch and others, 1997) and has undergone significant uplift historically (Reilinger and others, 1980; Larsen and others, 1986; Fialko and Simmons, 2001). The area has had a recent earthquake swarm (1989-1990) with the largest quakes of M 4.7 (Sanford and others, 2002). Several faults with Quaternary movement cut deposits in the quadrangle or in the surrounding quadrangles (Kelley, 1977; Machette and McGimsey, 1982; Machette and others, 1998). The COCORP group developed a seismic image of the basin fill, crust, and upper mantle across the southern Albuquerque basin and the Abeytas Quadrangle (Brown and others, 1979; DeVoogd and others, 1988). The deepest oil well in the quadrangle, drilled on the west side of the Llano de Albuquerque, reached a depth of 907.7 m (2,978 ft) and while well-log interpretations suggested Cretaceous rocks at the base of the hole, we consider this very doubtful.

The Rio Grande and the Rio Puerco in this quadrangle have been subjects of USGS Water Resources Division research for more than 40 years (e.g. Nordin, 1963; Friedman and others, in prep.). Davis and others (1994) and Davis and Cross (1994) surveyed reports concerning the Rio Puerco and found more than 1100 citations. It is one of the most sediment-laden streams in the world with a record 680,000 parts per million suspended sediment concentration (Bondurant *in* Nordin, 1963), and while it contributes only about four percent of the water, it contributes almost 72 percent of the sediment to the Rio Grande downstream from the confluence (Gorbach and others, 1996). In recent years, the amount of suspended sediment has declined (Gellis, 1991).

Groundwater exhibits significant changes in chemistry across the quadrangle (Spiegel, 1955; Roybal, 1991) with poor quality, high sulfate water on both margins of the Rio Grande valley.

COMMENTS TO MAP USERS

This quadrangle map has been Open-filed in order to make it available to the public. The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards, and due to the ongoing nature of work in the area, revision of this map is likely. As such, dates of revision are listed in the upper right corner of the map and on the accompanying report. ***The contents of the report and map should not be considered final and complete until published by the New Mexico Bureau of Geology and Mineral Resources.***

A geologic map graphically displays information on the distribution, nature, orientation, and age relationships of rock and surficial units and the occurrence of structural features such as faults and folds. Geologic contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic map are based on field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. Significant portions of the study area may have been mapped at scales smaller than the final map; therefore, the user should be aware of potentially significant variations in map detail. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown everywhere.

The cross-sections are constructed based on exposed geology, and where available, subsurface and geophysical data. The cross sections are interpretive and should be used as an aid to understand the geologic framework and not used as the sole source of data in locating or designing wells, buildings, roads, or other structures.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of either the State of New Mexico or the U.S. Government.

STRATIGRAPHY

All depositional units of the Abeytas Quadrangle are late Neogene in age and include those related to basin fill in the Albuquerque basin and units that post-date the basin fill, either overlying or inset against the basin fill. No pre-Late Neogene bedrock crops out in the quadrangle, but both upper Paleogene and Proterozoic rocks crop out a few miles to the southeast (Myers and others, 1986; De Moor and others, 2005). The basin fill (Santa Fe Group) consists of sediments derived from the basin margins and fluvial sediments from beyond the basin margin transported by larger streams such as the Rio Grande, Rio Puerco, Rio Salado, and Abo and Salas Arroyos. We recognize the following formations of the Santa Fe Group in the Abeytas Quadrangle: Sierra Ladrones axial facies (QTsa), Sierra Ladrones piedmont facies (QTsp), the western fluvial fan facies of the Ceja Formation (Tc) and a western-southwestern mixed fluvial facies of the Ceja Formation (Tcs). The timing of arrival of the Rio Grande in the southern Albuquerque basin is not well constrained. To the north, the Rio Grande was established by 6 million years ago. In the Socorro area and farther south, the Rio Grande became a through-flowing stream in the rift by about 4.5 million years ago. The Albuquerque basin continued to aggrade along the Rio Grande until about 800,000 years ago (Connell and others, 2005). Tributaries are either graded to the top of the basin fill, or are graded to several inset levels between the top and the Rio Grande valley.

Basin fill of the Santa Fe Group.

The lowest exposures on the east side of the Rio Grande consist of partially to well-cemented red to yellowish red (2.5YR4/6 to 5YR5/6) sandstone, siltstone, and claystone, and paler, grayish pink (7.5YR7/2) well-cemented conglomeratic cross-bedded sandstones and less cemented finer-grained planar-low-angle cross-bedded sandstones. These cemented units exhibit dips in various directions on the order of 1 to 4 degrees. The finer-grained cross-bedded sandstone exposures near the present Rio Grande floodplain margin are mapped as QTsa, but their affiliation and provenance are not determined. Some channel-form conglomeratic units contain subangular intermediate volcanic clasts with imbrications to the northwest. The channels are interbedded with red claystone and red eolian (?) sandstones. We lumped these in with QTsp, but some of this unit may be much older because these exposures are reminiscent of Popatosa Formation (Miocene, closed rift basin deposits) northeast of Socorro.

Ancestral Rio Grande deposits included in the basin fill (QTsa) and known as Sierra Ladrones Formation (Machette, 1978a, 1978b; Connell and others, 2005) crop out only on the eastern side of the quadrangle. As summarized above, exposures low on the landscape are extremely rare and may or may not be part of the Rio Grande system or may be part of the pre-Quaternary basin fill. The contact between typical Rio Grande crossbedded pebbly sands and underlying partially indurated red sand, silt and claystones and pinkish gray conglomerates of QTsp is traceable throughout most of the southeastern corner of the map. This is also the base of deposits known to have pebbles of Rabbit Mountain obsidian from the Jemez Mountains ($^{40}Ar/^{39}Ar$ age of 1.428 ± 0.003 Ma; Love and others, 2004) at an elevation of 1,504 m (4,935 ft). The upper surface of QTsa is confined to the highland south of Pino Draw and extends eastward into the Black Butte and Becker SW quadrangles. The aggradational top is preserved at an elevation of about 1,530 m (5,020 ft) beneath piedmont deposits that form the constructional top of the Santa Fe Group (diagonal map pattern of QTsp) in the southeastern part of the quadrangle. The ancestral Rio Grande deposits interfinger with coarse alluvial channel deposits from the east toward the eastern edge of the quadrangle and up section (see cross section B-B') and are mapped as a transitional facies, QTst.

On the west side of the Abeytas quadrangle are deposits we correlate to the Ceja Formation (Tc) farther north in the Albuquerque basin. The Ceja Formation of Connell (in prep., c.f. Kelley, 1977) ranges to 700 m thick near Albuquerque and consists of coarse and fine alluvial deposits derived from the Rio Puerco and Rio San Jose on the west side of the Albuquerque basin. Clasts in the gravel portion of gravelly sand channels in the unit tend to be bimodal, with larger clasts (ranging to small boulders in size) commonly basalt, intermediate volcanic rocks, granite, Cretaceous sandstone, and Miocene chalcedony ("Pedernal Chert"). The smaller pebbles are well-rounded, reworked siliceous clasts derived from Paleogene and Mesozoic conglomerates, early Cenozoic and Cretaceous petrified wood, and Cretaceous pelcypod fossils. The Ceja Formation also includes several intervals of fine-grained sediments cut by steep-sided arroyo-channel-like sediments (Davis and others, 1993). The upper 53 m of the Ceja Formation in the southern Albuquerque basin include obsidian from East Grants Ridge, which traveled down the Rio San Jose drainage (Morgan and others, 2001). This obsidian has a K-Ar age of 3.2±0.3 Ma (Lipman and Mehnert, 1980) so the upper 50 m of the formation is less than about 3 million years old. This age is corroborated by the presence of Blancan fossils in the section, including a Blancan-age horse leg bone (G. Morgan, personal commun., 2006) found near the West Ceja fault on the Abeytas quadrangle during the course of mapping. The Llano de Albuquerque at the top of the Ceja Formation represents the quasi-stable top of aggradation in this part of the Albuquerque basin. Pedogenic calcium carbonate accumulation in the soil of the Llano de Albuquerque is Stage III+ with a thickness on the order of 1.5-2 m.

On the southwest edge of the Abeytas quadrangle and in adjacent quadrangles to the west and south, fine-grained (fine sand, silt, and clay) alluvium and pebbly to bouldery sand channels are stacked in a set of units at least 150 m thick. Large angular and subangular cobbles and boulders of Precambrian igneous and metamorphic rocks, Paleozoic limestone, Paleogene volcanic rocks derived from the Rio Salado and Sierra Ladrones are added to obsidian from Grants and the regular suite of pebbles of the Ceja Formation. We map these exposures as Ceja Formation with a Salado component (Tcs), but recognize that this additional facies with sediment contributions from the west may warrant a separate formation name. The top surface of these deposits was termed the Cliff

Surface by Machette (1978b). We suspect that there is more than one surface west of our quadrangle, so we suggest the addition of the Llano de Salado and Ladron piedmont surfaces.

Major River Terraces.

In the Abeytas quadrangle, three terraces of Rio Grande gravels form discontinuous exposures along the eastern side of the map area and on adjacent quadrangles. As is the case farther north (see description of the terraces in the Albuquerque area below), the top of the basin fill is not considered to be a terrace. All three terraces rest on older basin fill (see cross sections), although the lowest terrace may also rest on earlier terrace deposits at least locally.

The first (highest) Rio Grande terrace-gravel deposit ($Qrgt_1$) ranges from 3 to 13 m thick with a base about 50 m above the Rio Grande floodplain (Figure 1). The ridge

Figure 1. Well cemented trough-crossbedded sandstone of QTsp overlain by gravel of terrace $Qrgt_1$ exposed in Maes Arroyo. Not shown are 15 + m of Maes terrace alluvium Qam_2 overlying $Qrgt_1$.

illustrated in cross section B-B' displays a well-exposed buttress unconformity at the eastern limit of this terrace. The second terrace gravel deposit ($Qrgt_2$) crops out in isolated places, is only 3 m thick, and has a base 38 m above the Rio Grande floodplain. The third level terrace deposit ($Qrgt_3$) is the most extensive, both north-south and laterally from the floodplain east several hundred meters (see cross sections). This terrace's base is just above floodplain level to 29 m above the floodplain (24-27 m thick). Lateral incision of older basin fill during aggradation of this terrace formed a paleo-bluff line (buttress unconformity) that was later overtopped with a laterally more extensive gravel, sand, and floodplain deposit (Figure 2). Where the lower gravel and bluff line are stripped by tributary erosion, they were initally misinterpreted as a fourth terrace level near the margin of the valley. To the east and above the eroded gravel-lag surface, finer sand, silt, and clay of the ancestral river interfinger with alluvium from the eastern tributaries (Qam_2). The tributary alluvial deposits are discussed below.

In the southwestern part of the Abeytas Quadrangle, we found a broad terrace ($Qrpt_1$) about 45-50 m above the Rio Puerco valley floor. Terrace deposits appear to be 3-4 m thick. While these terrace sands and gravels exhibit a Rio Puerco / Rio San Jose provenance, we tentatively correlate this terrace with $Qrgt_1$ on the opposite side of the Rio Grande valley.

North of the Abeytas Quadrangle, Rio Grande terraces in the greater Albuquerque area have been described by numerous workers, most lately by Connell and Love (2001). Each terrace has been given a separate formation name in order to distinguish similar-looking deposits at different geomorphic positions along the valley borders. The highest

Figure 2. Basal exposure of Rio Grande terrace $Qrgt_3$ overlying red sandstone (note small uncovered area to the leftmost center). Well-sorted, well rounded river gravel is overlain and interfingers with tributary arroyo alluvium of Qam_2.

surface with Rio Grande deposits within the Albuquerque basin, the Sunport, or Mesa del Sol surface is the top of the basin fill and is not considered a terrace. The highest terrace, called the Lomatas Negras Formation, is typically 70-75 m above the Rio Grande valley floor, is commonly less than 5 m thick, and includes Lava Creek B ash (0.639±0.002 Ma; Lanphere and others, 2002). The Edith Formation has a base typically 12-24 m and a top about 30-40 m above the valley floor. It contains Rancholabrean fossils but is older than the Los Duranes Formation. The Los Duranes Formation is a predominantly non-gravelly fluvial terrace with a base just below the modern valley floor and a top 40-52 m higher. A basalt flow from the Albuquerque volcanoes is a tongue within the Los Duranes Formation and has an age of 156±20 ka (Peate and others, 1996). The Cat Hills basalt overlies the formation west of Isleta Pueblo and has an age of 98-110 ka (Maldonado and others, 1999). The Menaul Formation is a 3-m thick gravel unit which interfingers with piedmont deposits above the Edith Formation, but below the top of the Los Duranes Formation. The Menaul Formation may be a coarser facies of the Los Duranes Formation. The lowest terrace, the Arenal Formation, is inset against the Los Duranes Formation, is 3-6 m thick and has a top 15-21 m above the valley floor. The valley in the Albuquerque area is underlain by 15-29 m of fill, primarily of sandy Rio Grande fluvial deposits called the Los Padillas Formation (Connell and Love, 2001).

Terraces and age-determined deposits along the Rio Puerco upstream of Abeytas include lower terraces at 3 m, 6-8 m, 24-30 m, 35-40 m, and 55-61 m, as well as the Llano de Albuquerque at the top of the Ceja Formation 145 m above the valley floor (Love and Connell, 2005). The top of the Ceja Formation contains 2.6 Ma pumice. Lava Creek B ash is found 67 m above the valley floor, and a lava flow with K-Ar ages from 0.28 to 0.32 Ma is 27 m above the valley floor. Valley fill beneath the current valley floor is 34-41 m thick, with archaeological sites ranging back to about 4,000 years ago in the upper 1-2 m. Several cycles of Holocene arroyo cut-and-fill have been described by Love and others (1982). The age of the lower valley fill of the Rio Puerco has yet to be determined. Upstream, the Rio San Jose tributary to the Rio Puerco achieved maximum incision and subsequent valley fill before late Pleistocene time (before 120 ka). On the other hand, the Rio Grande apparently achieved maximum incision in the past 20,000 years and accumulated 20 m of valley fill in the past 10-12,000 years (Love and Connell, 2005).

Machette (1978b; 1985) described the Cliff Surface north of the Rio Salado in the San Acacia quadrangle to the southwest of the Abeytas quadrangle as being post-Sierra Ladrones Formation. Machette also described two terraces north of the Rio Salado below that. The higher terrace projects about 63 m above the Rio Salado and is offset by about 6 m along the Cliff fault. The lower terrace has a constructional top 32-34 m above the Rio Salado.

Tracing the Rio Grande terraces from north to south along the river bears on the history of surface uplift and deformation related to the Socorro Magma Body. Ouchi (1983; 1986) reported that terraces ascended across the surface uplift to the south. He did not report actual terrace locations and how he correlated them. We found no evidence of north or eastward tilting of any of the terraces on the Abeytas Quadrangle. In fact, we found only a fault offsetting the lowest terrace (see below).

Valley floor deposits.

The alluvium of the Rio Grande, occupying the valley floor running north to south through the Abeytas Quadrangle, averages 4.4 km (2.7 mi) wide and is thought to be approximately 25 m deep. While technically a braided stream system, the channels of the Rio Grande collectively have aggraded and meandered back and forth across (and thus widening) its floodplain throughout the Holocene, revealing cross-cutting relationships amongst these fluvial deposits. Pearce and Kelson (2004) developed a surficial geologic map of these deposits along a reach from Isleta to San Acacia, crossing some ten 1:24,000 quadrangles including Abeytas, based upon 1935-vintage aerial photography. Their study focused on both historic geomorphic and vegetative changes along this reach by comparing these 1935 photo data to 2001 aerial photos. Their 1935 stereophotographic analysis was extremely useful for delineating surficial geologic units because this dataset predated the 1940s-1950s infestation of tamarisk, or salt cedar (*Tamarix pentandra*) that covered floodplains of the southwest, especially the middle Rio Grande and its tributaries, and floodplain agriculture was less extensive and disruptive at this time as well.

For the purposes of this map, we deemed that there was very little modification of the work of Pearce and Kelson (2004) necessary. We reorganized their 1935 data into a more useful morpho-stratigraphic framework by combining several of their units (described below), reinterpreted the western floodplain margin adjacent to the confluence of the Rio Puerco with the Rio Grande, with field mapping and additional photo-interpretation using 1993-vintage, large scale (1:7,920) aerial photography, and redefined the modern channel of the Rio Grande ($Qrgc_2$) using 1996 orthophotograph quarter quads at a scale of 1:12,000. We did not reclassify areas that have undergone extensive modification (bulldozing, etc.) for tamarisk removal and farming.

Thus, we have subdivided the alluvium of the Rio Grande into two channel deposits ($Qrgc_2$ and $Qrgc_1$), two meander-bend deposits ($Qrgm_2$ and $Qrgm_1$), which mark former channel localities, and undifferentiated valley bottom alluvium (Qrg). For the modern channel, we combined Pearce and Kelson's (2004) units "W35" (the 1935 active channel), "Rib35" (1935 channel in-stream bars), and "Rsb35" (Recent [i.e., early Historic time--16th-19th centuries to 1935] channel scroll bar deposits). Older channel (predominantly sand) deposits (Historic to Holocene) were combined from their units "Hch" (channel deposits), "Hib," (in-stream bars), and "Hsb" (scroll bar deposits). Likewise, youngest meander-bend deposits ($Qrgm_2$ -- Historic) were combined from

“Rch35” (Recent channel deposits), “Rcs35” (Recent crevasse splay deposits), and “Rcb35” (Recent meander bend deposits), while older meander-bend deposits ($Qrgm_1$ – Historic to Holocene) were combined from units “Hcb” (channel meander-bend deposits) and “Hcs” (channel crevasse splay deposits).

The alluvium of the Rio Puerco valley is divided into several general units based also on geomorphic position and cross-cutting relationships. The deposits on broad alluvial slopes of the valley margins that are a combination of reworked Ceja Formation and eolian sand are mapped as Qaeo if they contain significant pedogenic horizons that indicate surface stability. Younger footslope alluvial and eolian deposits that lack near-surface pedogenic horizons are mapped Qae. The broad valley floor (Qarp) is alluvium deposited primarily by overbank flow of the Rio Puerco and tributaries that used to flow down-valley parallel to the main stream. Alluvium accumulated below the valley floor includes both paleochannels and overbank deposits and probably is at least 20 m thick. Upstream, the valley fill is up to 40 m thick. Inset below the level of the valley floor along the arroyo margins are intermediate alluvial terraces and an older floodplain and oxbow channels (Qarpm). Below that is the active Rio Puerco channel (Qarpc2) and active floodplain (Qarpc1; cross section B-B'). Bryan (1925) and Bryan and Post (1927) attempted to establish when the Rio Puerco incised its valley floor in the 19th century. Historic photographs of the Rio Puerco channel in the vicinity of the railroad and U.S. Highway 85 bridges show remarkable channel changes during the 20th century from a broad, shallow, braided channel to one trapezoidal silt-sided meandering channel between aggraded tamarisk-stabilized banks now (Qarpc1 and Qarpc2; J.Wall and C. Gorbach, unpublished compilation). Elliot (1979), Meyer (1989), and Gellis (1991) addressed the possible evolution of the modern Rio Puerco channel through time, while Love and others (1982) and Love and Young (1983) described several buried Holocene arroyo channels within the Rio Puerco valley fill upstream from the Abeytas Quadrangle.

We mapped a separate deposit inset below the Rio Puerco valley floor on the northern margin of the valley (Qarps). This deposit partially fills an eastward-trending swale eroded into the valley floor and probably fed by runoff from the valley border to the north. This swale appears to have developed in response to gradient increases due to trimming Rio Puerco valley floor deposits by the Rio Grande east of Bernardo.

Tributary stream-valley alluvium and other alluvium.

Alluvium associated with the development of tributaries to the Rio Grande and Rio Puerco is found at several levels along the drainage courses. In the southeastern part of the quadrangle, the alluvium is a bedded mixture of sand and coarse cobble and boulder gravel. The coarse clasts are subangular to subrounded pebbles and cobbles of limestone, sandstone, granitic, metamorphic, and sparse volcanic rock types indicating derivation from drainages from uplands to the east. The oldest alluvium (Qao) is inset below the top of basin fill and either parallels incised drainages or spreads out as piedmont deposits not readily associated with modern drainages. Its surface and soil horizons are mostly stripped. Inset below the oldest tributary alluvium are flights of at least three tributary terraces along major drainages (but not smaller ones) and designated as Qam1, Qam2, and Qam3. Locally, a fourth terrace, Qam4, is adjacent to the modern floodplain and modern tributary channels (Qay and Qafy). Soil development increases from negligible on modern floodplains and Qam4, to pedogenic carbonate Stage I on Qam3, to Stage II on Qam2, to Stage III on Qam1.

Alluvium at the mouth of Abo Arroyo (lumped as Qam) in the northeastern corner of the Abeytas quadrangle is very extensive and quite thick (up to 21 m). The bulk of the accumulation overrides the top of Rio Grande terrace ($Qrgt_3$) and probably buries $Qrgt_2$ east of the edge of the quadrangle as well. The lack of soil development on this accumulation is surprising, but perhaps the stable top has been stripped, much like Qao to the south. North of Abeytas Quadrangle the valley of Abo Arroyo is inset 45 m below this surface and is graded to the modern Rio Grande.

Alluvium, colluvium, and eolian deposits deposited downhill from fault scarps and raised footwalls on the Llano de Albuquerque are mapped as Qase (slope deposits) and as Qag (graben fill). The footwall block making the east side of the graben on the adjacent Veguita quadrangle is more than 20 m higher than the graben floor and the slope is several hundred m wide so Qase is extensive. The thickness of graben fill is unknown on the Abeytas quadrangle. On the Veguita quadrangle, exposures of Qag show multiple soils developed on fill more than 10 m thick (see Figure 7-- a photograph of similar soils in hanging- wall deposits of West Ceja fault below).

Eolian and mixed deposits.

Eolian deposits are most extensive on the Llano de Albuquerque and overlie the soil developed there. Thin sand cover is mapped as Qe/Tc and thicker sand is mapped as Qe. More extensive vegetationally stabilized eolian sand sheets and low dunes that appear to be older are mapped as Qedi. Larger active dunes are mapped as Qed. Interdune areas are mapped as Qe/Tc.

Slope deposits along valley borders are mapped as Qae and Qaeo, showing that they are deposits from colluvial, alluvial, and eolian processes. The old deposits (Qaeo) have significant pedogenic calcium carbonate accumulation in soils on slopes and are found on slopes below the top of basin fill and the highest river terraces. Younger slope deposits along the Rio Grande can be divided into Qae_1 on higher alluvial sloping surfaces and Qae_2 inset below and adjacent to the Rio Grande floodplain.

Discussion of stratigraphic relationships.

The correlation chart shows relative times when various deposits are thought to have accumulated. Notice that Tc, Tcs, QTsa, QTst, and QTsp are all thought to have accumulated at the same time during the Pliocene and perhaps early Pleistocene. However, nowhere in the quadrangle do we see the relationship between the ancestral Rio Grande (QTsa) and its western tributaries, the Rio Puerco (Tc) and Rio Salado (and Puerco, Tcs). Therefore, on the cross sections, we have placed the contact between Tc and QTsa and between Tcs and QTsp under the present Rio Grande Valley.

Cross-cutting stratigraphic relationships in southeastern Abeytas Quadrangle are complicated. Tributary stream alluvium Qam_2 cross-cuts Rio Grande terrace $Qrgt_2$ (cross section B-B'), interfingers with the uppermost deposits of Rio Grande terrace $Qrgt_3$, and progrades across $Qrgt_3$ to its westernmost exposures (Figure 3). Therefore it must post-date $Qrgt_2$ and is contemporaneous to and largely post-dates $Qrgt_3$. Tributary stream alluvium Qam_3 and Qam_4 are inset below $Qrgt_3$ and are younger than that terrace.

The extent of Rio Puerco Valley floor deposits Qarp southwest of the Rio Puerco Valley margin, and perhaps east to the middle of the Rio Grande valley suggests that sediment delivery to the Rio Grande valley dominated deposition by either river, but the Rio Grande had larger erosive power to remove Rio Puerco deposits farther east. These deposits need to be investigated in detail.

Figure 3. Mouth of Maes Arroyo looking southwest. Red unit of sand, silt and clay (QTsp) on opposite bank underlies terrace $Qrgt_3$ and forms a buried bluff line near the center of the photo. Terrace $Qrgt_3$ continues east (to left and in foreground). Road in middle ground is on Maes Arroyo terrace Qam_3 and Maes Arroyo channel is between Qam_3 and QTsp.

STRUCTURE

Although the Abeytas Quadrangle is near the southern edge of the Albuquerque basin, formations exposed at the surface are only slightly deformed, and give no indication of major structures at depth. Older basin fill exposed in the southeastern part of the quadrangle exhibits dips of a few degrees in a variety of directions (see map). North-trending faults within and just beyond the quadrangle are presumably related to extension across the Rio Grande rift. Although we have not yet attempted a comprehensive study of faults in the southern Albuquerque basin, it appears that full grabens with minor amounts of offset are more common here than farther north.

We traced the Sabinal fault of Machette and McGimsey (1983) southward along the eastern edge of the Llano de Albuquerque to where it descends toward Abeytas. The offset decreases from several meters down-to-the-west at the edge of the Llano (Figure 4) to a slightly faulted monocline a few hundred meters to the south, to a gentle monocline descending to the west farther south along the trend of the fault. The top of the hanging

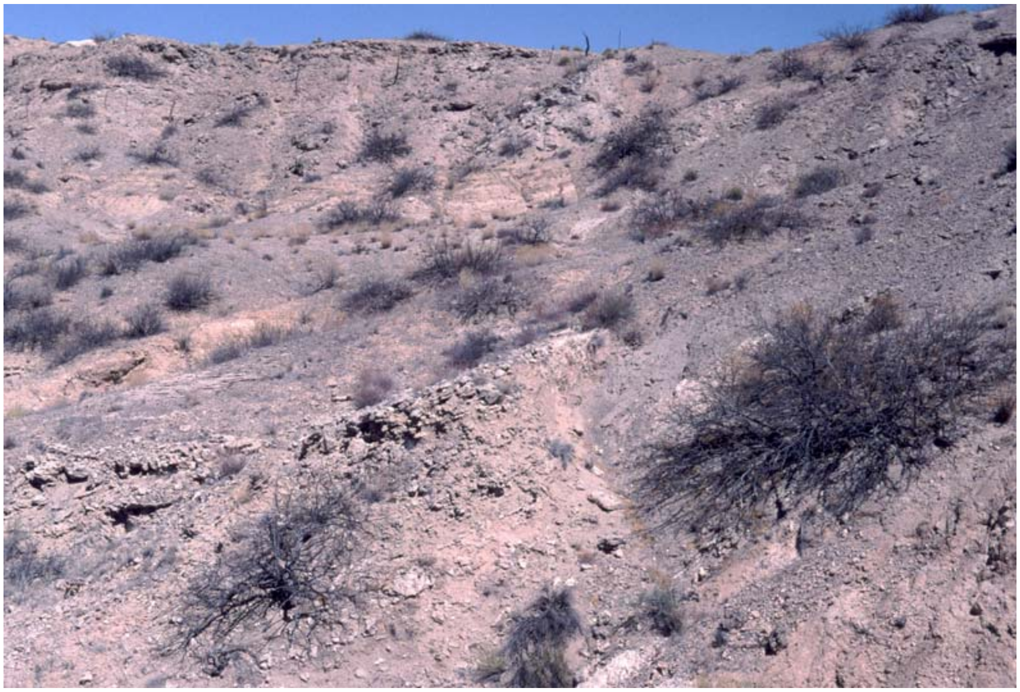

Figure 4. North-trending, down-to-the-west Sabinal fault showing warping which becomes a monocline to the south.

wall preserves pedogenic calcium carbonate horizons (number undetermined) and a reduced zone in a fine-grained unit within the underlying Ceja Formation not seen on the footwall (Figure 5).

A few hundred meters west of the Sabinal fault, a small graben is formed between a fault with a small amount of offset down-to-the west, and an antithetic fault with similar offset farther west (see map and cross section A-A'). These faults and the small graben

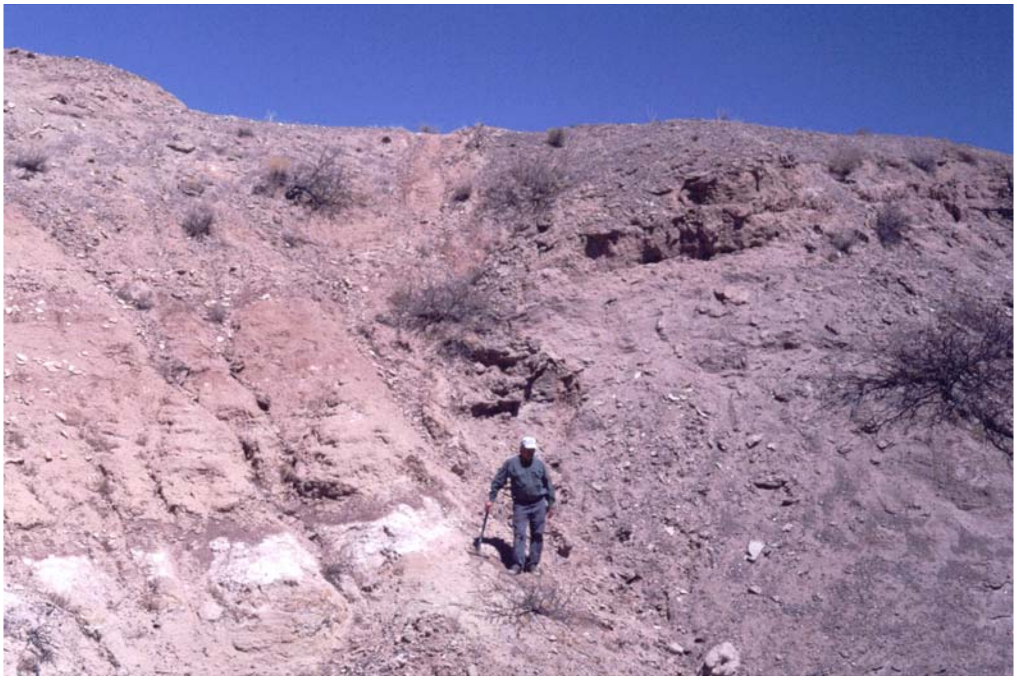

Figure 5. Down-to-the west offset along Sabinal fault with pale reduced-zone within fine-grained unit preserved in the hanging wall.

die out before they reach the edge of the Llano de Albuquerque. A small horst with possible scarps just a few meters high is denoted on the Llano de Albuquerque farther west. It too dies out farther south.

Kelley (1977) mapped a fault cutting Ceja Formation deposits below the eroded Ceja del Rio Puerco at the west edge of the Llano de Albuquerque (cross section A-A" and Figure 6). For lack of other place names, we suggest naming this fault the West Ceja fault. We traced this fault from the northern edge of the Abeytas Quadrangle southward to where it dies out. From aerial photographs, it appears that the fault can be traced farther north, suggesting that the geologic map of the Veguita Quadrangle needs revision. The fault is down-to-the east with several meters of displacement and at least three pedogenic calcium carbonate horizons preserved locally on the hanging wall (Figure 7).

Figure 6. Trace of down-to-the-east Ceja fault along the Rio Puerco valley border. Note dip of Ceja Formation on the hanging wall into the fault below skyline left-center.

Figure 7. Stack of at least three pedogenic soil horizons on hanging wall of West Ceja fault depicted by the light-colored calcium carbonate horizons which dip westward toward the fault (out of picture to right).

We found a previously unmapped north-trending down-to-the-west fault cutting Rio Grande terrace ($Qrgt_3$) from just east of the Contreras Cemetery north to near U.S. Highway 60 where it is obliterated by gravel mining operations and then becomes buried beneath the Rio Grande Valley. The top of the terrace is offset 2-4 m (see cross section B-B'), but units within the terrace are either offset more or are preserved only on the hanging wall. Younger Qam units bury the scarp and are not offset. We suggest the fault be called the Contreras Cemetery fault (Figure 8).

Figure 8. View south showing trace of Contreras Cemetery fault cutting terrace $Qrgt_3$. Note very thick floodplain deposits within terrace (dark reddish brown) on the hanging wall and outcrop of cemented sandstone on footwall block in near midground.

DISCUSSION OF STRUCTURAL, GEOMORPHIC, AND DEPOSITIONAL RELATIONSHIPS.

The Abeytas quadrangle does not show extensive deformation from faulting and folding. Yet, from channel orientations and pebble imbrication data, streams tributary to the Rio Grande from at least three directions (Rio Puerco, Rio Salado, and Los Pinos drainages) were converging toward the Bernardo-Contreras area at the same time between 2 and 3 million years ago. Although we are not sure where the ancestral Rio Grande was at this time (commonly extensive deposits seen upstream and downstream not in evidence here), it should have flowed through this area! After the Rio Grande began incising its valley and marked its path with a stepped sequence of south-directed terraces, the Rio Puerco from the northwest and tributaries from the east persisted in heading toward the Abeytas Quadrangle. It is particularly noteworthy that eastern tributaries such as Abo Arroyo, Pino Draw, Turututu Draw, Maes Arroyo, Pascual Arroyo, and Salas Arroyo, all make their way northwest. Is this due to tectonic sagging in the Abeytas area, or is it due to tectonic uplift farther southeast and southwest?

Possible indications of influence of uplift above the Socorro Magma Body on stream courses are weak. The Rio Grande terraces are all preserved on the east side of the valley but the younger terraces are shifted west toward the presumed uplift. The high Rio Puerco terrace is preserved on the south side (presumed uplifted side) of the Rio Puerco valley, but the Rio Puerco is not shifted farther north through time.

DESCRIPTION OF MAP UNITS

NEOGENE

Alluvial-fan, alluvial-slope, alluvial-fill, eolian, and anthropogenic deposits

af **Artificial fill (Historic) —** Dumped fill and areas affected by human disturbances mapped where deposits or extractions are areally extensive. Commonly includes levees in the Rio Grande floodplain, borrow pits for interstate road construction and raised roads, and large sand and gravel quarries located on the lowest Rio Grande terrace ($Qrgt_3$) immediately east of the Rio Grande floodplain.

Qe **Eolian sand, undivided (Holocene – uppermost Pleistocene) —** Unconsolidated to very poorly consolidated, moderately to well sorted, light brown sand. Forms extensive sheets and low dunes along the rim of the Llano de Albuquerque. Deposits range from less than 1 m to about 3 m in thickness.

Qe/Tc **Eolian sand covering Ceja Formation, undivided (Holocene – uppermost Pleistocene) —** Unconsolidated to very poorly consolidated, moderately to well sorted, light brown sand. Forms extensive sheets in the central areas of the Llano de Albuquerque. Eolian deposits are less than 1 m to slightly greater than 1 m thick covering the underlying Ceja Formation (Tc).

Qed **Eolian sand dunes, undivided (Holocene) —** Unconsolidated, moderately to well sorted, light brown sand dunes. Common either as active or coppice dunes beneath mesquite (*Prosopis glandulosa*) thickets. Covers approximately 1.5 km^2 of the southernmost tip of the Llano de Albuquerque. Dunes range in thickness from about 1 to 3 m.

Qedi **Eolian sand dunes on older eolian deposits, undivided (Holocene – uppermost Pleistocene) —** Unconsolidated, moderately to well sorted, light brown sand dunes found covering older unconsolidated to slightly consolidated eolian deposits. Unit is located on the Llano de Albuquerque at the northern edge of the quadrangle and extends north into the Veguita quadrangle, where it is more extensive. Commonly 1-3 m thick.

Qase **Eolian sand and slope-wash alluvium, undivided (Holocene – uppermost Pleistocene) —** Unconsolidated to very poorly consolidated, moderately to well sorted, light brown sand in finer grained, light brown slope-wash alluvium. Unit is found flanking both sides and sloping into a structural graben on the Llano de Albuquerque. Maximum relief of the deposit is 20m on the east side. Commonly 1-3 m thick.

Qag **Graben fill alluvium, undivided (Holocene to upper Pleistocene) —** Unconsolidated to very poorly consolidated, moderately to well sorted, light brown fine-grained sand to silty clay alluvial fill occupying a structural graben on the Llano de Albuquerque. A major source of Qag sediments is derived from adjacent eolian and/or slope-wash deposits of Qase. Possibly up to 10 m thick.

Qae **Valley-slope alluvium with eolian sand, undivided (Holocene to upper Pleistocene) —** Unconsolidated to very poorly consolidated, poorly to moderately sorted, light reddish-brown to light-brown, fine- to medium-grained sand and silty sand with scattered pebbles. Commonly forms a relatively thin mantle of alluvium and/or eolian slope deposits shed off of broad upland areas, and locally can exhibit a large eolian component adjacent to floodplains or east of the Llano de Albuquerque. Subdivided along the valley margins of the Rio Grande floodplain where a scarp is present. Varies considerably in thickness from less than 1 m immediately adjacent to floodplains and in upland settings mantling the Ceja Formation (Tc), to up to 4 m, downslope of the lowest alluvial terrace of the Rio Grande ($Qrgt_3$).

Qae_2 **Valley-slope alluvium with eolian sand (Holocene) —** Lowest alluvial valley-slope and eolian deposits found immediately above the Rio Grande floodplain. Commonly exhibits a lag deposit of alluvial sand and small pebbles reworked out of adjacent Qay fans. Thickness ranges from less than 1 m to 2 m.

Qae_1 **Valley-slope alluvium with eolian sand (Holocene to uppermost Pleistocene) —** Upper alluvial valley-slope and eolian deposits. Textures and thicknesses vary considerably on opposite sides of the Rio Grande valley. To the west, these deposits thinly mantle Tc and are predominantly composed of sandy facies with considerable eolian input. Deposits found below $Qrgt_3$ on the east, however, are much thicker, more poorly sorted, and have higher gravel concentrations derived from the terrace above.

Qaeo **Valley-slope alluvium with eolian sand (upper to middle Pleistocene) —** Unconsolidated to moderately consolidated, moderately sorted, light reddish-brown to light-brown, slope-wash deposits consisting of fine- to coarse-grained sand with abundant pebbles. Upper 20 cm commonly exhibits a loose eolian mantle covering a well developed (Stage II to II+) soil developed into these deposits. Located immediately downslope of the highest alluvial terraces of both the Rio Grande ($Qrgt_1$) and the Rio Puerco ($Qrpt_1$). Commonly thins downslope from 3 m to 1 m in thickness.

Qafy **Alluvial-fan deposits, undivided (Historic to uppermost Pleistocene) —** Light reddish-brown (5YR 6/4), poorly to moderately sorted, unconsolidated to moderately consolidated, fine- to coarse-grained sand commonly containing stringers of small pebbles. Forms large lobate fans upon debouching from the uplands west of the Rio Puerco out onto either valley margin alluvium (Qae) or the Rio Puerco floodplain (Qarp). Deposits on one fan are subdivided based upon aerial photography; the modern lobe has clearly built out onto older fan surfaces. Fan thicknesses vary from 3-4 m near apexes to less than 1 m (often less than 0.3 m as they commonly grade to floodplain levels) at their distal margins.

Qafy$_2$ **Alluvial-fan deposits (Historic to upper Holocene) —** Modern fan lobe of fan roughly centered at UTM 13S 328000 3809500. Deposit is clearly distinct from underlying older fan deposits of the same fan and could have formed as the result of recent debris flood events.

Qafy$_1$ **Alluvial-fan deposits (Holocene to uppermost Pleistocene) —** Underlying and extending beyond the alluvial-fan deposits of the same fan as Qafy$_2$.

Alluvium of the Rio Grande

Qrg **Rio Grande alluvium, undivided (Historic to upper Holocene) —** Unconsolidated to poorly consolidated coarse-grained sand and gravel with lensoidal interbeds of fine-grained sand, silt, and clay. Forms the lowest inset fluvial deposit of the inner valley and floodplain of the Rio Grande and basal deposits are significantly coarser-grained. The Rio Grande floodplain alluvium is divided into four subunits based upon and modified from aerial photographic work of Pearce and Kelson (2004) using 1935-vintage aerial photography, prior to tamarisk infestation and agricultural disturbance was significantly less than present. Base not exposed but commonly up to 25 m thick in this vicinity.

Qrgc$_2$ **Modern channel facies (Historic) —** Unconsolidated sand and gravel within the active channel of the Rio Grande. Generally modified from the unit W35 of Pearce and Kelson (2004) (i.e., the channel in 1935) using the 1996 digital orthophotoquad, and also includes units Rib35 and Rsb35 of Pearce and Kelson (2004).

Qrgc$_1$ **Modern channel facies and scroll-bar deposits (Historic to upper Holocene) —** Unconsolidated sand and gravel deposits of former Rio Grande channels and scroll bars recognized in aerial photography. Corresponds to the units Hch, Hsb, and Hib of Pearce and Kelson (2004).

Qrgm$_2$ **Meander-bend deposits (Historic) —** Deposits preserved along recently abandoned and active meander bends. Corresponds to units Rch35, Rcs35, and Rcb35 of Pearce and Kelson (2004).

Qrgm$_1$ **Meander-bend deposits (Historic to upper Holocene) —** Deposits preserved along older abandoned meander-bend courses. Corresponds to units Hcb and Hcs of Pearce and Kelson (2004).

Qrgt$_3$ **Rio Grande alluvium, youngest terrace deposits (middle Pleistocene) —** Very pale-brown (10YR 7/3) to light brown, poorly consolidated, medium- to very coarse-grained sand and clast-supported cobble-gravel beds. A distinct pinkish gray (7.5YR6/2) cross bedded fluvial sand is seen in places. Deposit is inset against older Rio Grande terrace deposits and represents lowest preserved terrace deposit in this area. Forms fairly continuous low-lying terrace along margin of modern Rio Grande valley with a surface tread of 29m above the modern river. Unit is commonly overlain by younger and intermediate stream-valley alluvium (Qay, Qam_3, Qam_2). Base is exposed in both the southeast area of the quad where it unconformably overlies piedmont basin fill (QTsp) and in the northeast corner where it rests on cemented fluvial cross bedded sands of axial-river basin fill (QTsa). Unit is approximately 22-27 m thick.

$Qrgt_2$ **Rio Grande alluvium, intermediate terrace deposits (middle Pleistocene) —** White to pale-brown (10YR 8/2-8/3), poorly consolidated, moderately sorted, pebbly to cobbly sand and clast-supported gravel. Unconformably overlies partially cemented light-colored parallel-bedded sandstone of unit QTsa. Contains abundant rounded orthoquartzite and polished chert pebbles and cobbles as well as igneous and metamorphic extrabasinal clasts. Also contains well cemented slabby clasts of QTsa imbricated to the southeast. Exposed base of deposits is about 38 m above the Rio Grande floodplain. Top is truncated by eroded base of overlying tributary alluvium Qam_2. Preserved thickness is only about 3 m.

$Qrgt_1$ **Rio Grande alluvium, oldest terrace deposits (middle Pleistocene) —** White to pale-brown (10YR 8/2-8/3;7.5YR 5/4), poorly consolidated, pebbly to cobbly sand and clast-supported gravel. Unconformably overlies red sandstone, siltstone and conglomerate of unit QTsp. Cross-bedded gravels are generally pebbles smaller than 5 cm diameter, but a few clasts are up to 20 cm in diameter. Pebbles consist of well rounded extrabasinal clasts of igneous and metamorphic rocks, orthoquartzite, and polished chert pebbles and cobbles. Sparse rounded pebbles of black obsidian are also found. Deposits sit between 50 and 65 m above the floor of the Rio Grande and locally are inset against a well exposed bluff line. Deposits are approximately 15 m thick near the bluff line.

Alluvium of the Rio Puerco

Qarp **Rio Puerco alluvium, undivided (Historic to middle Pleistocene) —** Unconsolidated sand, pebbly sand, silt and clay with a range of pale brown and reddish brown colors (colors?). This unit makes up the bulk of the Rio Puerco valley floor and extends tens of m below the surface. Interfingers with Qae and Qafy on valley margins. Generally corresponds to the unit Pfa of Pearce and Kelson (2004).Upstream unit is more than 40 m thick, but must be only as thick as the Rio Grande valley fill (Qrg) here, estimated to be 20-30 m thick.

$Qarpc_2$ **Modern channel facies (Historic) —** Unconsolidated pale brown, medium sand, silt, and clay within the active channel of the Rio Puerco. Generally modified from the units W35, Rsb35, and Rcs35 (i.e., the channel in 1935) of Pearce and Kelson (2004) using the 1996 digital orthophoto. Thickness varies with each waning flow event.

$Qarpc_1$ **Modern channel facies and scroll-bar deposits (Historic to upper Holocene) —** Unconsolidated, light brown sand and silty clay deposits of former Rio Puerco channels recognized in aerial photography and roughly corresponding to the units Hcs, Hcb, and Hsb of Pearce and Kelson (2004). Scroll-bars marked by arcuate vegetation such as tamarisk. Ranges to 4 m thick.

Qarpm **Meander-bend deposits (Historic to upper Holocene) —** Unconsolidated reddish brown sand, silt, and clay deposits preserved along recently abandoned and active meander bends. Meanders outlined by arcuate vegetation such as tamarisk. Ranges to 4 m thick

Qarps **Swale-fill deposits (Historic? to Holocene) —**Unconsolidated deposits of pale brown to reddish brown (7.5 YR 5/6) pebbly sand, silt, and clay that partially fill a swale eroded parallel to the northern edge of the Rio Puerco valley floor near Bernardo. Estimated thickness less than 4 m.

$Qrpt_1$ **Rio Puerco alluvium, oldest terrace deposits (middle Pleistocene)** — Poorly exposed, unconsolidated deposits of pale brown to reddish brown (7.5 YR 5/6), cobbly to pebbly sand, silt, and clay that form a terrace deposit about 45- 50 m above the Rio Puerco valley floor. Coarsest clasts include angular and subangular cobbles and small boulders of rhyolitic, intermediate volcanic, and basaltic rocks, Proterozoic igneous and metamorphic rocks, and limestones derived from unit Tcs and perhaps from piedmont deposits of the Ladron Mountains to the west. Stable upper surface of terrace has stage II pedogenic calcium carbonate horizon more than 50 cm thick. Overall terrace thickness estimated to be no more than 4 m.

Tributary stream-valley alluvium

Qay **Stream alluvium, undivided young deposits (Holocene to uppermost Pleistocene) —** Pale brown to light reddish-brown (10 YR 8/3 to 5YR 6/4), poorly to moderately sorted, unconsolidated pebbly sand with gravel bars of cobbles and boulders. Deposit surfaces are less than 5 m above local base level near mouths of tributary drainages, but sit less than 0.5 m above local base level upstream. Soils are weakly developed. Corresponds to units Qt_6 and Qt_5 of Treadwell (1996) who reports that a similar deposit at an archaeological site yielded a radiocarbon date of 1635±60 yrs. BP on the La Joya Quadrangle. Deposit is about 3 m thick.

Qam **Stream alluvium, undivided intermediate deposits (upper to middle Pleistocene) —** Unconsolidated to weakly consolidated sand and gravel associated with first inset drainages east of Rio Grande. Inset against older stream alluvium and Santa Fe Group. Locally divided into three subunits. Thickness ranges to 25 m.

Qam4 **Stream alluvium, younger subunit (upper Pleistocene) —** Pale brown to light reddish-brown (10 YR 8/3 to 5YR 6/4), poorly to moderately sorted, unconsolidated pebbly sand with thin gravelly channels of cobbles and/or boulders, associated with inset drainages east of Rio Grande. Deposit surfaces are more than 5 m above local base level near mouths of tributary drainages, continue to be more than 4 m above local base level upstream. Soils are weakly developed. Estimated to be 5 to 7 m thick.

Qam3 **Stream alluvium, younger subunit (upper Pleistocene) —** Pale brown to light reddish-brown (10 YR 8/3 to 5YR 6/4), poorly exposed, poorly to moderately sorted, unconsolidated pebbly to cobbly sand associated with inset drainages east of Rio Grande. Deposit surfaces are more than 7 m above local base level near mouths of tributary drainages, continue to be more than 7 m above local base level upstream. Soils are weakly developed and exhibit Stage I+ pedogenic carbonate morphology. Estimated to be 7 to 10 m thick.

Qam2 **Stream alluvium, intermediate subunit (middle to upper Pleistocene)** — Pale brown to light reddish-brown (10 YR 8/3 to 5YR 6/4), poorly exposed, poorly to moderately sorted, unconsolidated pebbly to cobbly sand associated with intermediate levels of inset drainages east of Rio Grande. Gravels consist of limestone, granitic and metamorphic, and red sandstone rock types as well as well-rounded pebbles reworked from older Rio Grande deposits (QTsa, $Qrgt_1$, $Qrgt_2$). Lowest part of unit that overlies Rio Grande terrace $Qrgt_3$ interfingers with Rio Grande sand, silt, and clay. Soils are moderately developed and exhibit Stage II pedogenic carbonate morphology. Corresponds to unit Qt_4 of Treadwell (1996) on the La Joya Quadrangle. Deposits range from 3-23 m thick.

Qam1 **Stream alluvium, older subunit (middle Pleistocene) —** Light reddish-brown (5YR 6/4), unconsolidated to moderately consolidated sand and gravel inset below top of Santa Fe Group. Gravels consist of limestone, granitic and metamorphic, and red sandstone rock types. Deposit surface exhibits well developed soils with Stage III+ pedogenic carbonate morphology. Corresponds to unit Qt3 of Treadwell (1996). Deposits are approximately 2 m thick and sit about 29 m above local base level.

Qao **Stream and slope alluvium, undivided older deposits(middle Pleistocene) —** Moderately consolidated, pale brown to light reddish-brown (10 YR 8/3 to 5YR 6/4), sand and gravel associated with valley border fans and adjacent slopes that bury paleo-bluffs formed on upper Santa Fe Group (QTsa and QTsp) by initial incision and early development of the ancestral Rio Grande Valley. Gravels are subangular to subrounded pebbles and cobbles of limestone, sandstone, granitic, metamorphic and sparse volcanic rock types indicating derivation from drainages from uplands to the east. Estimated to be 5 m thick.

Santa Fe Group

QTsa **Sierra Ladrones Formation, axial-fluvial deposits (upper Santa Fe Group, lower Pleistocene) —**White to pale brown (10YR 8/2-8/3) unconsolidated to partially cemented cross-bedded sand, pebbly sand, and clast-supported gravel of the ancestral Rio Grande. Gravels contain abundant volcanic (~40%), granite (25%), rounded orthoquartzite (20%) and polished rounded chert (15%) and differ in composition from the more angular Proterozoic igneous and metamorphic rocks, volcanic rocks, and sedimentary sandstone and limestone-dominated clasts found in the adjacent piedmont facies. Included in this designation are rare outcrops of cemented and partially cemented cross-bedded coarse to medium sand and sandstone cropping out beneath the $Qrgt_3$ terrace. These outcrops are only tentatively correlated to Sierra Ladrones Formation. The main unit of QTsa crops out from 4875- to 5020-ft elevations in the southeastern part of the Abeytas Quadrangle and contains Rabbit Mountain obsidian. Locally contains tongues of piedmont cobble and boulder gravel and reddish sand and silty clay. Main unit is 44 m thick.

QTsp **Sierra Ladrones Formation piedmont deposits, undivided (upper Santa Fe Group, lower Pleistocene-Pliocene) —** Pink to reddish-yellow (7.5YR 6/6-7/3), well consolidated and moderately well cemented, poorly to moderately sorted sandstone, siltstone, conglomerate and conglomeratic sandstone. Bedding is subhorizontal to gently dipping. Gravel clasts in QTsp are dominated by sandstone, limestone, granitic, metamorphic, and volcanic rock types indicating derivation from the southern Los Pinos Mountains. Paleocurrent data, measured from pebble imbrications, channel margins, and cross beds, indicate a generally northwesterly to westerly paleoflow direction, which supports derivation from the east. Similar deposits to the south in La Joya and Mesa del Yeso quadrangles form a westward-thickening wedge that overlies moderately tilted volcanic rocks and Popotosa Formation (de Moor and others, 2005). Upper parts of QTsp intertongues with fluvial deposits of the ancestral Rio Grande (QTsa), which contain very sparse rounded obsidian from Rabbit Mountain, suggesting an early Pleistocene age. No fossils in this unit were found on Abeytas quadrangle. Similar strata mapped to the south in Valle de la Parida and interbedded with QTsa yielded Pliocene-aged mammal fossils (Connell and others, 2001). The uppermost surface is preserved along the eastern margin of the map area, where a strongly developed soil is exposed. This soil exhibits Stage III+ to possibly Stage IV pedogenic carbonate morphology and represents a local depositional top to the Santa Fe Group basin fill. Treadwell (1996) reported soil-profile development of Stage V to VI on the Pino surface, a relict piedmont-slope surface locally preserved on the adjacent Becker SW quadrangle. Treadwell (1996) considered the upper several meters of this unit (which she called Qp) to represent a younger inset unit, however, mapping indicates that the uppermost gravels that underlie the broad, west-sloping surfaces along the northwestern margin of the map area are part of the aggradational succession of the Santa Fe Group basin fill. Eroded slopes developed on this deposit are commonly mantled by thick (less than 0.5 to more than 1 m thick), poorly consolidated colluvium, alluvium, and eolian deposits. Unit thickens to the west and ranges from about 10 m to well over 300 m in exposed thickness.

QTst **Sierra Ladrones Formation interfingering axial-fluvial and piedmont deposits, undivided (upper Santa Fe Group, lower Pleistocene-Pliocene) —** This map unit is applied to areas where the axial river facies (QTsa) and piedmont facies (QTsp) interfinger on a scale of a few meters vertically and hundreds of meters horizontally. The zone where these two facies interfinger is a transition zone between fluvial and tributary facies. Commonly this zone also is marked by color and cementation changes due to oxidation/reduction and ground-water chemistry differences between the two facies. As a result, the fine sand, silt, and clay can be reduced from reddish-yellow to gray-green, and calcium carbonate can make tufa-like mounds and/or elongate cemented concretions oriented along paleoflow paths. Where mapped, this zone ranges up to 20 m thick.

Tc **Ceja Formation (upper Santa Fe Group, Pliocene) —** Pinkish-gray to light-brown (7.5YR 6/4-7/3), unconsolidated to moderately consolidated ledge-forming, moderately to well sorted sandstone, cobbly sandstone and conglomerate, and interbedded brown, yellowish brown, and reddish brown (colors) mudstone beneath the Llano de Albuquerque west of the Rio Grande valley and north of the Rio Puerco. Paleocurrent observations from cross bedding and gravel imbrications indicate a southeasterly to southerly flow direction. Gravels are predominantly pebbles less than 5 cm in diameter, consisting of abundant well rounded chert, quartzite, basaltic and intermediate volcanic rocks, and lesser amounts of granite, sandstone, and limestone. Within these gravels and pebbly sands are much larger cobbles and small boulders of basalt, sandstone, and Pedernal Chert. From 50 m below to the Llano de Albuquerque surface, gravels also contain rare Grants obsidian (from East Grants Ridge; K-Ar age of 3.2±0.3 Ma; Lipman and Mehnert, 1980) and Blancan fossils, indicating an age of 2-3 million years for the upper part of this basin fill (Morgan and others, 2001). Intervals of sand and mudstone within the formation consist of arroyo-like paleochannels and over-bank floodplains. Also within the deposits are eolian sheet sands and partially developed soils consisting of reddened horizons and stage I to II carbonate horizons. These soils can be traced laterally over thousands of meters (Davis and others, 1993). Exposed thickness is about 100 m. Subsurface data from the Belen area suggests that the Ceja Formation may be more than 560 m thick in this area.

Tcs **Ceja Formation with interfingering and intermixed Rio Salado alluvium (upper Santa Fe Group, Pliocene) —** This unit is similar to the Ceja Formation north of the Rio Puerco Valley. It occurs in the southwest corner of the Abeytas Quadrangle and consists of units identical to the Ceja Formation farther north: grayish-pink to light-brown (7.5YR 6/4-7/3), unconsolidated to moderately consolidated ledge-forming, moderately to well sorted sandstone, cobbly sandstone and conglomerate, and interbedded brown, reddish brown, yellowish brown, to light yellowish brown (2.5 YR 5/4 to 10 YR 6/4) mudstone. However, mixed in with the suite of Ceja pebbles and Grants obsidian are angular to subrounded cobbles and boulders of Proterozoic granitic and metamorphic rocks, rhyolitic, intermediate, and basaltic volcanic rocks, and sandstones and limestones. The coarse clasts increase up-section and to the south, and apparently were derived from the headwaters of the Rio Salado and the piedmont areas of the Ladron Mountains. The predominance of volcanic rock types suggests a source from the paleo-Rio Salado, which heads into volcanic terrain. Connell et al. (2001) interpreted these deposits to have been deposited by east- and northeast-flowing channels, rather than by west-flowing streams draining the Joyita Hills and Los Pinos Mountains as suggested by Machette (1978a). A Blancan horse tooth was found in these deposits a few km south of this quadrangle (Connell et al., 2001). Unit is provisionally correlated to the Ceja Formation. Machette (1978b) called the top of the unit the "Cliff Surface" which is offset by the down-to-the-west Cliff fault west of the Abeytas Quadrangle. This surface and inset surfaces to the west are similar to the Llano de Albuquerque farther north, but may be younger. Exposures are about 100 m thick.

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