Geologic Map of the Romero Canyon 7.5-Minute Quadrangle, Sierra and Socorro Counties, New Mexico

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Open-file Digital Geologic Map OF-GM 270

Scale 1:24,000

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1. Introduction

1.1. Geologic and geographic setting

The Romero Canyon 7.5-minute quadrangle straddles the Rio Grande roughly 26 km north of the city of Truth or Consequences. The quadrangle extends from the base of the Fra Cristobal Mountains on the east to about 9 km up the piedmont of the San Mateo Mountains to the west, and from “The Narrows” of the Rio Grande on the south to about the latitude of the northern end of the Fra Cristobal Mountains on the north. It covers the outlets of Nogal Canyon and San Jose Arroyo as each enters the inner Rio Grande valley from the west. During the time that field work was performed (2016-18), Elephant Butte Lake lay entirely south of the quadrangle, although during high lake levels the lake would extend into the quadrangle and flood the on-quadrangle Rio Grande floodplain. Land surface elevations range from about 1,653 meters (m) above mean sea level (amsl) on a ridge top extending into the quadrangle from the San Mateo Mountains to about 1,338 m amsl where the Rio Grande exits the quadrangle.

Geologically, the quadrangle lies mainly in the Engle basin, an east-tilted rift basin down-dropped along the Hot Springs and Walnut Canyon faults, which lie at the base of the Cutter Sag and Fra Cristobal Mountains, respectively. The basin is of at least Plio-Pleistocene age, during which time it accumulated sediments delivered to the basin by an ancestral Rio Grande as well as piedmont deposits derived from both the Fra Cristobal Mountains to the east (eastern piedmont alluvium) and the San Mateo Mountains, Sierra Cuchillo, and Mud Springs Mountains to the west (western piedmont alluvium). From ~5 to ~0.8 Ma (Mack et al., 2006), the Rio Grande and its tributaries overall aggraded and alluvial sediment accumulated. Since ~0.8 Ma, however, these streams have overall incised, with periods of stability and/or aggradation resulting in flights of terrace deposits along both the Rio Grande and its tributaries. The highest constructional surface associated with the aggradational phase is here referred to as the Cuchillo surface (Lozinsky and Hawley, 1986; McCraw and Love, 2012), and the sediment below this surface that accumulated coeval with an ancestral Rio Grande is referred to the Palomas Formation of the Santa Fe Group (Lozinsky and Hawley, 1986). The aggradational phase was punctuated by a series of basaltic volcanic eruptions associated with the Caballo (also called Engle and Cutter Sag) volcanic field, several vents of which are exposed on the quadrangle.

Pre-Plio-Pleistocene rocks are exposed in a few hills in the northwestern quarter of the quadrangle. These are exclusively underlain by Vicks Peak Tuff, a regional Oligocene ignimbrite that erupted from the Nogal Canyon caldera, located in what is now the San Mateo Mountains. This tuff is generally considered a part of the sequence of volcanic units associated with the Mogollon-Datil volcanic field, the majority of which lies to the west of the quadrangle. That no thick volcanic rocks appear to be found east of the quadrangle suggests that the quadrangle lies at the eastern edge of that volcanic field.

1.2. Previous work

Warren (1978) mapped much of the eastern piedmont of the south half of the Fra Cristobal Mountains as well as the area of The Narrows, and his work extended into the Romero Canyon quadrangle to cover the extents of the basalt of Mitchell Point and the basalt of the Rio Grande. His work concentrated on the volcanic strata, and his names for volcanic features are adopted herein, where applicable. He did not attempt to subdivide the Palomas Formation or post-Santa Fe Group alluvium, however.

Several authors have studied the Fra Cristobal Mountains. Nelson et al. (2012) provided a recent published summary, while Nelson et al. (in prep.) will provide a more detailed review of the stratigraphy and structural geology of the area. These authors extended their mapping westward to the Rio Grande floodplain, but largely left the Palomas Formation and intercalated volcanic rocks undifferentiated.

Detailed study of the Palomas Formation of the Engle basin presented here is largely original and extended from the quadrangle to the south (Black Bluffs quadrangle; Cikoski et al., 2017). Additional studies on the Palomas Formation stratigraphy have been performed further south in the Palomas basin (cf., Seager and Mack, 2003; Mack et al., 2006; Mack et al., 2012; Koning et al., 2015; Jochems, 2015; Jochems and Koning, 2015; Jochems and Koning, 2016).

1.3. Methods

Geologic mapping was performed during the years 2016-18 using standard methods (e.g., Compton, 1985). Field mapping was supplemented with remote mapping using 2009-vintage digital stereo aerial imagery using the ERDAS StereoAnalyst extension to the ESRI ArcMap software package. Data was compiled into a geographic information systems (GIS) geodatabase using ESRI's ArcGIS software platform. Geologic terms used herein are after Compton (1985), soil terms after Birkeland (1999), carbonate horizon stages after Gile et al. (1966) and Machette (1985), diatreme and maar terminology after White and Ross (2011), and color notation after Munsell Color (2009). Coordinates are given in Universal Transverse Mercator (UTM) coordinates after the NAD83 Zone 13S datum.

1.4. Acknowledgements

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2. Post-Santa Fe Group

2.1. Piedmont alluvium

The Santa Fe Group, as defined by Baldwin (1963) and Hawley et al. (1969), consists of all Rio Grande rift basin-filling sediments up to and including the maximum level of aggradation. All sediments post-dating the maximum level of aggradation, achieved approximately 800 ka here (Mack et al., 2006) and referred to as the Cuchillo surface, are "post-Santa Fe." The most conspicuous and extensive such deposits are flights of terrace alluvium inset below the Cuchillo surface along piedmont drainages. Throughout the quadrangle, four levels of piedmont terrace alluvium can commonly be identified and correlated based on soil development and terrace tread heights; these are referred to, in order of increasing age, as Qawy, Qaw3, Qaw2, and Qaw1 on the west side of the Rio Grande, and as Qaey, Qae3, Qae2, and Qae1 on the east side. Terraces along the larger drainages of Nogal Canyon and San Jose Arroyo are distinguished separately due to slightly different characteristics, and the presence of a fifth terrace level along San Jose Arroyo. Nogal Canyon terrace deposits (Qan3, Qan2, and Qan1) in terms of soil development appear correlative to units Qaw3, Qaw2, and Qaw1. San Jose Arroyo terrace deposits (Qaj4, Qaj3, Qaj2, and Qaj1) are not as well exposed; evidence collected, however, suggest that, in terms of soil development, Qaj3 and Qaj2 correlate to Qaw3 and Qaw2, and by inference Qaj1 likely correlates to Qaw1.

Surface soil development in Qawy and Qaey deposits, the youngest terrace levels, is characterized by A/Bw/Bk horizonation, with the carbonate horizon exhibiting no more than weak or discontinuous Stage I morphology. Bar and swale topography is not uncommonly preserved along the tops of terrace treads, and matrices are free of clay films. Terrace tread heights are typically low, up to about 2 m above adjacent stream floors.

Surface soil development in unit Qaj4 is similarly weak, characterized by A/Bk horizonation, though with more consistent Stage I morphology to the carbonate horizon as compared to Qawy-Qaey. Tread heights are up to 7 m above the San Jose Arroyo floor. Soil development and tread height suggests that Qaj4 is slightly older than Qawy and younger than Qaw3.

Surface soil development in Qaw3, Qae3, Qan3, and Qaj3 deposits is characterized by A/Bw(t)/Bk horizonation, with the carbonate horizon exhibiting Stage I-I+ to discontinuous Stage II morphology. Stage II horizons are more common in units Qan3 and Qaj3, while Stage I horizons are more common in Qae3. Clay films are only locally apparent in unit Qaw3, and even when present they are sparse and very fine. Terrace tread heights are typically 1-3 m above adjacent stream floors along smaller streams (units Qaw3, Qae3) and about 6 to 13 m above adjacent streams along larger drainages (Qaj3, Qan3).

Surface soil development in Qaw2, Qae2, Qan2, and Qaj2 deposits is characterized by A/Bwt-Bt/Bk horizonation, with the carbonate horizon exhibiting Stage II-II+ to locally Stage III morphology. Clay films in the Bwt-Bt horizon are commonly apparent, though often rare or fine-grained; clay film abundance and size appears to increase downstream at least in Qaw2 soils, a trend that was not confirmed in other units. Clay films were not observed in these deposits below the surface soil. Terrace tread heights are highly variable, and largely depend on the level of incision of the nearby stream. In general, tread heights increase downstream and northward through the quadrangle. Overall, tread heights for these units are 2 to 40 m above nearby channels.

Surface soil development in Qaw1, Qae1, and Qan1 deposits is characterized by a Stage III to III+ ("plugged" horizon with no overlying laminae) morphology carbonate horizon occurring at or just below the surface; any previously overlying horizons have been stripped by erosion. The surface soil for unit Qaj1 was not found in outcrop. Clay films are found throughout these deposits below the carbonate horizon as rare to moderately common fine coats on gravels or bridges between sand grains in units Qan1, Qaj1, and Qaw1; similar films were not observed in Qae1. As with the Qaw2-Qae2-Qan2-Qaj2 units, tread heights are highly variable, typically increasing downstream and northward through the quadrangle. Overall, tread heights for these units are 3 to 40 m above nearby channels.

Ages were assigned to the units above by comparing soil development, particularly carbonate horizon morphology, to Table 2 of Machette (1985), which suggests that in the Engle basin area, lying between Socorro and Las Cruces, Stage I carbonate horizons are found in surface soils of Holocene age, Stage II carbonate horizons are found in surface soils of Late Pleistocene age, and Stage III carbonate horizons may be found in surface soils of Late Pleistocene age but are more commonly associated with soils of Middle Pleistocene age.

Terrace deposit compositions vary with the bedrocks exposed upstream of the terrace. Qaw_ deposits are dominantly gravels of phenocryst-poor rhyolites, similar to the Vicks Peak Tuff, with rare to absent plagioclase±pyroxene andesitic porphyries, rare to absent quartz-feldspar rhyolitic porphyries, and trace to absent limestones. Qaj_ deposits are similar, though no limestones were observed. Qan_ deposits are similar but with more abundant plagioclase±pyroxene andesitic porphyries, with ratios of phenocryst-poor rhyolites to plagioclase±pyroxene porphyries of about 3:1 to 1:2. Trace volcaniclastic sedimentary clasts were also found in Qan_ deposits. Qae_ deposits vary with varying bedrock exposed in the Fra Cristobal Mountains. Overall, deposits consist of gravels of varying proportions of mainly limestone and granite with accessory schist, quartzite, rhyolite, sandstone, and basalt. Where piedmont streams on either side of the quadrangle have incised into ancestral Rio Grande deposits, associated terrace deposits may also include trace Rio Grande-affinity pebbles (e.g., rounded quartzites, cherts, granites, etc.).

South of San Jose Arroyo, terrace deposits on either side of the Rio Grande are typically thin, often less than 2 m thick, with Santa Fe Group sedimentary rocks or sediments exposed in the slopes or at the bases of outcrops beneath the terrace deposits. Along and north of San Jose Arroyo, however, post-Santa Fe piedmont gravels are found more irregularly inset into underlying Santa Fe Group strata (e.g., FIGURE 2.1). On the west side of the Rio Grande, these gravels can be found underlying terrace treads of all levels, and commonly bear at least rare fine clay films in gravel beds well below any capping surface soil. These observations suggest that the deeply-incised piedmont gravels belong to units Qaw1-Qan1-Qaj1, and that where the incised gravels are overlain by any younger (lower elevation) terrace tread and associated soil, that tread and soil is associated with a relatively thin younger deposit that is inset into the underlying Qaw1-Qan1-Qaj1 deposit. Following this interpretation, the deeply-incised gravels were assigned to map units Qaw1, Qan1, or Qaj1, as appropriate for the location of the gravels. The alternative hypothesis is that there were multiple periods of deep excavation, and that these incised gravels are of varying ages and should not all be assigned to one map unit/deposit. Poor exposure and the general similarity between terrace deposit characteristics would impede demonstrating this hypothesis occurred, however.

In addition to the gravel-dominated terrace deposits, sand-dominated post-Santa Fe piedmont alluvium deposits are found along the margin of the Rio Grande floodplain in the northern half of the quadrangle. These deposits are found on either side of the Rio Grande, but is only mapped as a separate unit on the east side (unit Qaes); poor exposure and time constraints precluded accurate mapping of the western sand-dominated piedmont unit. On either side, the sand-dominated unit forms a broad lenticular deposit inset into adjacent Santa Fe-age ancestral Rio Grande deposits (map unit QTpa) and, locally, into Santa Fe-age diatremes. Thin, lenticular, piedmont gravel-dominated paleochannel fills intercalate with the sand deposits. On the west side, the sand-dominated deposits can be found underlying terrace treads of units Qaw1, Qaw2, Qaw3, Qaj1, Qaj2, and Qaj3. Following the hypothesis discussed above that deep incision and backfilling is associated only with the Qaw1-Qaj1-Qan1 deposits, I assigned the sand-dominated deposits on the west side of the Rio Grande to map units Qaw1 and Qaj1. On the east side, the sand-dominated units are mapped separately, but are suggested to be age-correlative to the sand-dominated deposits on the west side and hence would be associated with the incision and backfilling cycle that deposited Qae1. Although the sand-dominated deposits can be difficult to distinguish from map unit QTpa through areas of poor exposure, map unit Qaes can be continued south of the latitude of San Jose Arroyo based on 1) the presence of intercalated piedmont gravels, a feature not observed in deposits of map unit QTpa, and 2) insetting of sand-dominated deposits into diatreme pyroclastics (**Figure 2.2**); no similar insetting was observed with deposits of unit QTpa.

An additional set of piedmont alluvial deposits are found along the base of the Fra Cristobal Mountains, map units Qap, Qapy, and Qapo. Each consists of alluvial fan and terrace deposits distinguishable from underlying Santa Fe Group piedmont deposits (map unit Qpeu) by a lack of compaction, cementation, and soil development. Surface soil development exposed in outcrops varies throughout each map unit, which is interpreted to indicate that each map unit consists of multiple deposits of varying ages that are difficult to distinguish from surface features and hence not mapped separately. Where insetting relationships permit, younger deposits (Qapy) are distinguished from older deposits (Qapo), although each is recognized to likely include multiple deposits of multiple ages. Surface soils observed in map unit Qapy exhibit carbonate horizons with at most Stage I+ morphology, while those observed in map unit Qapo are at most Stage II+ morphology.

A final level of piedmont alluvium occurs locally on the west side of the Rio Grande and south of San Jose Arroyo, map unit Qawo. These deposits are poorly exposed, but where outcrop is available up to 8 m of poorly sorted pebbles and minor cobbles of dominantly phenocryst-poor rhyolites are found above the elevations of nearby Qaw1 deposit treads. The surface soils for the Qawo deposits have been stripped, and the unit appears restricted to this one area of the quadrangle. Tread heights for these deposits are 16 to 40 m above nearby channels, increasing downstream.

2.2. Axial (Rio Grande) alluvium

Along the Rio Grande, two levels of post-Santa Fe terrace deposits can be distinguished based on stratigraphic relationships and soil development. An ancestral Rio Grande terrace deposit is well exposed on the north side of The Narrows beneath the “Stone House” on Elephant Butte Lake State Park. Here, a Stage II morphology carbonate horizon can be found developed in variably cobbly pebble-gravels of rounded quartzites, cherts, minor felsic and intermediate volcanic rocks, rare granites and basalts, and trace limestones and sandstones. The level of soil development is comparable to that seen in the intermediate-age piedmont deposits Qaw2-Qan2-Qaj2-Qae2, which suggests the Rio Grande terrace is of comparable age; it is hence mapped as Qrgt2. This map unit is continued north and south of the exposure based on the presence of rounded pebbles and cobbles of quartzites and cherts on terrace treads of comparable tread height above the Rio Grande; tread heights overall are about 22 to 24 m above the Rio Grande for this unit.

In the northeast corner of the quadrangle, uncompacted/uncemented siliceous sands and lesser pebble-gravels overlying moderately compacted or concretionary-cemented Santa Fe-age Rio Grande sands and underlying piedmont terrace deposits of unit Qan1 are interpreted to be another post-Santa Fe Rio Grande terrace deposit. In some outcrops, the juxtaposition of uncompacted and compacted sands is sharp (**Figure 2.3a**), while in other outcrops it is more subtle (**Figure 2.3B**). Locally, carbonate accumulation at the contact in the underlying Santa Fe-age Rio Grande sands may reflect a period of soil development prior to deposition of the post-Santa Fe deposit (**Figure 2.3a**). Where post-Santa Fe terrace sands overly Santa Fe-age sands, the former are better structured, bearing prominently trough cross-stratified lenticular beds, as compared to the generally massive or subtly structured underlying Santa Fe-age deposits (**Figure 2.3**). In all outcrops, the Rio Grande terrace deposit is overlain by a piedmont gravel deposit, and hence no surface soil was found developed in the Rio Grande terrace deposit; however, each outcrop is capped by map unit Qan1, indicating the Rio Grande terrace deposits in these outcrops are older than the Qan1 deposits, and hence older than the Qrgt2 terrace deposits below the Stone House. Rio Grande terrace deposits in the northeastern corner of the map are therefore assigned to an older map unit, Qrgt1. A local outcrop of uncemented/uncompacted Rio Grande pebbly sands ~2 km north of San Jose Arroyo is assigned to map unit Qrgt1 as well based on a map pattern that suggests the deposit underlies a deposit of Qaw1, although this relationship is not exposed in outcrop.

3. Santa Fe Group

The Santa Fe Group, as defined by Baldwin (1963) and Hawley et al. (1969), consists of all Rio Grande rift basin-filling sediments up to and including the maximum level of aggradation. Regionally, the Santa Fe Group is commonly divided into upper and lower formation-rank units based on the presence (upper) or absence (lower) of through-flowing ancestral Rio Grande deposits. All Santa Fe Group strata exposed on this quadrangle interact with ancestral Rio Grande deposits, and hence belong to the local upper formation-rank unit, which is the Palomas Formation of Lozinsky and Hawley (1986).

3.1. Western stratigraphy

Palomas Formation strata exposed on the west side of the Rio Grande generally follow a continuous sequence of, in ascending order: ancestral Rio Grande sands (QTpa), a piedmont sand-dominated unit (Qpwf), and a piedmont gravel-dominated unit (Qpwc). At The Narrows and extending approximately 2 km northward, the basalt of Mitchell Point (Tbm) intercalates with unit QTpa. Two diatreme pyroclastic units also intrude unit QTpa; volcanics are described in more detail in subsequent sections. Overall, from south to north, the contact between Qpwf and QTpa rises in elevation from about 1400 m amsl to circa 1435 m amsl, while the contact between Qpwc and Qpwf, with much variation, overall descends from about 1480 m amsl to 1460 m amsl. The effect is the steady thinning of the intervening sand-dominated unit. In the northeastern corner of the quadrangle, along Nogal Canyon, a gravel-dominated piedmont unit directly overlies QTpa. This gravel-dominated deposit has relatively common plagioclase-pyroxene porphyry andesitic lava clasts as compared to unit Qpwc, a clast suite that resembles that of the post-Santa Fe terrace deposits along Nogal Canyon (units Qan3, Qan2, Qan1). This gravel-dominated deposit is mapped as Qpwn, a Nogal Canyon-specific subunit.

Map unit QTpa is dominated by poorly-cemented very fine- to very coarse-grained siliceous sands with rare pebbly sands. Overall, pebbles are a trace component of the map unit, but are locally common and consist of rounded felsic to intermediate volcanic rocks, quartzites, granites, cherts, basalts, and trace reworked clastic sedimentary rocks. The unit is poorly exposed, but where outcropping bedding is typically lenticular and trough cross-stratified, with cementation typically concretionary or concentrated along certain bedding or cross-bedding planes. The exception is in the northeastern corner of the map area, where the unit is typically somewhat consolidated and locally cemented by white carbonate that is potentially pedogenic (**Figure 2.3A**). Deposits of QTpa are found above and below the 3.0 Ma basalt of Mitchell Point (**Table 4.1**), and where deposits entirely underlie the basalt on the geologic map they are mapped as Tpa. QTpa is also the only unit to be observed in outcrop to be cut by diatremes. The base of QTpa is unexposed.

Piedmont sand-dominated map unit Qpwf conformably overlies QTpa, and in places the basal Qpwf interfingers with the uppermost QTpa. Qpwf consists dominantly of pinkish gray to light brownish gray sands and sandstones consisting mainly of very fine to fine grains of common volcanic lithics and quartz and rare feldspars; the abundance of volcanic detritus distinguishes the piedmont sands from the axial Rio Grande sands. Beds are variably massive and tabular or lenticular and cross-stratified. Lenticular beds of conglomerate, comparable to those of unit Qpwc, are found throughout but generally increase in abundance upsection to the upper contact. Weak buried soils, defined by Bw, Bt, or Bk horizons with up to Stage II+ morphology, are found throughout as well, and also increase in abundance upsection toward the upper contact.

In outcrop, piedmont conglomerate-dominated map unit Qpwc appears to conformably overlie unit Qpwf, as conglomerate beds are found in and increase in abundance upsection through unit Qpwf, suggesting an interbedded contact. The contact is placed where conglomerates begin to dominate (i.e., outcrops are consistently >1:1 conglomerate:sandstone), and my experience has been that this definition well-defines the transition, as outcrops appear to increase rapidly in conglomerate abundance across the 1:1 ratio, jumping rapidly from just under 1:1 to nearly 100% conglomerate upsection across the contact. Considering the sharpness of the transition from sandstone-dominated to nearly 100% conglomerate, as well as the variation in elevation of the contact across the study area, it is possible that the Qpwc-Qpwf contact is at least somewhat erosional and hence possibly a minor unconformity. The missing strata and time gap are not expected to be substantial, however.

Qpwc consists of poorly sorted conglomerates of mainly subangular to rounded pebbles, with rare cobbles and trace boulders, of principally phenocryst-poor rhyolites (similar in appearance to Vicks Peak Tuff) with rare or absent plagioclase±pyroxene andesitic porphyries, quartz-feldspar rhyolitic porphyries, and locally limestone. Beds are lenticular, medium to thick, commonly cross-stratified, and matrix-poor. Rare sandstones and sandy conglomerates interbed with the conglomerates. Clay films as medium to coarse gravel coats and sand grain bridges are common to the matrices of conglomerate beds, but typically rare or finer-grained in sandy and sandstone beds. Qpwc is capped by the Cuchillo surface of Lozinsky and Hawley (1986), which is associated with a surface soil over 1.5 m deep with carbonate horizons of Stage III+-IV morphology (McCraw and Love, 2012).

The Nogal Canyon subunit of the gravel-dominated piedmont unit, map unit Qpwn, is comparable to unit Qpwc, with the exception that the abundance of plagioclase±pyroxene andesitic porphyries is as much as 20% of beds, and the sand content in gravel beds appears to be greater, also as much as about 20%, although this decreases upsection. Map unit Qpwn lies directly on QTpa (FIGURE 3.1) with no intervening Qpwf.

3.2. Eastern stratigraphy

Locally, particularly at the east-central margin of the quadrangle, the sequence of Palomas deposits on the east side of the Rio Grande mirrors that of the west side, with ancestral Rio Grande sands and pebbly sands (QTpa) underlying a sandstone-dominated piedmont unit (Qpef) and capped by a conglomerate-dominated piedmont unit (Qpeu; Qpeu abbreviation refers to "upper eastern piedmont Palomas Formation unit," an abbreviation that is continued from the Black Bluffs quadrangle to the south, where underlying middle and lower Palomas strata are present: Cikoski et al., 2017). To the north and south, however, unit Qpef thins in outcrop and does not extend far across the quadrangle. In the southeastern corner of the quadrangle, limited outcrop suggest that piedmont conglomerates and Rio Grande sands interfinger in a zone along the eastern flank of the Rio Grande floodplain and stratigraphically above the basalt of the Rio Grande (Qbrg); no such interbedding was observed beneath this basalt. In this area, strata are mapped as an interbedded axial-piedmont unit, Qpai.

Map unit QTpa along the east side of the Rio Grande is identical to that on the west side. QTpa deposits were not found cropping out beneath the basalt of Mitchell Point, but such deposits likely do underlie the basalt, as seen on the west side. No piedmont conglomerate interbeds were found in outcrop in map unit QTpa. From the southern margin of the quadrangle for approximately 3.5 km northward, QTpa is overlain by the basalt of the Rio Grande (map unit Qbrg), above which Rio Grande sands interbed with piedmont conglomerates and are mapped as unit Qpai. North of the sand sheet diatreme (map unit Qdss), deposits of QTpa are directly overlain by piedmont conglomerates in outcrop with no interbedding of the two, and here unit Qpeu is mapped as directly overlying QTpa. Through the poorly-exposed region in between, the top of QTpa is largely interpolated.

Above map unit Qbrg lies the interbedded Qpai unit. Qpai is poorly exposed on this quadrangle, but better outcrops to the south on the Black Bluffs quadrangle (Cikoski et al., 2017) well expose the interbedding, and outcrop observations along east-west traverses up piedmont streams on that quadrangle reveal that the Rio Grande pebbly sands terminate eastward at an interfingered lateral contact with the piedmont conglomerate unit Qpeu. These relationships were extended into the Romero Canyon quadrangle. Axial sands of Qpai are like those of QTpa, while piedmont conglomerates are like those of unit Qpeu.

At the east-central margin of the quadrangle, QTpa is conformably overlain by piedmont sandstones of unit Qpef. Sandstones of Qpef dominantly consist of very fine to fine grains of quartz, siliceous lithics, and granitic lithics, in massive tabular or lenticular cross-stratified beds. Rare lenticular conglomerate channel fills intercalate with the sandstones that are comparable to conglomerates of Qpeu.

Conglomerate-dominated piedmont unit Qpeu dominates the eastern piedmont. This unit conformably overlies Qpef where Qpef is present, conformably overlies QTpa where Qpef is absent, and interfingers with Qpai where Qpai is present. Conglomerates of Qpeu consist dominantly of pebbles with rare cobbles and trace boulders of compositions that vary with the nature of the bedrocks exposed upstream in the Fra Cristobal Mountains; in general, lithologies consist of varying proportions of mainly limestone and granite, with lesser foliated metamorphic rocks and quartzite, and trace sandstone. Limestones are most abundant in the southern extent of the map unit, while granites and metamorphic rocks are more common in the northern extent. Bedding is typically lenticular with common cross-stratification. Rare sandstones interbed with the conglomerates. Along the base of the Fra Cristobal Mountains, deposits of Qpeu are overlain by piedmont alluvial fan deposits with no cementation or compaction and bearing surface soils exhibiting carbonate horizons of Stage II or less morphology; these deposits, clearly younger than the ~800 ka "maximum aggradation level" that caps the Santa Fe Group, are hence excluded from map unit Qpeu and mapped as younger, post-Santa Fe alluvium (units Qap, Qapy, and Qapo).

On the Black Bluffs quadrangle to the south, map unit Qpeu is underlain by the relatively widespread outflow pyroclastics erupted from the White Cliffs maar, which in turn is underlain by the 2.50 Ma basalt of Walnut Canyon (Cikoski et al., 2017; TABLE 4.1). Additionally, the 2.15 Ma basalt of Crater Hill intercalates with unit Qpeu to the south (Cikoski et al., 2017; TABLE 4.1).

4. Volcanic rocks

4.1. Volcanic rocks intercalated with or intruding the Santa Fe Group

Two basalt flows, four diatremes (following the terminology of White and Ross, 2011), and associated outflow pyroclastic deposits either intercalate with or intrude Santa Fe Group strata. Age dating is only available for one of these units, and clear stratigraphic relationships are not available for all of the diatremes.

The basalt of Mitchell Point (Tbm) is likely the oldest of these volcanic units. Two age estimates are available for this basalt, both of which indicate an age of 3.0 Ma (**Table 4.1**). The map unit consists of 1 or 2 flows, each a fine porphyritic basalt bearing common phenocrysts of pyroxene, plagioclase, and olivine, typically <1 mm across but very locally up to 4 mm across. The basalts erupted from a low hill underlain by abundant basaltic cinder, mapped as unit Tbmc. North of this hill, a thin outflow pyroclastic unit (Tmpp) commonly underlies the basalt, and locally intercalates between the two Mitchell Point flows; the proximity of the pyroclastic unit to the Mitchell Point vent area strongly suggests the pyroclastic unit erupted from the same vent. The basalt intercalates with Rio Grande sands (QTpa) throughout its extent on this quadrangle. Near the northern extent of the basalt, just south of the diatreme of Pete Well, the base of the basalt is intruded by sandstone dikes and elsewhere exhibits possible pillow structures (**Figure 4.1**). The sandstone dikes are identical in composition to the surrounding QTpa sands, and these two features are interpreted to indicate the basalt flowed onto unlithified, saturated, and potentially submerged QTpa sands in this location.

The diatreme of Pete Well (new name; map unit Tdpw) is potentially older than the basalt of Mitchell Point, as the relationship between the two is not clear, but is interpreted to be younger. The diatreme intrudes QTpa sands in outcrop, and a nearby normal fault in somewhat stratigraphically higher QTpa sandstones that dips towards the diatreme is likely associated with the diatreme. The elevation of the fault-bearing outcrop is approximately 10 m below the base of the basalt of Mitchell Point where it crops out 300 m west of the margin of the diatreme. This may indicate that the diatreme predated the basalt, as the diatreme-related features are all lower in elevation than the nearby basalt. However, despite the proximity of the basalt flow to the diatreme, no pyroclastics are found beneath the basalt in this location, and no basalt is found resting on the diatreme. Assuming the diatreme produced a (unpreserved) maar crater, if diatreme emplacement predated the basalt flow one might expect to either find the basalt within the diatreme extent (flowing into the maar crater) or to have onlapped the ejecta ring of the maar, given the proximity of the flow to the diatreme. Neither appears to be the case. In addition, this diatreme is unusually massive in structure for the diatremes found in this area (**Figure 4.2**; compare with foreground pyroclastics in **Figure 2.2**). White and Ross (2011) suggest that massive pyroclastic material is commonly associated with a lower diatreme zone that underlies a well-foliated/well-bedded zone. Thus, the diatreme of Pete Well may be an exposure of the deeper portion of a diatreme that formerly extended significantly higher through the stratigraphic section than is preserved. The diatreme is light brown to pink and consists of basaltic ash and lesser lapilli with abundant incorporated siliceous sands and rare rounded Rio Grande pebbles.

A more clear stratigraphic relationship is seen for the salt cedar diatreme (new name; unit Qdsc), which is exposed inset against a Tbm flow and for which a thin ejecta ring pyroclastic unit, Qmpc, is preserved intercalated with QTpa deposits just below the basalt of the Rio Grande (Qbrg). The diatreme is therefore interpreted to post-date (and intrude) Tbm and pre-date Qbrg. The diatreme is well-foliated pink tuff and lesser lapilli-tuff, with individual beds bearing as much as 35% lapilli. Accidental lithics of siliceous sand grains and trace rounded Rio Grande pebbles are common, as much as 20% of beds. It is erosionally inset upon by the post-Santa Fe Qaes unit (**FIGURE 2.2**), and the overlying unit masks the original extent of the diatreme. The associated outflow pyroclastic unit Qmpc consists of pink to light brown, thin tabular- to undulatory-bedded tuff. This tuff unit thickens around the diatreme, indicating derivation from a vent associated with the diatreme. QTpa sands are found both above and below the outflow tuff.

The basalt of the Rio Grande (Qbrg) overlies both the basalt of Mitchell Point (Tbm) and the outflow pyroclastics erupted from the salt cedar diatreme (Qmpc). Within the Romero Canyon quadrangle, it overlies QTpa sands and underlies Qpai and Qpeu; further south, the basalt overlies a pyroclastic unit (Cikoski et al., 2017) that was not observed on this quadrangle. The Qbrg source vent is not certain; Warren (1978) interpreted the basalt to have erupted from and buried a maar vent located just south of the quadrangle boundary, but alternatively the basalt could have erupted from a poorly exposed cinder cone (mapped as Qbc) that lies to the east of the basalt. Qbrg has not been age dated, but from stratigraphic considerations Cikoski et al. (2017) suggested the basalt was one of the younger of a sequence of basalts on the Black Bluffs quadrangle, possibly in the age range of the 2.5 Ma basalt of Walnut Canyon and the 2.2 Ma basalt of Crater Hill (**TABLE 4.1**). The basalt is a xenolith-bearing fine porphyry, bearing rare phenocrysts of olivine, pyroxene, and plagioclase. Warren (1978) describes a xenolith suite consisting of pyroxenites, granulites, olivine megacrysts, and lherzolites.

The remaining two diatremes are poorly constrained stratigraphically. The diatreme of San Jose Arroyo (new name; unit Tdsj) crops out ~1.2 km northeast of exposures of the diatreme of Pete Well and is well-foliated at elevations where the diatreme of Pete Well is massive. If the massive pyroclastics are found stratigraphically below well-foliated zones (e.g., White and Ross, 2011), then this juxtaposition could potentially be the result of Tdsj pre-dating Tdpw, but the certainty of this inference is weak. The diatreme of San Jose Arroyo consists of prominently foliated pinkish gray to pink tuff and rare lapilli-tuff with common incorporated siliceous sands, as much as 50% of some beds, and trace rounded Rio Grande pebbles.

The sand sheet diatreme (new name; unit Qdss) is poorly exposed along an arroyo to the north of the salt cedar diatreme. It consist of light yellowish brown, generally well-foliated lapilli-tuff and lesser tuff, both with common incorporated siliceous sands and trace rounded Rio Grande pebbles. It is exposed at elevations comparable to those of the salt cedar diatreme. No clear stratigraphic controls are available for the age of this unit, but it is suggested to be of comparable age to the salt cedar diatreme.

4.2. Pre-Santa Fe Group volcanic rocks

Several hills in the northwestern quarter of the quadrangle are underlain by phenocryst-poor, well-foliated rhyolitic tuff. Regional mapping by Farkas (1969) indicates this tuff is the 28.4 Ma (**TABLE 4.1**) Vicks Peak Tuff (Tvp), a regional ignimbrite that erupted from the Nogal Canyon caldera located to the west of the quadrangle in what is now the San Mateo Mountains. Although Farkas (1969) also mapped pre-Vicks Peak Tuff in some of these hills, I did not find any evidence to support the presence of these other units within the quadrangle bounds. The Vicks Peak Tuff is a light gray, phenocryst-poor, well-foliated, generally pumice-rich rhyolitic ignimbrite. Phenocrysts are <1 to at most 1% of fresh faces and consist of fine crystals of sanidine. Pumices may be as much as 35% of faces, and are commonly strongly flattened and often granular-textured from recrystallization (**FIGURE 4.3A**). Concentrically-laminated spherulites are also locally common (**FIGURE 4.3B**).

5. Permian geology

In the far southeast of the quadrangle, the San Andres Formation occurs in fault contact with the Palomas Formation. On this quadrangle, the San Andres consist of medium gray, granular, and highly fractured limestone, with thin arcuate traces of sparry calcite that may be replaced fossils; Cserna (1956) reports small gastropods in the San Andres within the Fra Cristobal Mountains. The unit was not studied in detail in this study. Nelson et al. (2012) report a maximum thickness of about 160 m in the Fra Cristobal Mountains.

6. Structure

6.1. Volcanic and intrusive structures

Four diatremes and one broad basalt vent area are exposed within the quadrangle. As used in this report, the term “diatreme,” following the terminology advocated by White and Ross (2011), refers to a roughly conical-shaped (widening upwards) deposit of pyroclastic rocks found below the (paleo)land surface that commonly underlies a maar volcano. A maar volcano is a vent area characterized by the explosive excavation of a crater that is inset into the pre-eruption (paleo)land surface. Maar volcanoes are often encircled by an ejecta ring of outflow pyroclastic material. A critical component of the use of the terms “diatreme” and “maar” is that each feature must be inset below the upper level of surrounding pre-eruption rocks. This is clearly the case for the diatreme of San Jose Arroyo, whose western contact with surrounding QTpa deposits is exposed and clearly inset into QTpa. The lateral juxtaposition of pyroclastics of the salt cedar diatreme against the basalt of Mitchell Point across a narrow arroyo indicates a vertical contact of some sort, and insetting of the pyroclastics is inferred. The remaining two diatremes are interpreted to be inset into the surrounding QTpa deposits based on map patterns and the commonality of diatremes in this volcanic field (cf., Warren, 1978, and Cikoski et al., 2017).

In contrast to the quadrangle to the south (Cikoski et al., 2017), no maar crater-filling sedimentary or basalt flow deposits are preserved on the Romero Canyon quadrangle. As such, the extent of any maar craters cannot be determined here, and no feature is referred to here as a “maar.” Presumably each diatreme underlay a maar crater at one point, but any deposits associated with the crater have been subsequently removed by erosion.

Also contrasting with the diatremes and maars on the quadrangle to the south (Cikoski et al., 2017), the extent of pyroclastic ejecta from each diatreme-maar volcano appears to be extremely limited on the Romero Canyon quadrangle. To the south, ejecta from the White Cliffs maar extends as much as 4 km from the inferred extent of the maar crater and can be as thick as 25 m. Smaller maars such as the Monticello Point and Black Mesa maars are associated with ejecta rings that extend 1 to 1.5 km from the crater. On Romero Canyon, a single ejecta ring deposit was identified, unit Qmpc, that is at most 10 m thick around the salt cedar diatreme and typically restricted to <500 m from the diatreme, although a thin pyroclastic deposit 1.3 km to the southeast is tentatively correlated to the ejecta ring.

Warren (1978) inferred the basalt of Mitchell Point vent area, in the vicinity of map unit Tbmc, to be underlain by a maar volcano. The only line of evidence to support this that I have seen is the presence of a thin outflow pyroclastic unit (Tmpp) that underlies or intercalates with flows of the basalt of Mitchell Point; otherwise, the eruptive products associated with the vent area appear to be magmatic and not phreatomagmatic, as required for a maar volcano. Although a maar may be concealed beneath the basalt, at the surface the basalt of Mitchell Point resembles a small shield volcano. The outflow pyroclastic interval may represent a brief period where water entered the vent area to produce a short period of explosive eruptions.

The diatremes of the Romero Canyon quadrangle are typically well-foliated/well-bedded and incorporate abundant Rio Grande material. The latter likely reflects the loose nature of the Rio Grande sands, which likely readily sloughed into the vent in between eruptions, or were readily plucked from the vent area wall during eruptions. The well-foliated nature of the diatremes is common to the upper portions of a diatreme (White and Ross, 2011). Foliations in diatremes typically dip radially inward toward the center of the diatreme extent, and this is generally observed for the diatremes on the Romero Canyon quadrangle. Well-foliated upper diatreme pyroclastics grade down-vent into massive lower diatreme pyroclastics (White and Ross, 2011), and the massive diatreme of Pete Well may be a lower diatreme pyroclastic deposit.

6.2. Tectonic structures

The study area lies in the Engle basin of the Rio Grande rift, an east-tilted "half-graben" for which the main basin-bounding fault at this latitude is the Walnut Canyon fault along the western base of the Fra Cristobal Mountains. This fault is exposed on the quadrangle in two laterally-restricted locations: the extreme southeastern corner of the quadrangle and approximately 4.4 km further north along the eastern edge of the quadrangle. In the former location, the fault juxtaposes basin-filling sediments against Permian San Andres Formation limestones. Abundant fracturing of the limestones in this location is likely associated with fault activity. In the latter exposure, the fault juxtaposes basin-filling sediments against Precambrian rocks across a highly silicified breccia zone a few tens of meters wide; the breccia is thick enough to be mapped separately, and is mapped as unit "sbr." This breccia show evidence for multiple ages of brecciation and recementation, and the degree of silicification is so strong as to completely obliterate the nature of the original protolith. Breccia clasts are angular blocks of pale gray silicified material that are surrounded and often entirely supported by reddish brown siliceous matrix (jasper). Both clasts and matrix are cross-cut by thin fractures often mineralized by black, bulbous oxides and sparry calcite. The degree of silicification and the evidence of multiple generations of brecciation and mineralization may reflect a long history of fault development, potentially spanning multiple periods of tectonism. Some previous authors have suggested the fault zone may, at least locally, reoccupy a Laramide-age transpressional fault system (e.g., Harrison and Cather, 2004), although the amount of Laramide displacement occurring along any such structures is in dispute (cf., Seager and Mack, 2003). A detailed study of this breccia, beyond the scope of the present study, might yield evidence to support a Laramide ancestry to the Walnut Canyon fault.

Few other tectonic structures are present at the surface on the Romero Canyon quadrangle. In the southwestern corner of the study area, two relatively low-offset normal faults extend into the quadrangle from the Black Bluffs quadrangle to the south, one forming a fault scarp in the Cuchillo surface that can be followed for approximately 1.3 km. Neither structure can be followed far across the quadrangle, however. Additionally, a short fault scarp appears to displace the top of map unit Qpeu along the east-southeast margin of the quadrangle. This topographic scarp can be followed off-quadrangle into the Walnut Canyon fault, and is suggested to be a splay of the Walnut Canyon fault.

Although the Cuchillo surface (estimated age of 0.8 Ma; Mack et al., 2006) is deformed by extensional faults in the southwest corner of the map, we saw no evidence to suggest that any post-Santa Fe Group deposits or surfaces were deformed by faulting here.

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8. Tables

Table 4.1 – Summary of geochronologic data

Unit	Age[1] (Ma)	±2σ[2]	Type[3]	Ref.[4]	Latitude	Longitude	Comments
Qbch	2.15	0.04	Ar-Ar	P16	33°21.38'N	107°08.06'W	Black Bluffs quadrangle; interbeds with Qpeu
Qbwc	2.50	0.06	Ar-Ar	P16	33°19.69'N	107°07.98'W	Black Bluffs quadrangle; lies at base of Qpeu
Tbm	3.00	0.02	Ar-Ar	P18	33°21'N	107°11'W	Black Bluffs quadrangle; new age
	3.0	0.3	K-Ar	BM78	33°21'N	107°11'W	Black Bluffs quadrangle
Tvp	28.39	0.19	Ar-Ar	C04	N/A	N/A	Average of multiple analyses

1: Age as published. No attempt made to normalize values.

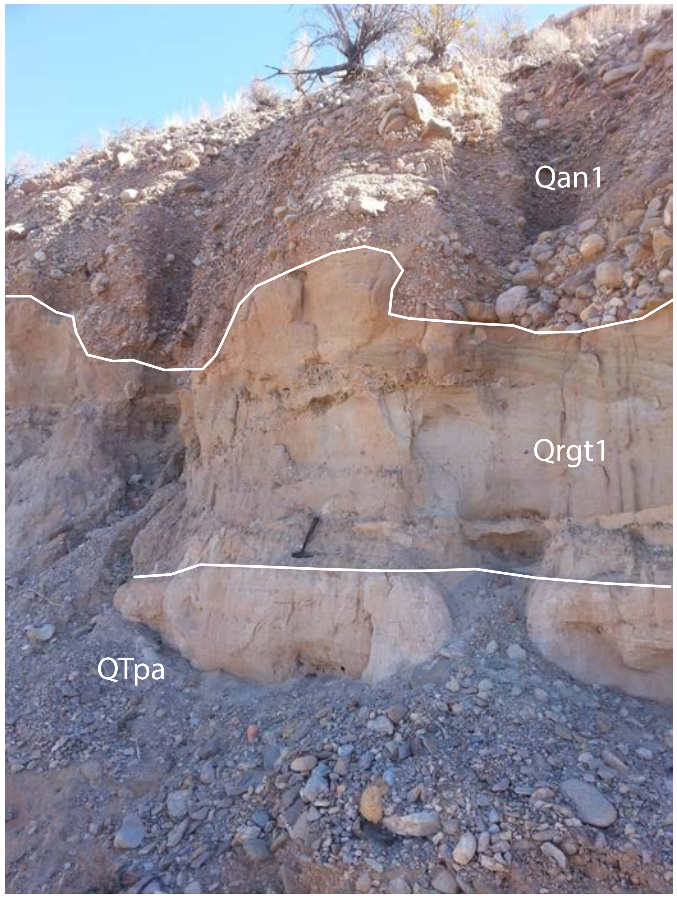
2: Uncertainty as published.

3: Ar-Ar: $^{40}Ar/^{39}Ar$ crystallization age; K-Ar: Potassium-argon crystallization age

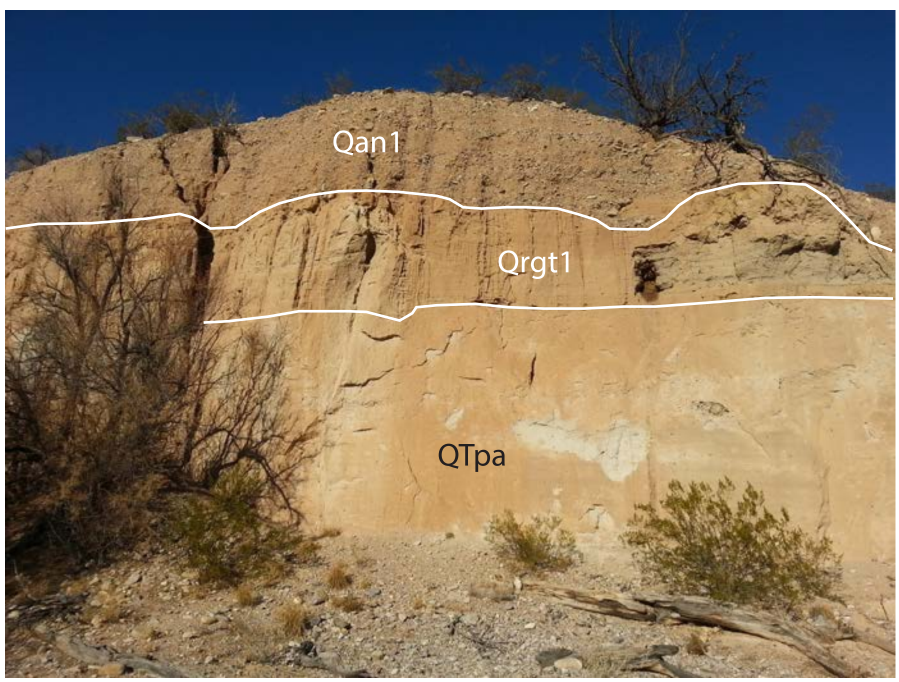
4: BM78 - Bachman and Mehnert, 1978, as modified by Wilks and Chapin, 1997; C04 – Chapin et al., 2004; P16 – Peters, 2016, and Cikoski et al., 2017; P18 – Peters, 2018, and this report.

Figure 2.1. Buttress unconformity between Qaw1 and QTpa north of San Jose Arroyo. Photo taken circa 298260 m E, 3704480 m N, view is to the east, Fra Cristobal Mountains in the background.

Figure 2.2. Buttress unconformity between Qaes and Qdsc, overlain by Qae1. Photo taken circa 299230 m E, 3698570 m N. View is looking east, Fra Cristobal Mountains in the background.



(a)



(b)

Figure 2.3. Exposures of Qrgt1 overlying QTpa. (a) Exposure with clear juxtaposition of loose Qrgt1 over compacted, weakly cemented QTpa. Note white carbonate in QTpa concentrated just below the contact. Photo taken circa 301510 m E, 3708390 m N. (b) Exposure with less clear juxtaposition. Note better-developed/preserved sedimentary structures in Qrgt1 as compared to QTpa. Photo taken circa 301380 m E, 3707240 m N.

Figure 3.1. Exposure of Qpwn lying directly on QTpa with no intervening Qpwf. Photo taken circa 300815 m E, 3707700 m N.

(a)

(b)

Figure 4.1. Structures in basal Tbm circa 298190 m E, 3700040 m N. Rock hammer circled in each photo. (a) Sandstone dikes intruding the base of the basalt. (b) Pillow-like structures.

Figure 4.2. Outcrop of the generally massive pyroclastics of the diatreme of Pete Well.

(a)

(b)

Figure 4.3. Features of the Vicks Peak Tuff. (a) Flattened pumices. (b) Concentrically-laminated spherulites.

10. Map unit descriptions

Map Unit	Name	Age	Description (Note: Geologic terms after Compton (1985), soil terminology after Birkeland (1999), carbonate horizon stages after Machette (1985), and color notation after Munsell Color (2009).)
	Anthropogenic units		
daf	Disturbed ground and artificial fill	Historic (<500 years BP)	Disturbed ground and uncompacted gravels, sands, and muds associated with gravel pit operations. Only mapped where laterally extensive or concealing underlying geologic features. The deposit thicknesses are <1 to 5 m.
	Post-Santa Fe Group deposits		
	Eolian units		
Qes	Eolian sandsheet deposits	Holocene	Isolated areas of relatively thick eolian sand deposits. Sands are well-sorted, rounded, very fine- to fine-grained, and dominantly siliceous, with trace rounded tributary alluvial fine pebbles. Deposits are laminated and have pink to pale brown color (7.5YR 7/3 measured). Deposit thickness is up to 2 m.
	Rio Grande floodplain alluvium		
Rw05	Water	Recent (<50 years BP)	Areas of flowing or standing water apparent in 2005 digital aerial imagery.
Rsb05	Sand bar deposits	Recent (<50 years BP)	Areas of unvegetated sand bars apparent in 2005 digital aerial imagery.
Rcu	Channel deposits, undivided	Recent (<50 years BP)	Areas of the floodplain with banded surface textures such as vegetation trends apparent in 2005 digital aerial imagery. Banding only locally exhibits distributary branching. The unit is laterally gradational with the unit Rcs.
Rcs	Channel splay deposits	Recent (<50 years BP)	Areas of the floodplain with fanning/distributary surface textures such as vegetation trends apparent in 2005 digital aerial imagery. Distributary textures commonly can be traced back to current or former locations of the Rio Grande channel. The unitis laterally gradational with the unit Rcu.
Rau	Recent floodplain alluvium, undivided	Recent (<50 years BP)	Areas of the floodplain with non-distinct surface textures. Includes areas of the floodplain that have been artificially disturbed by land management activities such that primary surface textures are unrecognizable.
Rlls	Lakeshore sediments	Recent (<100 years BP)	Loose sands to gravels associated with highstands of Elephant Butte Lake. Sediments are principally reworked from underlying deposits and tributary alluvium. The unit is only mapped where particularly thick or extensive or where masking underlying geologic relationships. Thickness is likely no more than 4 m.

Qrgy	Holocene alluvium, undivided	Holocene	Cross-section only. Loose sands, gravelly sands, and muds underlying the Rio Grande floodplain. Up to 30 m thick.
	Generic alluvial deposits		
	Channelized piedmont alluvium		
Qar	Recent alluvium	Recent (<50 years BP)	Unvegetated gravels underlying active drainage channels. Gravels are loose and matrix-poor, in medium-thick, lenticular, trough cross-stratified beds. No notable soil development. Locally distinguished from surrounding historic alluvium by insetting relationships, particularly around I-25. Deposit thicknesses 0 to perhaps 2 m.
Qah	Historic alluvium	Historic (<500 years BP)	Poorly or non-vegetated gravels lying along and beneath active drainage channels. Gravels are loose and matrix-poor, commonly in medium-thick, lenticular, often trough cross-stratified beds. Gravel compositions are reflective of upstream exposed materials. No notable soil development. Not uncommonly overtops surrounding Qay deposits as thin channel splay or fluvial fan deposits. Deposit thicknesses 0 to 2 m.
Qayh	Younger and historic alluvium, undivided	Late Holocene	Deposits of historic and younger terrace alluvium that cannot be mapped separately at this scale. Commonly indicates areas with historic alluvium overtopping younger terrace alluvium. Deposit thicknesses 0 to 3 m.
Qayu	Younger and slopewash alluvium, undivided	Holocene	Alluvial deposits underlying low-gradient, non-channelized, slopewash-dominated drainageways. Deposits are poorly sorted, variably gravelly, variably muddy sands with absent to weakly-developed surface soils. Compositions reflect sediments exposed along hillslopes along the drainage way. Deposit thicknesses 0 to perhaps 1 m.
	Small-scale fan alluvium		
Qafy	Younger fan alluvium	Holocene	Brown sandy pebbles and pebbly sands underlying low-level fan and bajada surfaces emanating from low-order tributary drainages. Gravel and sand compositions are reflective of upstream exposed materials. Fan surfaces typically grade to younger terrace or historic alluvium levels. Surface soils are weakly-developed, bearing carbonate horizons with no more than Stage I morphology. Deposit thicknesses 0 to perhaps 2 m.

Qaf	Undivided fan alluvium	Middle(?) Pleistocene to Holocene	Sandy pebbles and pebbly sands underlying fan and bajada surfaces emanating from low-order tributary drainages and graded to surfaces above the modern arroyo floors. Gravel and sand compositions are reflective of upstream exposed materials. Fan and bajada surfaces typically grade to one of the older terrace levels or to the top of the Palomas, and the source drainage(s) is/are commonly incised into the fan or bajada surface. Surface soils are weakly- to well-developed, comparable to those of the older terrace levels. Deposit thicknesses 0 to perhaps 6 m.
	Axial-fluvial alluvium		
Qrgt2	Intermediate-level terrace alluvium	Upper Pleistocene	Loose, siliceous-lithology-rich, variably cobbly pebble-gravels underlying terrace treads along the Rio Grande with tread heights and surface soils comparable to those of Qaw2. Deposits are poorly exposed, and typically identified by an abundance of siliceous gravels at Qaw2 terrace levels. Where exposed, deposits are fining-upwards rounded pebbles with up to 15% cobbles and trace boulders of quartzite and chert with minor felsic-intermediate volcanic rocks, rare granites and basalts, and trace limestones and sandstones, in massive, thick, vague beds. Matrices consist of poorly sorted very fine to very coarse sand grains (fining upwards to fine to medium grains) of dominantly quartz and siliceous lithics. Where preserved, surface soils consist of Bk horizons with Stage II morphology just below terrace tread surfaces that are 22 to 24 m above the channel. Additional carbonate occurs as localized phreatic cement along preferential planes. Deposit thicknesses 0 to 7 m.
Qrgt1	High-level terrace alluvium	Middle Pleistocene	Loose siliceous sands, pebbly sands, gravels, and trace clay beds underlying high-level tributary alluvial deposits (Qan1, Qaw1) and overlying consolidated and variably cemented QTpa deposits. Sands are dominantly well-sorted, rounded, and fine- to medium-grained, coarser-grained and poorer-sorted where mixed with gravels, and occurring in prominently trough cross-stratified lenticular beds 0 to 70 cm thick. Gravels are dominantly rounded fine to medium pebbles of quartzite, granite, chert, felsic to intermediate volcanics, limestone and sparse foliated metamorphic rocks and "red bed" clastic sedimentary rocks. Clay beds are thin to medium planar to undulatory tabular beds with internal planar laminations; clay also occurs as trace mudballs. Sand colors are pink to very pale brown to light gray (7.5YR 7/3, 10YR 7/4, and 10YR-2.5Y 7/1 measured) with local redoximorphic coloration; clay beds are light reddish brown (5YR 6/4 measured). Preserved deposit thicknesses 0 to 4 m.
Qaw_	**Western piedmont alluvium**		Gravels and sands derived from the San Mateo Mountains and upstream Santa Fe Group deposits. Gravels are dominantly phenocryst-poor rhyolites, with absent to rare plagioclase±pyroxene andesitic porphyries, absent to rare quartz-feldspar rhyolitic porphyries, and absent to trace fine-grained limestone. Sands consist dominantly of rhyolitic lithics with lesser but common quartz and potassium feldspars, and absent to rare plagioclase and andesitic lithics.

	Generic terrace and tributary fan alluvium		
Qawy	Younger terrace alluvium	Holocene	Brown sandy pebbles and pebbly sands underlying low-level terrace treads with weakly-developed surface soils. Terrace treads are up to 2 m above nearby channels, and are a constituent of the modern arroyo floors. Soil development is characterized by A-Av/Bw/Bk surface soils with carbonate horizons of weak or discontinuous Stage I morphology. Matrices are free of clay films, with 7.5YR 4/4 color measured. Deposit thicknesses are 0 to 2 m.
Qaw	Older terrace alluvium	Middle Pleistocene to Holocene	Brown to reddish brown gravels and sandy gravels underlying discontinuous terrace treads and tributary fan surfaces overlooking modern arroyo floors with weakly- to well-developed surface soils. Usually assigned to one of three subunits. Where undivided map unit is used, deposit may reflect the characteristics of any combination of the below subunits.
Qaw3	Low-level older terrace alluvium	Holocene (to Upper Pleistocene?)	Brown to reddish brown gravels and sandy gravels underlying low-level terrace treads and tributary fan surfaces with weakly-developed surface soils. Terrace treads are 1 to 3 m above nearby channels and typically discontinuous. Soil development is characterized by A/Bwt/Bk surface soils with carbonate horizons of Stage I-I+ to weak, discontinuous Stage II morphology; clay in Bwt horizons are sparse, very fine to fine films on pebbles. Matrix colors of 7.5YR 4/4-5/4 measured. Deposit thicknesses 0 to 2 m.
Qaw2	Intermediate-level older terrace alluvium	Upper Pleistocene	Reddish brown to brown or yellowish red gravels and sandy gravels underlying intermediate-level terrace treads with moderately-developed surface soils. Terrace treads and tributary fan surfaces are 1 to locally 13 m above nearby channels, increasing downstream, with particularly high treads where the channel has breached the basalt of Mitchell Point. Soil development is characterized by A/Bwt-Bt/Bk surface soils with carbonate horizons of Stage II to weak, discontinuous Stage III morphology; clay in B(w)t horizons increases downstream from sparse very fine-fine films on gravels to rare fine-medium films and bridges between sands. Matrix colors of 7.5YR-5YR 5/4-4/4, 2.5YR 4/4, and 5YR 5/6 measured. Deposit thicknesses 0 to 2 m.
Qaw2-3	Low- to intermediate-level older terrace alluvium	Upper Pleistocene to Holocene	Units Qaw3 and Qaw2 undivided. Map unit used where the two cannot be mapped separately at this scale.

Qaw1	High-level older terrace alluvium	Middle Pleistocene	Reddish brown to brown gravels, sandy gravels, and sands underlying high-level terrace treads and tributary fan surfaces with well-developed, but partially stripped, surface soils. Terrace treads are 3 to 18 m above nearby channels, increasing downstream, with particularly high treads where the channel has breached the basalt of Mitchell Point. Soil development is characterized by Bk-K horizons at or just below the tread surface, with carbonate horizons of Stage III to locally III+ (plugged horizon without overlying laminae) morphology, and any previously overlying A and/or B horizons stripped by erosion. Clay occurs below the surface soil as sparse very fine-fine films on gravels. Matrix colors of 5YR-7.5YR 5/4 measured. Sand beds are only found along the Rio Grande inner valley, and consist of light brown (7.5YR 6/4 measured) variably muddy very fine grains of mainly quartz and volcanic lithics in thick planar tabular beds with vague internal planar stratification, which interbed with lenticular gravel beds. Deposit thicknesses 0 to 20 m.
Qawo	Older valley-margin fan alluvium	Middle(?) Pleistocene	Reddish yellow to reddish brown pebble gravels underlying high-level tributary fan surfaces with stripped surface soils. Gravels are poorly sorted fine to coarse pebbles with minor (<10%) cobbles. Matrices consist of variably clayey sands; sands are poorly sorted angular to subrounded very fine to very coarse grains; clay occurs as rare to common, fine to coarse bridges between sand grains and lesser gravel coats. Beds are medium to thick, massive to cross-bedded, and lenticular. Phreatic carbonate cement occurs along preferential bedding and cross-bedding planes. Fan surfaces are 16 to 40 m above nearby channels, increasing downstream, with particularly high surfaces where channels have breached the basalt of Mitchell Point. Surface soils are stripped. Deposit thicknesses 0 to 8 m.
Qan_	*Nogal Canyon alluvium*		Gravels and sands derived from the San Mateo Mountains and upstream Santa Fe Group deposits, and underlying terraces and tributary fan surfaces along the modern Nogal Canyon arroyo. Gravels are dominantly phenocryst-poor rhyolites and plagioclase±pyroxene andesitic porphyries in ratios of 3:1 to 1:2, with additional trace volcaniclastic sedimentary rocks and trace to rare Rio Grande-affinity lithologies (quartzite, chert, etc.). Sands consist dominantly of quartz and volcanic lithics.

Qan3	Low-level older terrace alluvium	Holocene (to Upper Pleistocene?)	Light brown sandy gravels and gravelly sands underlying low-level terrace treads and tributary fan surfaces with weakly- to moderately-developed surface soils. Terrace treads are 5 to 8 m above the nearby active channel, generally increasing downstream. Soil development is characterized by A/Bw/Bk surface soils with carbonate horizons of up to Stage II morphology. Color of 10YR 6/4 measured. Deposit thicknesses 0 to 5 m.
Qan2	Intermediate-level older terrace alluvium	Upper Pleistocene	Light brown gravels and sandy gravels underlying intermediate-level terrace treads and tributary fan surfaces with moderately-developed surface soils. Terrace treads are 8 to 13 m above the active channel, generally decreasing downstream. Soil development is characterized by A/Bwt/Bk surface soils with carbonate horizons of Stage II morphology; clay in Bwt horizons occurs as rare fine to medium films on gravels. Matrix colors of 7.5YR 6/4 measured. Deposit thicknesses 0 to 2 m.
Qan1	High-level older terrace alluvium	Middle Pleistocene	Brown to reddish yellow gravels and sandy gravels underlying high-level terrace treads and tributary fan surfaces with well-developed, but partially stripped, surface soils. Terrace treads are 16 to 24 m above the active channel, generally decreasing downstream. Soil development is characterized by Bk-K horizons at or just below the tread surface, with carbonate horizons of Stage III morphology, and any previously overlying A and/or B horizons stripped by erosion. Clay occurs below the surface soil as rare very fine-fine films on gravels and bridges between sand grains. Matrix colors of 7.5YR 5/4-6/6 measured. Deposit thicknesses 0 to 15 m.
Qaj_	*San Jose Arroyo alluvium*		Gravels and sands derived from the San Mateo Mountains and upstream Santa Fe Group deposits, and underlying terraces and tributary fan surfaces along the modern San Jose Arroyo. Gravels are dominantly phenocryst-poor rhyolites, with trace plagioclase±pyroxene andesitic porphyries and phenocryst-rich rhyolitic porphyries. Sands consist dominantly of rhyolitic lithics with lesser but common quartz and potassium feldspars, with absent to rare plagioclase.
Qaj4	Low-level older terrace alluvium	Holocene (to Upper Pleistocene?)	Light yellowish brown gravels and sandy gravels underlying low-level terrace treads and tributary fan surfaces with weakly-developed surface soils. Preserved terrace treads are 1.5 to 7 m above nearby channels, increasing downstream, with tread height projecting into the arroyo floor upstream. Soil development is characterized by A/Bk surface soils with carbonate horizons of Stage I morphology. Terrace deposits are poorly exposed, poorly sorted, subrounded pebbles with <1-1% cobbles in loose, unstructured tabular beds with matrices of very poorly sorted very fine to very coarse sands. Matrix color of 10YR 6/4 measured. Deposit thicknesses 0 to 1 m.

Qaj3	Low-intermediate-level older terrace alluvium	Upper Pleistocene	Yellowish red gravels and sandy gravels underlying low-intermediate level terrace treads and tributary fan surfaces with weakly-developed surface soils. Terrace treads are 6 to 9 m above the nearby channel, increasing downstream. Soil development is characterized by A/Bw/Bk surface soils with carbonate horizons of Stage I+ to II morphology. Clay occurs in the sandy matrix as detrital aggregates, but no films were observed. Color of 5YR 4/6 measured. Gravels are dominantly fine pebbles, with trace gravel up to 1 m diameter boulders, in thick massive tabular beds up to 60 cm thick. Deposit thicknesses 0 to 5 m.
Qaj2	High-intermediate-level older terrace alluvium	Upper Pleistocene	Yellowish red gravels and sandy gravels underlying high-intermediate level terrace treads and tributary fan surfaces with moderately-developed surface soils. Terrace treads are 11 to 34 m above the nearby channel, decreasing downstream. Surface soils are poorly exposed, but appear to bear carbonate horizons with Stage II+ to locally III morphology. Clay occurs in the sandy matrix as detrital aggregates, but no films were observed. Colors of 5YR 4/6-5/6 measured. Gravels are dominantly pebbles with rare (<3%) cobbles and trace boulders. Deposit thicknesses 0 to 6 m.
Qaj1	High-level older terrace alluvium	Middle Pleistocene	Gravels, sandy gravels, and sands underlying high-level terrace treads and tributary fan surfaces. Terrace treads are 16 to 23 m above the nearby channel, generally decreasing downstream. Terrace deposits are poorly exposed, and no evidence of preserved surface soils was identified; surface soils are potentially stripped. Gravels are dominantly pebbles with rare cobbles and trace boulders. Sand beds are only found along the Rio Grande inner valley, and consist of light brown variably muddy very fine grains of mainly quartz and volcanic lithics in thick planar tabular beds with vague internal planar stratification, which interbed with lenticular gravel beds. Deposit thicknesses 0 to perhaps 20 m.
Qae_	**Eastern piedmont alluvium**		Gravels and sands derived from the Fra Cristobal Mountains. Gravels consist of variable proportions of mainly limestone and granite with accessory schist, quartzite, rhyolite, sandstone, and basalt, with gravel lithologies present varying with the lithologies exposed upstream. Sands similarly vary in composition, with limestone lithics and quartz grains most common, and lesser amounts of feldspars and granitic lithics also present.
	Terrace alluvium		
Qaey	Younger terrace alluvium	Holocene	Grayish brown to brown sandy pebbles and pebbly sands underlying low-level terrace treads with weakly-developed or absent surface soils. Terrace treads are up to 1 m above nearby channels, and are a constituent of the modern arroyo floors, commonly exhibiting bar-and-swale microtopography. Soil development is weak to absent; maximum surface soil development is characterized by A/Bw/Bk horizonation with carbonate horizons of weak or discontinuous Stage I morphology. Deposit thicknesses are 0 to perhaps 2 m.

Qae	Older terrace alluvium	Middle Pleistocene to Holocene	Grayish brown to brown to yellowish brown gravels and sandy gravels underlying discontinuous terrace treads and tributary fan surfaces overlooking modern arroyo floors with weakly- to well-developed surface soils. Usually assigned to one of three subunits. Where undivided map unit is used, deposit may reflect the characteristics of any combination of the below subunits.
Qae3	Low-level older terrace alluvium	Holocene (to Upper Pleistocene?)	Brown to light brown gravels and sandy gravels underlying low-level terrace treads and tributary fan surfaces with weakly-developed surface soils. Terrace treads are 1 to 3 m above nearby channels and typically discontinuous. Soil development is characterized by A/Bw/Bk surface soils with carbonate horizons of Stage I morphology. Matrix colors of 7.5YR 5/4 measured. Deposit thicknesses 0 to 2 m.
Qae2	Intermediate-level older terrace alluvium	Upper Pleistocene	Grayish brown to locally reddish yellow gravels and sandy gravels underlying intermediate-level terrace treads and tributary fan surfaces with moderately-developed surface soils. Terrace treads are 3 to 40 m above nearby channels, increasing downstream and northward, with particularly high treads along the inner valley of the Rio Grande. Soil development is characterized by A/Bwt/Bk surface soils with carbonate horizons of Stage II-II+ to locally III morphology; clay in reddish yellow Bwt horizons occurs as rare very fine bridges between sands. Deposit thicknesses 0 to 6 m.
Qae1	High-level older terrace alluvium	Middle Pleistocene	Yellowish brown gravels and sandy gravels underlying high-level terrace treads and tributary fan surfaces with well-developed, but partially stripped, surface soils. Preserved terrace treads are 4 to 30 m above nearby channels, increasing downstream and northward. Soil development is characterized by Bk-K horizons at or just below the tread surface, with carbonate horizons of Stage III to locally III+ (plugged horizon without overlying laminae) morphology, and any previously overlying A and/or B horizons stripped by erosion. Matrix colors of 10YR 5/4 measured. Deposit thicknesses 0 to about 10 m.
Qaes	Sandy older alluvium	Middle Pleistocene	Pink to yellowish brown variably clayey sands with interbedded lenticular gravels inset into surrounding Palomas-age deposits and underlying younger post-Palomas alluvial deposits. Sands are poorly sorted; clayey, silty, or clean; very fine- to fine-grained; and rounded, of dominantly quartz, lesser siliceous lithics, and trace limestone and volcanic lithics, occurring in poorly exposed, uncemented, medium-thickness planar tabular beds. Clays occur as detrital chips; no pedogenic films were observed. Colors of 7.5YR-10YR 5/4 and 7/3 measured. Deposit thicknesses 0 to locally about 20 m.
	Mountain front alluvium		

Qap	Piedmont fan alluvium	Upper Pleistocene to Holocene	Gravels and sandy gravels underlying alluvial fan surfaces along the western foot of the Fra Cristobal Mountains. Gravels are poorly sorted subrounded pebbles to boulders of varying proportions of mainly limestones and granites with lesser foliated metamorphic rocks, quartzites, sandstones, and rhyolites; proportions vary with lithologies exposed in the nearby mountains. Sands are poorly sorted very fine to very coarse grains of quartz and lithics of compositions comparable to the gravels. Surface soils vary from no development to A/Bw/Bk horizonation, with Bk horizons exhibiting up to Stage II+ morphology. Where insetting relationships, surface textures, or expose soils and map scale permit differentiation of older and younger subunits, Qap is subdivided into a younger Qapy and older Qapo. Deposit thicknesses 0 to at least 6 m.
Qapy	Younger piedmont fan alluvium	Holocene	Gravels and sandy gravels underlying alluvial fan surfaces along the western foot of the Fra Cristobal Mountains with surface or soil evidence indicating a younger subunit age. Sedimentologic characteristics like those of unit Qap. Surface soils vary from no development to A/Bw/Bk horizonation, with Bk horizons exhibiting up to Stage I+ morphology. Surfaces commonly exhibit bar-and-swale microtopography, and are inset below surfaces capping nearby Qapo deposits. Deposit thicknesses 0 to at least 6 m thick.
Qapo	Older piedmont fan alluvium	Upper Pleistocene to Holocene	Gravels and sandy gravels underlying alluvial fan surfaces along the western foot of the Fra Cristobal Mountains with surface or soil evidence indicating an older subunit age. Sedimentologic characteristics like those of unit Qap. Surface soils consist of A/Bw/Bk horizonation, with Bk horizons exhibiting Stage I+ to Stage II+ morphology. Surfaces may exhibit subdued bar-and-swale microtopography, and lie above inset surfaces capping nearby Qapy deposits. Deposit thicknesses 0 to at least 6 m thick.
	Santa Fe Group deposits		As defined by Baldwin (1963) and Hawley et al. (1969).
	Palomas Formation		As defined by Lozinsky and Hawley (1986).
	Axial-fluvial alluvium		
Qpai	Interbedded axial-fluvial and piedmont deposits	Gelasian to Calabrian (Lower Pleistocene)	Light gray Rio Grande-derived variably pebbly sands interbedded with eastern piedmont sands and gravels. Axial sands consist of moderately to poorly sorted, subrounded to rounded, fine to coarse sands of dominantly quartz with minor feldspars and rare chert and volcanic lithics. Axial pebbles, generally sparse, are of quartzite, chert, rhyolitic and intermediate volcanics, and gravel reworked from the eastern piedmont. Beds are thin to medium, lenticular, trough cross-stratified, and uncemented. Color of 2.5Y 7/2 measured. Eastern piedmont sediments are like those described for unit Qpeu. Map unit used where poor exposures and/or map scale prevents mapping piedmont and axial deposits separately. Thickness as much as about 25 m.

QTpa	Axial-fluvial facies	Pliocene to Gelasian (Lower Pleistocene)	White to pink to very pale brown, trough cross-stratified, locally concretionary, variably pebbly siliceous sands/sandstones. Sands are moderately-poorly to well sorted, subangular to rounded, very fine to very coarse grains of dominantly quartz with minor crystalline siliceous lithics, minor basaltic lithics, and trace each of felsic-intermediate volcanic lithics, chert, feldspars, black ferromagnesian lithics, and detrital clay aggregates, in thin to medium, lenticular beds. Colors of 7.5YR-10YR 7/2-7/4 and 8/1-8/2 common, with local reddish yellow colors (5YR-7.5YR 6/6) beneath unit Qpwn. Clayey mud/mudstone beds are generally trace in abundance but are locally common. Gravels are up to 15% of beds, mainly pebbles with trace cobbles, poorly to moderately sorted, mainly subrounded to well rounded, and consist of common felsic-intermediate volcanic rocks, variable quartzites and granites, rare cherts and basalts, and trace clastic sedimentary rocks. Cementation is highly localized, and exposures are poor. Base unexposed; unit thickness at least 60 m.
Tpa	Axial-fluvial facies underlying Pliocene volcanics	Pliocene	Axial-fluvial variably pebbly sands/sandstones like those of QTpa, with age constrained to Pliocene by overlying or cross-cutting igneous rocks.
	Western piedmont alluvium		
Qpwc	Dominantly gravelly deposits	Calabrian (Lower Pleistocene)	Yellowish red to pink, variably cobbly pebble conglomerates with rare sandy conglomerates to sandstones. Gravels are dominantly poorly sorted, subangular to rounded, fine to coarse pebbles with rare cobbles and trace boulders in medium to very thick (max 1.5 m thick), commonly cross-stratified (tangential and trough), matrix-poor (<5%), lenticular beds; locally, cobbles are common (up to 25%), or matrix is more abundant (up to 15%). Gravel are mainly phenocryst-poor rhyolites with absent to rare plagioclase±pyroxene andesitic porphyries, absent to rare quartz-feldspar rhyolitic porphyries, and trace fine-grained limestones. Matrices are poorly sorted clayey fine to very coarse sands; sands are dominantly rhyolitic lithics with lesser but common feldspars and quartz. Clay typically occurs as common medium-coarse films that coat gravels and bridge sand grains; cobbly and sandy beds typically bear less abundant and/or finer clays. Colors of 5YR 5/4-5/8 and 7/4 measured. Unit bears very local buried soils with Bt and Bk horizons with up to Stage II morphology. Lower contact is placed where conglomerates become >50% of exposures. On-quad unit thickness varies from 0 to at least 40 m.

Qpwf	Dominantly sandy deposits	Gelasian to Calabrian (Lower Pleistocene)	Pinkish gray to light brownish gray variably muddy sands/sandstones with local gravelly sandstone and conglomerate channel-fills. Sands are dominantly moderately to poorly sorted and very fine- to fine-grained, with rare medium to coarse grains in lenticular channel fills, and consist of common volcanic lithics and quartz, rare to common potassium feldspar, and rare plagioclase in medium to thick beds that are massive and tabular to cross-stratified and lenticular. Gravels are poorly to moderately sorted, mainly pebbles with rare cobbles and trace boulders, of fine-grained rhyolites to subequal rhyolites and plagioclase±pyroxene porphyry andesites, with additional trace fine-grained limestones. Gravelly channel-fills occur as medium-thick (up to 40 cm thick), lenticular, massive or cross-stratified beds, and constitute 0 to 50% of exposures, with abundance increasing upsection. Unit bears buried soils marked by Bw, Bt, and/or Bk horizons with up to Stage II+ morphology that become increasingly common upsection. Unmodified colors of 7.5YR-10YR 6/2-7/3 and buried soil colors as strong as 5YR 4/6-6/4 measured. Interbedded lower contact, locally irregular upper contact. Overall unit thickness 0 to as much as 80 m.
Qpwn	Gravelly deposits along Nogal Canyon	Gelasian(?) to Calabrian (Lower Pleistocene)	Yellowish red pebble conglomerates. Gravels are dominantly poorly sorted, subrounded, coarsening-upsection fine to coarse pebbles with rare cobbles in thick, vaguely-defined lenticular to tabular, locally cross-stratified, commonly matrix-poor beds. Sand matrix is as much as 20% of beds at the base, decreasing upsection; cobbles generally are <10% of beds. Gravel are mainly phenocryst-poor rhyolites with less common (up to 20%) plagioclase±pyroxene andesitic porphyries. Matrices are poorly sorted, clayey, subangular to rounded, medium- to very coarse-grained sands of quartz and volcanic lithics. Clay occurs as common to ubiquitous medium to coarse films that coat and bridge between grains. Matrix color of 5YR 5/6 measured. Deposits are as much as 15 m thick.
	Eastern piedmont alluvium		
Qpeu	Upper gravel-dominated deposits	Gelasian to Calabrian (Lower Pleistocene)	Pink to brown and locally yellowish red variably sandy gravels/conglomerates and rare sands/sandstones. Gravels consist of poorly sorted subrounded pebbles, rare cobbles, and trace boulders of varying proportions of mainly limestones and granites with lesser foliated metamorphic rocks and quartzites and trace sandstones; clast lithologies vary with the bedrocks exposed upstream. Matrix materials and sand beds consist of poorly sorted very fine to very coarse grains of quartz and lithics, with variable cementation by clay, carbonate, or sparry calcite. Lenticular beds are thin to medium and commonly cross-stratified. Unit grades laterally into Qpai in the southern part of the field area, and overlies QTpa and Qpef in the northern part. Unit thickness up to at least 40 m.

Qpef	Upper sand-dominated deposits	Calabrian (Lower Pleistocene)	Light yellowish brown to pink to reddish yellow variably muddy sands/sandstones with lesser gravelly sandstone and conglomerate channel-fills. Sands are poorly sorted dominantly very fine- to fine-grained, with rare medium to coarse grains, of common quartz and lesser siliceous and granitic lithics, in medium-thickness generally massive planar tabular beds and less common lenticular cross-stratified beds. Gravels in rare channel fills are poorly to moderately sorted, mainly pebbles with rare cobbles, of mainly granite with lesser foliated metamorphic rocks, quartzite, and trace limestone. Channel-fills occur as medium-thickness, lenticular, massive or cross-stratified beds, and constitute up to 50% of exposures and commonly <10% of exposures. Colors of 7.5YR-10YR 6/4-8/3 and 5YR 6/6 measured. Unit thickness 0 to as much as 40 m.
QTpae	Piedmont and axial deposits, undivided	Pliocene to Gelasian (Lower Pleistocene)	Cross-section only. Undivided interfingering eastern piedmont conglomerates and sandstones and axial pebbly sandstones, likely including intercalated volcanic rocks. Exposures to the north and south of the cross-section line suggest axial deposits may extend to within 600 m of the basin-bounding fault along the base of the Fra Cristobal Mountains. Unit thickness unconstrained.
	Syn-Santa Fe Group igneous rocks		
	Volcanics along The Narrows		
Qbrg	Basalt of the Rio Grande	Gelasian (Lower Pleistocene)	Dark gray xenolithic fine porphyry basalt. Phenocrysts are rare and commonly weathered to reddish replacement minerals; unweathered crystals consist of olivine, pyroxene, and plagioclase. Weathered faces commonly exhibit pale gray "spots" up to 2 mm across. Flow bears trace upper mantle-lower crustal xenoliths; Warren (1978) reports a xenolith suite of pyroxenites, granulites, olivine megacrysts, and lherzolites. Thickness 0 to about 20 m.
Qbc	Basaltic cinder	Gelasian (Lower Pleistocene)	Dark reddish brown to black scoriaceous pyroclastics. Dominantly aphanitic lapilli to bombs with trace fine pyroxene phenocrysts up to 1 mm across. Base unexposed; thickness 0 to at least 20 m.
	Salt cedar diatreme		Use of the terms "maar" and "diatreme" is after White and Ross (2011).
Qdsc	Salt cedar diatreme	Gelasian (Lower Pleistocene)	Commonly foliated pink tuff and lesser lapilli-tuff. Beds are principally coarse basaltic ash with as much as 35% vesicular dark gray basaltic lapilli and lesser fine ash, with as much as 20% accidental lithics of siliceous sand grains and trace pebbles of granite, quartzite, and xenolith-bearing basalt. Finer ash grains (<1 mm across) are variably degraded to pale yellowish brown clays. Beds are medium-thickness, undulatory to massive, with foliations generally dipping toward the center of the outcrop extent. Color of 10YR 7/2 measured. Diatreme is inset into surrounding QTpa in outcrop and inferred to cross-cut unit Tbm. Unit exposed width of up to about 790 m.

Qmpc	Salt cedar outflow pyroclastics	Gelasian (Lower Pleistocene)	Pink to light brown, variably fluvially-reworked, accidental lithic-rich basaltic tuff. Ash is mainly coarse grains of variably weathered, vesicular basaltic material, with trace basaltic lapilli up to 15 cm across also present, in thin undulatory to tabular beds with weak internal cross-stratification. Accidental lithics and additional material incorporated by reworking consist mainly of fine siliceous sand grains. Colors of 7.5YR 7/2-7/3 and 6/4 measured. Thickness trends suggest Qmpc forms a thin, laterally-restricted ejecta ring around unit Qdsc. Although not exposed in outcrop, Qmpc appears to lie stratigraphically below unit Qbrg. Unit thickness 0 to locally about 10 m.
	Mitchell Point volcanics		
Tbm	Basalt of Mitchell Point	Pliocene	Dark gray fine porphyry basalt. Fine (<1 mm across) phenocrysts are common (up to 30% of fresh faces) and consist of pyroxene, plagioclase, and olivine, with trace coarser phenocrysts up to 4 mm across. Unit intercalates with QTpa in outcrop. ^{40}Ar/^{39}Ar age of 3.0 Ma (Table 4.1). Thickness 0 to 35 m.
Tbmc	Cinder of Mitchell Point	Pliocene	Black to locally dark reddish brown, commonly vesicular, basaltic bombs and lapilli with local irregular bands of solid basalt. Bombs and solid basalt bear rare (up to 5%) phenocrysts of plagioclase. Siliceous sands and trace siliceous pebbles commonly mix with and mantle basaltic material at the surface. Deposit base unexposed; thickness perhaps as much as 55 m.
Tmpp	Pyroclastics of Mitchell Point	Pliocene	Pinkish white to very pale brown, variably fluvially-reworked pyroclastics underlying and interfingering with the basalt of Mitchell Point. Primary pyroclastic deposits are planar- to undulatory-tabular laminated to thinly-bedded lapillistone to lapilli-tuff consisting of variably-weathered, dark gray, vesicular basaltic lapilli with minor to subequal (10-50%) basaltic ash (variably degraded to clay) and rare (up to 2%) accidental siliceous sands and pebbles. Fluvial reworking is apparent in enrichment of siliceous sands and pebbles; thoroughly reworked beds consist of basalt pebble-bearing sandstones or sandstones dominated by basaltic lithic grains. Individual outcrops may bear no reworked beds or be all reworked. Colors of 7.5YR 7-8/2 and 10YR 7/4-8/3 measured. Unit thickness 0 to 4 m.
	Miscellaneous diatremes		

Qdss	Sand sheet diatreme	Gelasian (Lower Pleistocene)	Light yellowish brown basaltic lapilli-tuff and lesser coarse tuff with common accidental lithics. Lapilli consist of black to very dark gray scoriaceous basaltic clasts; ash is basaltic material variably weathered to pale yellowish clays. Accidental lithics are principally siliceous sand grains with lesser feldspar grains and trace siliceous fine pebbles. Beds are thin to medium, generally well-foliated, and typically tabular in outcrop. Color of 2.5Y 6/3 measured. Unit exposed width of up to about 390 m.
Tdpw	Diatreme of Pete Well	Pliocene	Light brown to pink juvenile pyroclastic material with abundant incorporated siliceous sands and lesser pebbles. Pyroclastic material is dominantly ash that is commonly degraded to clays that bridge and envelope coarser juvenile and incorporated material; 5-25% of outcrops is angular-subangular, dark gray to black, vesicular and amygdule-bearing basaltic lapilli up to 10 cm across. Abundant rounded fine- to medium-grained siliceous sands, rare (up to 5%) rounded siliceous and granitic pebbles, and trace pale brown clayey mudballs are thoroughly incorporated in and supported by the ash matrix. Exposures are typically massive and form rounded blocky outcrop, with local vague planar tabular foliations. Colors of 7.5YR 6/4 and 7/3 measured. Exposed width of diatreme is up to 330 m.
Tdsj	Diatreme of San Jose Arroyo	Pliocene	Prominently foliated pinkish gray to pink juvenile pyroclastic material with common incorporated siliceous sands. Foliations are undulatory to tabular and defined by a very thin (1-3 cm thick) layering. Layers are dominantly ash with up to 50% accidental lithics of siliceous sand grains and up to 5% lapilli. Approximately 10% of beds are 30 to 60% lapilli. Lapilli are variably weathered black to yellowish brown subangular basaltic material up to 15 cm across. Ash color of 7.5YR 7/2 measured. Trace rounded siliceous pebbles also present. Exposed width of 380 to 490 m.
	Pre-Santa Fe Group rocks		
	Oligocene volcanics		
Tvp	Vicks Peak Tuff	Oligocene	Light gray, weathering pale brown to black, phenocryst-poor, well-foliated, generally pumice-rich rhyolitic ignimbrite. Phenocrysts are <1-1% of faces, and are mainly <1 mm-across (locally up to 3 mm-across) sanidines. Pumices constitute 5 to 35% of faces and are commonly strongly flattened, and are also commonly granular-textured from recrystallization. Concentrically-laminated spherulites as much as 8 cm across are 0 to locally 15% of outcrops. Ar-Ar age estimate of 28.4 Ma (Table 4.1). Base unexposed, unit thickness at least 80 m.
	Permian System		

Psa	San Andres Formation	Permian (Leonardian-Guadalupian)	On this quadrangle, consists of highly fractured, medium gray, granular limestone. Thin arcuate traces of sparry calcite may be replaced fossils; Cserna (1956) reported small gastropods. Thickness unconstrained on quadrangle; Nelson et al. (2012) estimate a maximum of 160 m within the Fra Cristobal Mountains.
	Cataclastic rocks		
sbr	Silicified breccia	Paleocene? to Pliocene?	Silicified breccia lying along the basin-bounding fault at the base of the Fra Cristobal Mountains. Breccia shows evidence of multiple periods of brecciation and silicification. Breccia clasts are angular pale gray silicified material generally <6 cm across; the nature of the protolith is obscured by heavy silicification. Clasts are surrounded and often supported by ubiquitous reddish brown siliceous cement (jasper). Clasts and cement are cross-cut by rare thin mineralized fractures and veins of black, bulbous oxides and sparry calcite. Unit extends off-quadrangle eastward, grading into solid rock over several tens of meters.