NEW MEXICO BUREAU OF GEOLOGY & MINERAL RESOURCES
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Qsth **Stream terrace deposits (lower Pleistocene) –** High-level, sandy gravel terrace deposits near the Pojoaque River, Rio Tesuque, Calabasa Arroyo, and Cañada Ancha. At least three terrace levels are present. The lower contact between these deposits and the underlying Tesuque Formation is marked by an angular unconformity and scour. Color of the sand fraction is commonly light yellowish brown to pale-brown to very-pale-brown (10YR 6-7/3-4). Sand and gravel beds are very thin to medium and lenticular to concave-up, ribbon-shaped. Gravel is dominated by pebbles and cobbles, with <10% boulders. Gravel is poorly to moderately sorted and clast-supported. Gravel is composed of granite to granitic gneiss with minor quartzite and Paleozoic limestone-siltstone and very minor amphibolite, schist, and chert (latter found to the south). Quartzite clasts are relatively abundant (30-60%) along Calabasa Arroyo, and Cañada Ancha but <10% to the north. Boulders, cobbles, and very coarse pebbles are rounded to subrounded; medium- and coarse pebbles are subrounded to subangular, and very fine to fine pebbles are subrounded to angular. Sand is fine- to very coarse-grained, subangular to subrounded, poorly to moderately sorted, and arkosic. Locally, there is evidence of a calcic soil horizon, generally eroded, that has a stage III to IV carbonate morphology. Both the Tsankawi and Guaje Pumice beds (1.2 and 1.6 Ma) have been noted these deposits, as well as pumice-lapilli from Cerro Toledo Rhyolite eruptions (Koning and Maldonado, 2001; Borchett et al., 1998). Terrace straths are 60-85 m above modern grade of Rio Tesuque and Pojoaque in the northern part of the quadrangle. Sediment is unconsolidated and 1-15 m thick.

QTgt **Gravel terrace deposits (lower Pliocene to lower Pleistocene) –** Stream sandy gravel terrace deposits that are typically poorly exposed and occupy the tops of ridges in the Santa Fe uplands (the highlands coincide with the Rio Tesuque-Santa Fe River drainage divide north of Santa Fe). Most of these deposits have been assigned to one of three mapped strath terrace deposits. An inset relationship with the Tesuque Formation is observed at one locality for the middle terrace (Koning and Maldonado, 2001). Beds are very thin to thin and dip less than 2° to the west. Gravel are poorly to moderately sorted and consist of 30-50% pebbles, 50-70% cobbles, and less than 20% boulders; the gravel forms a protective armor on exposed surfaces. Coarse to very coarse pebbles, cobbles, and boulders are subrounded to rounded; very fine to medium pebbles are subrounded to subangular. Clast composition is generally about 25-50% quartzite and 50-75% granite with <1% amphibolite, schist, and chert; and trace to 3% chert. Sand is mostly light yellowish brown (10YR 6/4) with minor pink (7.5YR 7/4) and yellowish brown (10YR 5/4). Sand is very fine- to very coarse-grained, moderately to well sorted, subangular to subrounded, and arkosic. The straths of the terrace deposits are generally expressed by a vertical distance of approximately 6 m. The upper two terrace straths projects at least 30 m above the southward base of the Ancha Formation (unit Ta) west of Cañada Ancha. Thus, the higher strath terraces are interpreted to have formed before erosion that produced the scoured lower contact of the Ancha Formation, approximately dated by zircon fission-track methods as 2.7 Ma (Manley and Naeser, 1977). Because the textures and composition of these high-level terrace deposits is notably different than the Ancha Formation (the terrace deposits being much coarser and significantly richer in quartzite clasts), the age difference between the Ancha Formation and these high-level terrace deposits is interpreted to be significant, with the terrace deposits perhaps extending into the lower Pliocene. Sediment is unconsolidated and 1-6 m-thick (locally up to 12 m-thick).

Pleistocene-Pliocene tephra, phreatomagmatic, and lava deposits

Qect **El Cajete tephra (lower Pleistocene) –** Pyroclastic-fall deposits of white, vesicular, pumice lapilli of rhyolitic composition that were erupted from the El Cajete crater within the southwestern Valles caldera. Vesicular pumice lapilli contain phenocrysts of quartz (some with clinopyroxene reaction rims), biotite, and plagioclase with rare microphenocrysts of hornblende and clinopyroxene. Most exposures have been reworked by slope processes. Miyaji et al. (1980) report a zircon-fission-track age of 170 a 70 ka. Toyoda et al. (1995) and Toyodo and Goff (1996) interpret ESR ages of about 53 a 6 ka for El Cajete and 59 a 6 ka Battleship Rock Members. Reneau et al. (1996) obtained thermal luminescence ages of 48 a 5 to 61 a 9ka for soils buried beneath the El Cajete fallout pumice, and a 14C age >50 ka for charcoal within the pumice deposit. Generally less than 1 m-thick. [Description is from Dethier, 1997; Sawyer et al., in review].

Qcrv **Cerros del Rio volcanic rocks (lower Pleistocene) –** Thin to thick flows of basalt, mugearite, and related rocks that are found in the southwestern Cerros del Rio volcanic field. Flow tops and bases brecciated. Overlies and fills canyons cut into older basalt and basaltic andesite. Source is an eroded, faulted cone and related vents east of the Tetilla Peak Recreation area. 40Ar/39Ar ages1.46 a 0.06 Ma, 1.31 a 0.08 Ma, and 1.14 ± 0.13 Ma (Thompson et al., 2006). Maximum exposed thickness 20 m. [Description modified from David P. Dethier, unpublished Cochiti Dam 7.5' Description of Map Units].

Qbt **Tshirege Member of the Bandelier Tuff (lower Pleistocene) –** Nonwelded to welded pyroclastic flows (Tshirege Member) and an underlying thin (<1 m) pumiceous fall unit (Tsankawi Pumice Bed), both of rhyolitic composition and derived from a powerful eruption associated with the Valles caldera. Common colors of white, gray, orange, and pink. The tuff contains 15-30% crystals of sanidine and quartz, rare microphenocrysts of black clinopyroxene and trace microphenocrysts of hypersthene (near the top) and fayalite (Broxton et al., 1995). Chatoyant sanidine is common within devitrified intervals of the deposit and anorthoclase is present in the upper part of the tuff. Hornblende-dacite pumice lapilli comprise less than 1 volume percent of the deposit and are most common in the earliest erupted ejecta, including the Tsankawi Pumice Bed (Stimac, 1996). Contains multiple flow units and at least four cooling units (Griggs, 1964; Bailey et al., 1969; Broxton et al., 1995). Dominates surface west of the Rio Grande and forms one prominent outcrop east of the Rio Grande (Section H of Dethier, 1997). As mapped, may include exposures of Otowi Member of Bandelier Tuff, which it lies above. Paleoflow direction to the east. Derived from the Valles caldera west of the map area. 40Ar/ 39Ar ages from single-crystal-sanidine range from 1.21-1.26 (Izett and Obradovich, 1994; Spell et al., 1996a, b; Phillips et al., 2007). Thickness is highly variable because of pre-existing topography. Thickness is generally 60 m or less, but locally is as much as 180 m. [Description slightly modified from Dethier, 1997, and Sawyer et al., in review].

Qbo **Otowi Member of the Bandelier Tuff (lower Pleistocene) –** Slightly to non-welded pyroclastic flows (Otowi Member) of pumiceous rhyolite and an underlying compound, rhyolitic pumiceous fall unit (Guaje Member) as thick as 6 m, both derived from the Valles Caldera. Common colors of white, light gray, and orange. Consists of multiple flow units forming a single cooling unit (Smith and Bailey, 1966; Broxton et al., 1995). Generally contains more abundant accidental and accessory lithic fragments than the Tsirege Member. Contains 5-10% crystals composed almost entirely of sanidine and quartz with traces of clinopyroxene, plagioclase, and hornblende (Broxton et al., 1995). Sanidine is chatoyant within devitrified intervals of the tuff. Derived from the Valles caldera west of the map area. Lies beneath upper Bandelier Tuff. Single-crystal-sanidine 40Ar/ 39Ar ages is 1.61-1.63 Ma (Izett and Obradovich, 1994; Spell et al., 1996a,b). Fills canyons as deep as 50 m cut into Cerros del Rio basalts, basaltic andesite, and phreatomagmatic deposits (collectively unit Tcv). Maximum thickness about 50 m (165 ft). [Description slightly modified from Dethier, 1997, and Sawyer et al., in review].

QTcrv **Cerros del Rio volcanic rocks (upper Pliocene to lower Pleistocene) –** Basalt, basaltic andesite, and andesite lava flows and associated phreatomagmatic deposits that cap the Caja del Rio Plateau. Central-vent volcanoes typify the eruptive centers in this field, and range from low-relief shields to steep-sided, breached cinder cones (Thompson et al., 2006). SiO2 conent ranges from 48 to 65 wt percent (mostly 48-60%; Thompson et al., 2006). Low silica, subalkaline basaltic lavas were generally erupted from broad shield volcanoes, are relatively thin (<3-4 m), and had long travel distances (Thompson et al., 2006). The basalt flows are medium- to dark-gray and generally contain olivine and clinopyroxene phenocysts in a fine-grained groundmass (Koning and Maldonado, 2001; Shroba et al., 2005; Koning and Hallett, 2000). Flows may display flow banding as well as varying degrees of vesiculation. The higher silica lavas (basaltic andesite and andesite) were erupted from high-relief, steep-sided vents, are thicker (as much as 30 m), and more discontinuous (Thompson et al., 2006). Basaltic andesite flows are medium-dark-gray with olivine phenocrysts in a fine- to medium-grained groundmass. Flow tops are similar to the basalt flows but are thicker and the lower part of the flows is platy (Koning and Maldonado, 2001). Andesite flows are brownish-gray to medium-gray and occasionally flow banded (Koning and Maldonado, 2001). These contain clinopyroxene and hornblende phenocrysts in a fine- to medium-grained groundmass (Shroba et al., 2005). Their flows are commonly massive and blocky (Shroba et al. 2005). Phreatomagmatic deposits and lapilli generally underlie the package of aforementioned flows. They are exposed along the eastern edge of the Caja del Rio Plateau, but are also found interbedded within the Ancha Formation. Primary ejecta lapilli is black and in very thin, planar to wavy, even beds or laminations. The phreatomagmatic deposits are composed of pale brown to very pale brown tuff and with 3-20% pebbles. The age of the volcanic rocks range from 2.7 to 1 Ma, with most rocks being 2.7-2.2 Ma (early to middle phase of Thompson et al., 2006). Thickness of the volcanic pile ranges from a few meters along the eastern margin to 100-240 m in the central part of the Caja del Rio Plateau [Description taken fromThompson et al., 2006]

QTbt **Basaltic tephra (upper Pliocene to lower Pleistocene) –** Interbedded basaltic lapilli (both primary and reworked magmatic ejecta) and phreatomagmatic sediments that underlie Cerros del Rio volcanic flows and overlie the Ancha and Tesuque formations. This unit locally includes subordinate beds of the Ancha Formation. Surge-and-fall deposits are moderately sorted and contain subangular to subrounded volcanic lapilli composed of basalt and basaltic andesite, ash, and cinders. Basaltic lapilli from surge-and-fall deposits is very thin, planar to wavy, even, distinct, well to moderately sorted, and clast-supported beds or laminations. This lapilli is black (5Y 2.5/1) and clast size is mostly 0.5-16 mm. Welding of adjacent lapilli is observed in primary magmatic vents. Bombs, up to 25 cm long, have formed impact-related depressions on the underlying sediment. Most deposits of this unit are reworked from primary ashfall (tephra) deposits and contain various amounts of sand-size quartz, feldspar, and locally scattered granite and siltstone clasts less than about 4 cm in diameter. These non-volcanic minerals and rock fragments were derived from the underlying Santa Fe Group. Some of the thicker beds of basaltic tephra are horizontally to sub-horizontally bedded and moderately well sorted, and contain one or more upward-fining sequences. Poorly to well developed cement grading is present locally. Basaltic tephra is black (2.5Y 2/0), but some grains are altered and are tan (10YR hue). The phreatomagmatic deposits are more common in the lower part of this unit and composed of pale brown to very pale brown (10YR 6-7/3) clayey-silty or sandy and with 3-20% pebbles. The sediment is in medium to very thick beds and is internally massive, matrix-supported, poorly sorted, and lacks sedimentary structures. Basaltic grains are subrounded and the granitic grains are subangular. The proportions of basalt to granite clasts vary greatly, but quartzite comprises less than 2% of the clasts. Minor, 5-10 cm thick, clast-supported lapilli lenses of very coarse-grained sand are locally found within this sediment. Up to five buried soils may be present on the phreatomagmatic deposits (Koning and Maldonado, 2001). The basaltic lapilli and phreatomagmatic deposits may locally be overlain by 1.5-6 m of light yellowish brown to very pale brown (10YR 6-7/4 and 10YR 8/2) silt-clay and very fine- to fine-grained sand with 2-5% basaltic and granitic pebbles and coarse sand. The top surface of this fine sediment is somewhat irregular because of post-depositional erosion. Overlying lava flows of unit Tcrv unconformably overlie this fine sediment and locally fill channels 10-15 m deep. The tephra has not been directly dated, but must immediately pre-date or overlap with ages of Cerros del Rio lava flows (2.2-2.7 Ma; Thompson et al., 2006). Thickness increases from 1-4 m near Las Campañas to as much as 60 m in mears near White Rock Canyon (mostly 10-30 m).

Santa Fe Group

Like other basins in the Rio Grande rift, the Española Basin is filled by siliciclastic sediment (primarily sand, with lesser silt, clay, and gravel) and volcanic rocks of the Santa Fe Group of Spiegel and Baldwin (1963), which ranges in age from upper Oligocene through lower Pleistocene (Smith, 2000a; Koning et al., 2002b; Koning and Aby, 2005; Koning et al., 2005a). In the Española Basin, pre-Pliocene strata of the Santa Fe Group has been divided into the Tesuque Formation (Spiegel and Baldwin, 1963) and the somewhat coarser-grained, overlying Chamita Formation (Galusha and Blick, 1971) – the latter being subdivided into the Hernandez, Vallito, Cejita, and Cuartelles Members west of the Rio Grande (Figure 3, Koning and Aby, 2005). The Tesuque Formation jas been divided into formal members that include the Nambé, Skull Ridge, and Pojoaque Members southeast of Española (in ascending stratigraphic order; Galusha and Blick, 1971).

The Tesuque Formation has also been subdivided into lithofacies assemblages, which are more easily recognized, practical, and applicable for the Tesuque Formation in the map area. These assemblages are termed lithosome A, B, S, and E. Lithosomes A and B are distinguished using composition, source area, and paleocurrent data (Cavazza, 1986). Both of these lithosomes extend vertically across the Nambe, Skull Ridge, and Pojoaque Members of Galusha and Blick (1971) and do not coincide with these three previous members. Lithosomes A and B each relate to separate drainage systems in the eastern Española Basin, which accounts for their different compositional and paleocurrent properties. Lithosome A was deposited by a piedmont-wide, west-flowing streams flowing out of the western Sangre de Cristo Mountains and deposited on an alluvial slope. An alluvial slope is a geomorphic feature, typically near the outer margins of the basin, whose surface slopes away from the foot of adjoining mountains or hills and is subject to deposition of sediment from this adjoining high topography. The sediment of lithosome A is characterized by having granite-dominated gravel and arkosic sand (and having abundant potassium feldspar and granitic lithic grains). Lithosome B was deposited by larger streams (or rivers) draining the Peñasco embayment (located in the northeast corner of Española Basin) and the San Luis Basin to the north of the Española Basin. Having a heterolithic composition, lithosome B occupies a basin-floor depositional environment west of lithosome A, and the two grade into and interfinger with one another at their common contact.

Near Santa Fe, we have differentiated two more lithosomes within the Tesuque Formation, called lithosome S and lithosome E. These two lithosomes are time-equivalent to the Nambe, Skull Ridge, and Pojoaque Members of Galusha and Blick (1971), but are readily distinguished from these three members to the north by their composition and, to a lesser extent, by their color. Lithosome S (Koning et al., 2004a) was deposited in the southern Española Basin by a relatively large drainage that extended along the present-day Santa Fe River Canyon and into the present-day Pecos River headwaters (an ancestral version of the Santa Fe River). The spatial distribution of the lithosome S suggests that the ancestral Santa Fe River formed a fan-shaped lobe where it exited the mountains. The headwaters of the ancestral Santa Fe River contributed minor amounts of detritus from quartzite and Paleozoic sedimentary rock mixed in more abundant granitic detritus. Lithosome S appears to be coarsest near the axis of the fan-shaped lobe (approximately coinciding with the course of the modern Santa Fe River), and is finer-grained near the margins of the fan. Lithosome E is not exposed on the surface (Koning and Johnson, 2006). Analysis of drill cuttings indicates a grayish volcaniclastic sediment consisting of basaltic and lattitic detritus likely derived from the Cerrillos upland to the southwest.

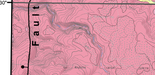
Three formations of Pliocene age overlie the Chamita and Tesuque Formations across an angular unconformity: the Ancha, Tuerto, and Puye and Ancha Formations. These three formations are notably coarser-grained than lower deposits but are relatively thin (maximum thicknesses in the study area of 90-100 m). Near the Sangre de Cristo Mountains, the Ancha Formation includes early Pleistocene deposits. The aforementioned unconformity has not been recognized west of the La Bajada fault. Here, the Sierra Ladrones Formation includes late Miocene through early Pleistocene sediment.

Post-Miocene Santa Fe Group

QTbta **Basaltic tephra and Ancha Formation, undivided (upper Pliocene to lower Pleistocene) –** Deposits of basaltic tephra (unit Tbt) about 15 cm to 5 m thick interstratified with sand, pebbly sand, and poorly sorted basaltic tephra-bearing sandstone of the Ancha Formation (unit QTa) about 1 cm to 4 m thick. Sediment in some of the basaltic tephra-bearing sandstone may have been deposited as hyperconcentrated flows. Unit underlies Cerros del Rio basalts (unit Tcrv) near Arroyo Calabasas and Cañada Ancha. A thin (45 cm), buried soil formed in sandy sediment of the Ancha Formation (unit QTa) is locally exposed beneath a bed of basaltic tephra about 60 cm thick that is overlain by a thick lava flow. The basaltic tephra and the underlying buried soil were baked by heat from the lava flow. The soil consists of a Bt horizon 10–25 cm thick that has well-expressed prismatic structure and light-red (2.5YR 6/6) clay films on ped faces. The underlying sandy Bkb horizon is 20–35 cm thick and contains tabular nodules as large as 8 x 10 x 18 cm at the base of the soil horizon that are well indurated by calcium carbonate. The calcium carbonate in these nodules and in the overlying basaltic tephra and the underlying sandy sediment may have precipitated from meteoric water percolating through fractures in the overlying lava flow. The basaltic tephra in this unit is correlative to unit Tbt and has an equivalent age (2.2-2.7 Ma). Maximum exposed thickness is about 34 m. [Description slightly modified from Shroba et al. (2006)]

QTa **Ancha Formation (upper Pliocene to lower Pleistocene) –** Fine- to coarse-grained alluvial slope deposits derived from the southwestern Sangre de Cristo Mountains, together with mostly coarse-grained ancestral Santa Fe River deposits. Alluvial slope deposits contain two distinct types of intercalated sediment: 1) moderately to well consolidated, silty-clayey sand (mostly very fine- to medium-grained sand with subordinate coarse- to very coarse-grained sand containing minor, scattered pebbles; beds are medium to thick, tabular to broadly lenticular, and internally massive or bioturbated; and 2) weakly consolidated, coarse channel fills of gravelly sand, sandy gravel, and medium- to very coarse-grained sand; the channel fills are lenticular to broadly lenticular in form, commonly medium to thick, and generally 2-30 m wide. The proportion of coarse channel-fills increases to the south and also towards the base of the deposit. Commonly-weathers of light yellowish brown (10YR 6/4), brownish yellow (10YR 6/6), very pale brown (10YR 7/3-4), and yellowish brown (10YR 5/4-6). Between approximately Interstate 25 and the modern Santa Fe River lies ancestral Santa Fe River deposits the Ancha Formation; these consist of predominantly sandy gravel interbedded with subordinate floodplain deposits of clayey-silty sand. In both alluvial slope and ancestral Santa Fe River deposits, the sand is arkosic and the gravel fraction contains greater than 20% granite clasts. There are minor interbeds of basaltic hydromagmatic deposits, which increase in abundance towards the Cerros del Rio volcanic field to the west. Unit generally overlies older Tesuque Formation with angular unconformity, but in the southern part of the Española basin it unconformably overlies Espinaso and Galisteo Formations. The Ancha Formation interfingers with basaltic lava flows of the Cerros del Rio volcanic field. Buried soils are locally preserved in the upper part of the unit. These soils have calcic (Btkb, Bkb, and Ckb) horizons about 15–60 cm thick that display stage I to III carbonate morphology. Locally, these horizons are overlain by thin, eroded Btb horizons. Unit is 10-76 m-thick, locally as much as 90-100 m, with the greatest thicknesses being near the center of the Santa Fe embayment. The base of the Ancha Formation is lower than the straths associated with unit Tgl, so it post-dates that unit. It is partly contemporaneous with unit Tcrv (2.2-2.7 Ma; Thompson et al., 2006) because of interfingering relations. Near the top of the Ancha Formation are beds of Guaje pumice (Qbo) and Cerro Toledo Rhyolite pumice that were dated at 1.48-1.67 Ma using 40Ar/39Ar methods (Koning et al., 2002). A terrace fill deposit inferred to be inset into the Ancha Formation contains scattered pumice clasts that were dated by 40Ar/39Ar methods, indicating an age of 1.2 Ma (Koning et al., 2002). Thus, most of the aggradation associated with the Ancha Formation occurred during 3-1.3 Ma. [Modified from Koning and Hallett, 2000; Koning et al., 2002, and Read et al. 2004]

QTt **Tuerto Gravel (upper Pliocene to lower Pleistocene) –** Silty-clayey sand interbedded with coarse channel fills of sandy gravel and gravelly sand derived from hypabyssal intrusive rocks of the northern Cerrillos Hills area. The silty sand is massive or very thinly to thinly bedded, and mixed with 1-10% pebbles that occur in discrete, very thin beds. The gravelly sediment is estimated to occupy 10-25% of the total sediment volume (the proportion increases towards the bedrock hills), and commonly occurs in: (1) thin to medium beds dominated by pebbles and generally unconsolidated, or (2) thick, extensive, indurated beds with subequal cobbles and pebbles. Gravel compositions dominated by monzonite, with less than 20% granite derived from the Sangre de Cristo Mountains. Common colors of yellowish brown (10YR 5/4-6), light yellowish brown (10YR 6/4), very pale brown (10YR 7/3-4), or brownish yellow (10YR 6/6). Clast lithologic types are similar to Tuerto Gravel strata underlying the Ortiz surface to the south. Sediment interfingers northwards and northeastwards with the Ancha Formation. Within about 6 m (20 ft) of the interpreted originality of the Tuerto gravel, there are multiple buried soils that define sediment units 1-2 m thick. On the Turquoise Hill quadrangle, the soils consist of Bt horizon(s) underlain by Bk horizon(s) with stage II to III calcium carbonate morphology (Koning and Hallett, 2000). Sparse buried soils are also found more than 6 m (20 ft) below the interpreted original top of the Tuerto gravel. The lower contact of the unit rests nonconformably on Oligocene intrusive rocks and contact metamorphosed sediments. Near the Cerrillos Hills, this unit interfingers with the Ancha Formation and thus has a similar age (i.e., 3-2 Ma). Thickness of 1-60(?) m. [Modified from Koning and Hallett, 2000].



QTpf **Puye Formation fanglomerate (lower Pliocene to lower Pleistocene; Griggs, 1964) –** Weakly lithified stream-flow and debris-flow sediment derived from the erosion of Tshicoma Dacite domes in the Los Alamos area. Exposed west of the Rio Grande except for an isolated outcrop south of the mouth of Cañada Ancha. Fills channels cut in rocks of the undivided Santa Fe Group and in most locations is exposed beneath quartzite-rich cobble gravel (Totavi Lentil) or phreatomagmatic deposits. However, along Los Alamos Canyon this fanglomerate fills a channel incised into cobble gravel of the Totavi Lentil (Puye Formation). Stream-flow sediment consists of pebble to boulder gravel, massive to planar-bedded sand, thin (<1 m) beds of clastic tephra and pumiceous alluvium, and beds of fine sand and silt. Gravel beds generally 0.5-3.0 m thick (1.5-10 ft) thick. Debris-flows are boulder-cobble gravel that range from 0.3 m (1 ft) to about 5.0 m (16 ft) thick. Clast and matrix lithology mainly clastic derived from the Tschicoma Formation of the Jemez Mountains, but Precambrian material composes >30% of some fluvial units. Paleocurrent directions measured on channels, gravelly crossbeds, and imbricated cobbles range from about 90° to 200° and average about 150°, slightly south of the trend of present canyons. Faulted locally near the mouth of Ancho Canyon; otherwise undeformed. Pumiceous Puye gravel 6.8 km (5 mi) north-northwest of Otowi Bridge gave a fission-track age of 2.9 Ma (Table 1 of Dethier, 1997). Immediately north of the northeastern corner of the map, a pumice lapilli bed at the base of the Puye Formation returned an age of 5.31±0.02 Ma (WoldeGrabriel et al., 2001). Turbeville et al. (1989) report that the upper part of the Puye Formation may be as young as 1.7±0.1 Ma northwest of the White Rock quadrangle. Thus, the age of the Puye Formation fanglomerate is 5.3-1.7 Ma. Thickness of 5-30 m (16-100 ft) in the map area [Modified from Dethier, 1997].

QTpt **Puye Formation, ancestral Rio Grande facies (lower Pliocene to lower Pleistocene;Totavi Lentil of Griggs, 1964) –** Slightly lithified pebble to cobble gravel (with abundant clasts of Proterozoic quartzite and granite), sand, and thin beds of silty sand deposited by the Rio Grande in the Pliocene. Unit is generally found west of the modern Rio Grande; east of the Rio Grande, unit is exposed at one outcrop south of the mouth of Cañada Ancha. Unit interfingers with the Puye Formation fanglomerate and underlies the fanglomerate in upper White Rock Canyon.The Puye Formation fanglomerate and underlies the fanglomerate in upper White Rock Canyon.The Puye Formation fanglomerate and forms one prominent outcrop east of the Rio Grande (Section H of Dethier, 1997). As mapped, may include exposures of Otowi Member of Bandelier Tuff, which it lies above. Paleoflow direction to the east. Derived from the Valles caldera west of the map area. 40Ar/ 39Ar ages from single-crystal-sanidine range from 1.21-1.26 (Izett and Obradovich, 1994; Spell et al., 1996a, b; Phillips et al., 2007). Thickness is highly variable because of pre-existing topography. Thickness is generally 60 m or less, but locally is as much as 180 m. [Description slightly modified from Dethier, 1997, and Sawyer et al., in review].

QTsp **Sierra Ladrones Formation, piedmont-stream deposits (upper Miocene to lower Pleistocene) –** Basin-fill deposits west of the La Bajada escarpment that consist of sand and clay-silt intercalated with lenses of pebbly and cobbly gravel. Colors of tan, pink, and red. Pebbles and cobbles consist mostly of Proterozoic granite, white vein quartz, and basalt in northern outcrops and Espinaso Formation latite and Galisteo Formation petrified wood in southern outcrops (Smith and Kuhle, 1998a). Sand is litho-arkosic and may be slightly silty or pebbly and cobbly. Unit was deposited by west and southwest flowing streams in the eastern Santo Domingo basin. Unit contains an eroded layer of the lower Pleistocene, 1.6 Ma Otowi Member of the Bandelier Tuff (as much as 3 m thick), which includes the Guaje Pumice Bed, that crops out almost continuously for 4 km along the north side of Galisteo Creek (Smith et al., 1970; Smith and Kuhle, 1998a). Neither base nor top of the unit are exposed and the upper part of the unit is buried by the alluvium of La Majada Mesa (Qalm). Lower age of unit is not constrained. Thickness exceeds 300 m. [from Smith and Kuhle, 1998; Sawyer et al., 2002].

Upper Miocene Santa Fe Group

Tcar **Axial river sediment of the Chamita Formation (upper middle to upper Miocene) –** Axial river deposits comprised of stacked channel-fills of sandstone and pebbly sandstone intercalated with overbank deposits of sandstone, siltstone, and clayey-silty very fine- to fine-grained sandstone. Conglomerate beds are sparse. Sandy channel-fills are broad (typically >10x of meters wide) and exhibit planar-horizontal to cross-stratified, laminated to very thin to medium beds. Stacked channel-fills form amalgamated packages as much as 12 m-thick. Gravelly channel-fills are marked by a variety of bed forms, ranging from planar to lenticular to cross-stratified. Gravels include very fine to very coarse pebbles and cobbles that are subrounded to rounded, very poorly sorted, and commonly clast-supported. Gravel consists of rhyolite, dacite, and variable quartz (or quartzite) with subordinate rhyolite and tuff; local gravel zones are rich in basalt. Northeast of Buckman Mesa, where the Cejita Member is recognized (Manley, 1976 and 1979; Dethier and Koning, 2007), clast lithologic types are dominated by Paleozoic sandstone, limestone, and siltstone, with 10-50% granite and 5-8% quartzite. Sand is very pale brown to pink to light gray, very fine- to very coarse-grained (mostly fine- to very coarse-grained), subangular to rounded, and well-sorted. Sand contains abundant quartz that is locally frosted and smoky-colored; lithic grains are minor and include 0-5% quartzite, 0-2% green-brown quartz grains (probably derived from erosion of Paleozoic sedimentary rocks), 5% mafic grains, and variable volcanic lithic grains (mostly rhyolite to dacite in composition). Amount of potassium feldspar and granitic gravel increases towards the eastern margin of the unit. Clayey-silty overbank sediment is light brown to very pale brown to pink and well consolidated. Unit includes the Vallito, Hernandez, and Cejita Members of Koning and Aby (2005) and described more in Koning et al. (2007). Unit grades and interfingers eastward with the Cuartelles Member of the upper Tesuque Fm (Ttacu and Ttacuf) and gradational overlies basin floor deposits (unit Tlb). The Chama-El Rito Member is inferred to underlie this unit under the Pajarito Plateau. Unit is interpreted to have deposited by a south-flowing, axial river system in the southern Espanola Basin during 6-13.2 Ma (Koning and Aby, 2005; Koning et al., 2007). Greater than 700 m thick in northwest corner of the map.

Tbce **Cejita Member (upper middle to lower upper Miocene)** *differentiated in cross-section only* **–** Stacked channel-fills of sand and gravelly sand deposited by a river flowing southwest out of the Peñasco embayment; channel-fills are up to 4 m-thick. Sand is composed of quartz, variable (mostly ~10%) potassium feldspar, and 10-20% lithic grains that include 1-3% quartzite, 1-2% green-brown quartz grains (probably representing eroded Paleozoic sedimentary rocks, 5% mafics, and trace to 1% felsic volcanic grains. Minor rhyodpah deposits of silt and silty-clayey very fine- to fine-grained sand. Channel-fills tend to be extensively cross-stratified. Clast lithologic types are dominated by Paleozoic sandstone, limestone, and siltstone, with 10-50% granite and 5-8% quartzite. Locally, granite and felsic-intermediate volcanic rock types dominate near the eastern and western margins of the deposit, respectively. Unit grades and interfingers eastward with the Cuartelles Member of the upper Tesuque Fm (Ttacu and Ttacuf) and westward with axial river sediment (Tcar).

Ttcu **Cuartelles Member of the Tesuque Formation (upper middle to upper Miocene) –** Alluvial slope deposits of sandy pebble-conglomerate and pebbly sandstone channel-fill complexes, with subordinate slightly clayey-silty sand containing <5% pebbles that was deposited by lower-energy flow outside of confined channels. We refer to the latter, fine-grained sediment as extra-channel sediment. Bedding within the channel-fill complexes (from most to least common) ranges from lenticular, horizontal-planar, to cross-stratified (up to 20 cm-thick foresets), and generally the beds are very thin to medium (with internal planar-laminations); bedding becomes more horizontal-planar westward where this unit grades into Ttcuf. Relatively narrow, U-shaped channels are locally present. Channel complexes may fine-upwards from gravel- to sand-dominated sediment. Pebble conglomerate is clast-supported and locally has up to 25% cobbles. Pebbles are poorly to moderately sorted and mostly angular to subangular (some subrounded). Clasts are composed of granite with trace to 1% yellowish Paleozoic limestone and siltstone, trace to 1% quartzite, trace chert, 0.5-2% green sand to 3% amphibolite. Channel-fill sand ranges from fine- to very coarse-grained but mostly is medium- to very coarse-grained, angular to subrounded (mostly subangular), poorly to moderately sorted, and an arkose. 1-15% of individual channel complexes are strongly to moderately cemented by calcium carbonate, the rest is weakly to non-cemented and loose to weakly consolidated.

Extra-channel deposits consist of slightly clayey-silty (visual estimate of 1-10% fines), very fine-to very coarse-grained sandstone (mostly very fine- to medium-grained) with less than 10% scattered pebbles; generally reddish yellow to pink to light brown in color. Extra-channel sediment is generally massive but may locally be in very thin to thick, tabular beds or be planar-laminated. The sand is poorly to moderately sorted, subangular to subrounded, and an arkose. Within the extra-channel sediment are minor very thin to thin, lenticular beds of medium- to very coarse-grained, arkosic sandstone and granitic pebble-conglomerate. Locally, paleosols are present that have 10-50 cm-thick calcic horizons with stage I to II+ morphology; also, some paleosols possess 5-15 cm-thick, reddish yellow, Bw or clayey Bt horizons 10-30 cm-thick. Extra-channel sediment has been observed to locally grade laterally into coarse deposits similar to those seen in channel-fills. They are interpreted to represent small, aggradational lobes at the mouths of discontinuous channels.

The Cuartelles Member is considered part of the Tesuque Formation east of the Rio Grande and part of the Chamita Formation west of the Rio Grande (Koning and Aby, 2005; Koning et al., 2005a). Unit gradationally overlies unit Ttx and has prograded southward over fluvial deposits of unit Ttcuf. The lower gradation zone of the Cuartelles Member is over 6-12 m thick to the south and becomes thicker to the north. This coarser sediment of the Cuartelles Member grades westward into fine-grained sediment of the distal alluvial slope (included in the Cuartelles Member; unit Ttcuf). The Cuartelles Member is interpreted to have been deposited in an alluvial slope depositional environment; specifically as channel-fills or small depositional lobes at the mouths of discontinuous channels. An age of 13.2-8 Ma is interpreted based on a synthesis of radiometric ages, biostratigraphy, and geomagnetic polarity studies (further discussed in Koning et al., 2005a; Koning and Aby, 2005). Up to 350 m thick.

Ttcu **Cuartelles Member of the Chamita Formation (upper middle to upper Miocene) –**Strata similar to that of the Cuartelles Member of the Tesuque Formation (Ttcu), as described above.

Ttcuf **Cuartelles Member of the Tesuque Formation, fine-grained, distal sediment (upper middle to upper Miocene) –** Alluvial slope silty-clayey very fine- to medium-grained sandstone, with subordinate siltstone and mudstone. Coarse channel-fills of pebbly sandstone and sandy-pebble-conglomerate comprise about 3-30% of the unit. These coarse channel-fills are scattered, lenticular to ribbon-shaped, and up to 10 to 100 cm-thick; locally, these channel-fills form thicker, multistory complexes. The internal bedding of the channels is very thin to thin, and planar to lenticular to cross-stratified. Pebbles are moderately to poorly sorted, subangular to subrounded, and granitic (with trace to 1% yellowish Paleozoic siltstone and limestone, quartzite, and gneiss). Channel-fill sand is fine- to very coarse-grained, subangular to subrounded, poorly to well sorted, and an arkose. Paleocurrent indicators in the channels indicate westward paleoflow. Channels-fills may fine-upward from pebbly to sandy sediment. Isolated channels tend to be strongly to moderately cemented, whereas laterally extensive and thick channel complexes are generally not as cemented.

Fine-grained sediment outside of coarse-grained channel-fills is in very thin to thick, tabular beds that may be internally laminated. Colors range from pink to light brown to reddish yellow to light yellowish brown. Sand is generally very fine- to medium-grained, well sorted, subangular to subrounded, and an arkose. There is 0 to 1%, very thin to thin, brown to light brown (7.5YR 5-6/4) clayey-silt sediment beds. Very thin to medium, ribbon- to lenticular-shaped, isolated channel-fills are present within the finer-grained sediment (generally 2-30% of the volume). Finer-grained sediment is moderately to well consolidated and weakly cemented by calcium carbonate. Coarse white ash and basaltic ash beds are locally present. Unit possesses 1-3% weakly developed paleosols with reddish Bw horizons 20- to 30-cm thick.

The Cuartelles Member is considered part of the Tesuque Formation east of the Rio Grande (Ttcu) and part of the Chamita Formation (Ttcu) west of the Rio Grande (Koning and Aby, 2005; Koning et al., 2005a). Unit grades laterally westward into axial river sediment (Tcar) and has also prograded westward over axial river sediment. This unit grades upward and laterally eastward into coarser sediment of the Cuartelles Member (Ttcu). This finer-grained part of the Cuartelles Member is interpreted to represent a generally low-energy alluvial environment where the distal alluvial slope transitioned to the flat basin floor. An age of 13.2-8 Ma is interpreted based on a synthesis of radiometric ages, biostratigraphy, and geomagnetic polarity studies (further discussed in Koning et al., 2005; Koning and Aby, 2005). 350-400 m-thick.

Tcarc **Zone of interfingering between axial river deposits (Chamita Formation) and fine-grained strata of the Cuarteles Member (Tesuque Formation) (upper middle to lower upper Miocene) –** See the individual descriptions for units Tcar and Ttcuf. Although only 30-40 m of this unit is exposed, cross-section B-B suggests it may be as much as 950 m-thick.

Tta **Lithosome A of the Tesuque Formation (lower to middle Miocene) –** Pink-tan alluvial slope deposits of sand, silty-clayey very fine- to medium-grained sand, and subordinate mudstone interbedded with minor, coarse-grained channel-fills. Colors of the sandy sediment range from very pale brown, light yellowish brown, pink, to light brown (most common). Sand is evidently of the coarse channel-fills is generally very fine- to medium-grained, mostly moderately to