GEOLOGIC MAP OF THE SOUTHERN ESPAÑOLA BASIN, SANA FE COUNTY, NEW MEXICO

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DESCRIPTION OF MAP UNITS

Descriptive terminology

Below are descriptions of the units depicted on the geologic map. Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). The term "clast(s)" refers to the grain size fraction greater than 2 mm in diameter and the term "matrix" refers to the particles less than 2 mm in size. Clast percentages are based on percent volume and were estimated in the field with the aid of percentage charts. Descriptions of bedding thickness follow Ingram (1954). Colors of unconsolidated sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992). Birkeland (1999), and Birkeland et al. (1991). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999).

Metric units are used in this report (see Table 1 for conversion of English units to metric units). The divisions of geologic time used in this report are provided below (Table 2).

Table 1. Factors for conversion of metric units to English units

Multiply	By	To obtain
centimeters (cm)	0.3937	inches
meters (m)	3.2808	feet
kilometers (km)	0.6214	miles

Table 2. Definitions of divisions of geologic time used in this report

ERA	Period	Epoch		Age (years)
CENOZOIC				
	Quaternary	Holocene		0-11,400
		Pleistocene	late	11,400-126,000
			middle	126,000-781,000
			early	781,000-2.588 million
	Tertiary	Pliocene		2.588-5.33 million
		Miocene		5.33-23.03 million
		Oligocene		23.03-33.9 million
		Eocene		33.9-55.8 million
		Paleocene		55.8-65.5 million
MESOZOIC				
	Cretaceous			65.5-145.5 million
	Jurassic			145.5-199.6 million
	Triassic			199.6-251 million
PALEOZOIC				
	Permian			251-299 million
	Pennsylvanian			299-318.1 million
	Mississippian			318.1-359.2 million
PROTEROZOIC				
	Mesoproterozoic			1,000-1,600 million
	Paleoproterozoic			1,600-2,500 million

After Gradstein, Ogg, and Smith (2004); Walker, J.D., Geissman, J.W. (2009)

Surficial deposits

Mapping of surficial deposits among geologists varies greatly and this necessitates discussion of how we treat these units. Age assignments for surficial deposits are based chiefly on height above modern perennial streams and arroyos. To a lesser extent, we use the degree of modification of original surface morphology and degree of soil development to assign ages.

Surface deposits can be subdivided into those related to slopes (e.g., colluvium and slopewash) and those related to drainages (e.g., alluvium). The term "colluvium" is reserved for sediment on a slope interpreted to be mainly transported by gravitational processes (such as topple, creep, slumping) but unconfined surface flow is also involved to some extent. In general, colluvium was not mapped except for thick (over 1 m-thick) talus deposits on the west slope of Cañada Ancha. The term "sheetwash" is used for sediment interpreted to be mainly transported by unconfined surface flow upslope from potential channels (i.e., Hortonian overland flow) after a period of sudden and heavy rainfall. Unconfined surface flow associated with sheetflooding on alluvial fans or on fluvial floodplains is not included in our definition of "sheetwash." Sheetwash deposits were not mapped except for thick deposits (over 1 m-thick) on top of Cerros del Rio volcanic rocks. Fractional map symbol **Qs/Tcb** denotes areas where slope wash mantles underlying basalt flows.

Surficial deposits associated with drainages include alluvial fan, terrace, and valley-fill deposits. These deposits consist of alluvium, which is a general term for detrital deposits made by streams on river beds, flood plains, and alluvial fans (Bates and Jackson, 1983). Alluvial fan deposits in the map area are general small and mapped where tributary streams enter larger drainages. These small alluvial fans are common in the Santa Fe River gorge, lower Arroyo Hondo, and along Cañada Ancha. They are also mapped adjacent to volcanic edifaces on the Caja del Rio Plateau. Alluvial fan deposits contain stream-flow deposits, debris-flow deposits, and hyperconcentrrated flow deposits, which are intermediate in character between stream-flow and debris-flow deposits. Terrace deposits are former channel-fill and overbank deposits associated with a given stream, but abandoned because of incision of that stream. Preserved terrace deposits are generally gravelly in texture. Lastly, valley-fill deposits occupy the floors of valleys and are mostly composed of sand, silt, and clay. Most valley-fills are middle to late Holocene deposits alongside recently incised, relatively narrow arroyos or gullies.

<u>Water and anthrogenic deposits</u>

water **Perennial water (modern) –** Unit assigned to large rivers (e.g., Rio Grande) and reservoirs.

afe **Artificial fill or excavation (modern) –** Sand, silt, clay, or gravel under highways or in landfills; loose or compacted.

<u>Eolian and slopewash deposits</u>

Qse **Sheetflood deposits and minor eolian sediment (upper Pleistocene to Holocene) –** Yellowish brown (10YR 5/4) to light yellowish brown (10YR 6/4), pebbly and silty-clayey sand deposited by sheetflooding; the fine sediment was probably derived chiefly from eolian material that was later reworked and deposited by unconfined surface flow. Pebbles are commonly subangular to subrounded and variably consist of volcanic rocks, granite, or sandstone (depending on location and source area). Sand is very fine- to very coarse-grained (mostly very fine- to medium-grained), quartz-rich, and vaguely bedded (mostly very thin-bedded). Sediment is poorly sorted, loose, and slightly to moderately plastic. This unit was not differentiated where it overlies Santa Fe Group sediment. Small deposits of El Cajete pumice are locally present in the northwestern part of the Montoso Peak quadrangle to the north (Thompson et al., in preparation). Surface soil generally has a weak argillic horizon underlain by a calcic horizon with stage I to II carbonate morphology. Buried soils on the Caja del Rio Plateau have calcic horizon(s) with stage III carbonate morphology locally overlain by eroded argillic horizons (Sawyer et al., 2002). These soils indicate periodic deposition during the Holocene and upper Pleistocene, followed by surface stability and soil development. Unit may include small deposits of alluvium, colluvium, or eolian sand. Mostly 1-2 m thick, with a possible maximum thickness of 5 m. [Description taken in part from Sawyer et al. (2002) and Shroba et al. (2005)].

Qse/Tcrv **Sheetflood deposits and minor eolian sediment overlying volcanic rocks (upper Pleistocene to Holocene) –** Sheetflood deposits, as described above, that overlie volcanic rocks of the Cerros del Rio Volcanic field. Mostly 1-2 m thick, with a possible maximum thickness of 5 m.

Qesd **Eolian sand dunes (middle to upper Holocene) –** Light yellowish brown to light brown (7.5-10YR 6/4) to yellowish brown (10YR 5/4), silty very fine- to medium-grained sand and very fine- to medium-grained sand transported by wind and deposited in dune forms. Northeast of the Cerrillos Hills, dune forms are irregular, linear, or parabolic. Parabolic dunes generally occur around a scoured "blow-out." Linear and coppice dunes have formed immediately east of, and parallel to, the Arroyo Ancho modern stream channel (north-central part of map area). The Arroyo Ancho dunes exhibit wavy laminated or cross-laminated sedimentary structures (foresets ≤ 10 cm-thick). The soil development on these dunes is very weak, thin (less than 80 cm thickness), and generally marked by A horizon(s) overlying C horizon(s). The weak soil development supports a middle to upper Holocene age. The deposit is loose and 1 to 2 m thick; dunes are 0.8-2.0 m tall.

<u>Mass-wasting, colluvial and talus deposits</u>

Qls **Landslides and other large-scale mass wasting deposits (lower Pleistocene to Holocene) –** Massive slumps on slopes below mesa tops composed of basalt or, less commonly, Bandelier Tuff. Unit mainly exposed along the La Bajada escarpment, White Rock Canyon, north of Chaquehui Canyon, and along Cañada Ancha. Slump blocks commonly contain coherent internal stratigraphy in their upper parts but become progressively more deformed in their lower parts. The lower parts include debris slide, debris slump, and debris flows deposits (as defined by Varnes, 1978) and are characterized by poorly to very poorly sorted and non-stratified rock debris. Dips in massive slump blocks range from 8° to 70° toward head scarps. Surface topography is typically hummocky. Many of the landslide deposits exhibit lobate toes and crescentic headwall scarps. Slide material at most sites overlies Santa Fe Group strata. Limited areas of autochthonous rocks are included in areas mapped as **Qls**. Slope failures probably initiate in weakly to moderately consolidated sediments beneath the hard strata and propagate upward into the overlyingcliff-forming units. Most slides are inactive. At several locations undisturbed late Pliocene deposits lie stratigraphically above landslide deposits (Section H of Dethier, 1997). Morphology of most failures and inclusion of Bandelier Tuff in some suggest that slides were active in early to middle Pleistocene time but that many became stable in the middle to late Pleistocene (Dethier, 1997). El Cajete tephra (~50-60 ka; Reneau et al., 1996) lies on landslide deposits south of the White Rock area. Some of the older landslide deposits have thick calcic soil horizons with stage III carbonate morphology, with stage IV present at some localities. Soils are generally 0.8-1.4 m (2.5-4.5 ft) thick. Landslide deposits may be prone to continued movement or reactivation due to natural as well as human-induced processes. Maximum thickness possibly 100 m. [Description from Dethier (1997) and Sawyer et al. (2002)].

Qct **Colluvium and talus (middle Pleistocene to Holocene) –** Talus and colluvium variably derived from Bandelier Tuff, Cerros del Rio volcanic flows, volcaniclastic deposits, and arkosic sandstone and conglomerate of the Tesuque, Chamita, and Ancha Formations. Locally includes minor rockfall and debris flow deposits at the base of cliffs. The talus is in poorly defined, medium to thick beds. These beds slope 20-25 degrees to the east away from the basalt flows. Beds are both matrix- and clast-supported. The talus includes pebbles, cobbles, and boulders. These clasts are poorly sorted and are generally angular to subangular. Boulders may be several meters in diameter. Clasts are mostly basalt, basaltic andesite(?), and andesite, but include minor pebbles and cobbles of quartzite (less than 2%) and granitic pebbles (generally less than 5%). The matrix is pale-brown to brown (10YR 5-6/3) silt and very fine-grained sand with slightly subordinate fine- to very coarse-grained sand. Unit includes thin (<2 m) alluvial deposits west of the Rio Grande and, in places, El Cajete tephra (~50-60 ka; Reneau et al., 1996). Surface soil possesses calcic horizon(s) with stage II or I calcium carbonate morphology. Locally, buried soils are observed. Generally loose but soils may provide some cohesion. A middle Pleistocene to Holocene age is implied by the degree of soil development. Thickness is 1-10 m, but locally along White Rock Canyon exceeds 25 m. [Description taken in part from Dethier, 1997].

Alluvial deposits

Qfa **Alluvial fan deposits (middle Pleistocene to Holocene) –** Gravelly stream-flow and debris-flow deposits in fan-shaped lobes at the mouths of incised tributary arroyos in Santa Fe River Canyon, White Rock Canyon, and along the Rio Galisteo; also found at the base of the La Bajada escarpment. Sediment is gravel or gravelly sand, with local interbeds of clay, silt, and clayey sand; sand is subangular to subrounded. Gravel ranges from pebbles to boulders (mostly pebbles and cobbles); clasts are angular to rounded, as large as 2 m, and composed of basalt (local granite and quartzite); granite dominates in alluvial fans near Santa Fe. Color varies according to changes in the parent material, but light yellowish brown to light brown (7.5-10YR 6/4) is common. Poorly to well sorted and unconsolidated. Stream-flow sandy gravel is generally clast-supported and in lenticular to concave-up, ribbon-shaped beds that are very thin to thin. Silt, clay,or sand may be massive or tabular and thin to medium-bedded. Debris-flow sediment consist of very poorly sorted and very poorly stratified boulders to granules supported in a sandy matrix.

Unit interfingers with **Qay** and alluvium of La Majada Mesa. Deposits locally overlain by and interbedded with unit **Qse**. A middle Pleistocene to Holocene age is assigned based on the unit's relatively low topographic position in the landscape. Deposits range in thickness from 2 to 30 m [Description taken in part from Sawyer et al., 2002].

Qva **Valley-fill allluvium (upper Pleistocene to Holocene) –** Very fine- to medium-grained sand and clayey-silty sand interbedded with subordinate gravelly beds; unit occupies the floors of valleys, where it commonly has a late Holocene terrace tread incised by a modern arroyo or channel. The modern channel is included in this unit and is generally composed of gravelly sand. The tread height of the late Holocene terrace relative to the modern arroyo is highly variable. Color of sediment varies according to texture and source area. Clayey-silty very fine- to medium-grained sand ranges from light yellowish brown (10YR 6/4), pale brown (10YR 6/3), brown (10YR 5/3), light brown (7.5YR 6/3), yellowish-brown (10YR 5/4), or very-pale-brown (10YR 7/4). Medium- to very coarse-grained sand beds are typically light brown to pink (7.5YR 6-7/3-4). Clay-silt or clayey-silty sand is generally massive or in very thin to thin beds. Sandy and gravelly sediment occurs in very thin to medium, tabular or lenticular beds. These beds contain internal planar- or cross-laminations. Gravel commonly occupies less than 50% of the total sediment volume; larger drainages have more gravel than smaller drainages. Gravel is clast- or matrix-supported and dominated by pebbles. Cobbles and boulders are abundant only near crystalline basement or in the modern channel of the Rio Grande. Gravel clasts are mostly granite to granitic gneiss (with very minor quartzite, schist, gneiss, and amphibolite). Cobbles and very coarse pebbles are rounded to subrounded whereas finer gravel are subrounded to angular. Sand is very fine- to very coarse-grained, poorly to well sorted, subangular to subrounded, and arkosic. Clayey sediment is typically hard whereas sandy sediment is loose. The top soil has a calcic horizon with stage I morphology (10-50 cm thick). Buried soils have calcic horizons with stage I to II pedogenic carbonate morphology (10-50 cm thick) and may have soil horizons (5-15 cm thick) with clay accumulation. Buried soils locally define 1 to 3 (possibly more) alluvial allostratigraphic units. An upper Pleistocene to Holocene age is supported by the relatively weak soil development of the top soil. Radiocarbon ages obtained from buried charcoal in this unit range from of 2,230 ± 250 radiocarbon years (Miller and Wendorf, 1958) to 4160 +/- 40 yr (Koning and Hallett, 2000), but the soil-bounded allostratigraphic units suggest that upper Pleistocene sediment is locally preserved.. 1 to 25 m in thickness.

Qaoe **Older alluvium east of Eldorado (Pleistocene) –** Sandy gravel east of Eldorado similar in composition and texture to the Ancha Formation in that area but occupying a lower geomorphic position. 1-10? m thick.

Qst **Stream terrace deposits (Pleistocene) –** Sand and gravel that underlie a suite of terraces above active drainages and associated valley-floor deposits, and below QTst and Tgt terrace deposits. Some thick fill-terraces are dominated by clayey-silty very fine- to medium-grained sand and overlie a strath with pronounced relief. The lower contact between these deposits and the underlying Tesuque Formation is marked by an angular unconformity and scour. In a longitudinal profile, it is common for straths to diverge in a downstream direction. At least four terrace levels are present, ranging from 3 to 65 m above modern stream grade. Sand and clay-silt exhibit colors of light-yellowish-brown (10YR 6/4), very pale brown (10YR 7/4), light-brown (7.5YR 6/4), pink (7.5YR 7/4), reddish-yellow (7.5YR 6-7/6), pale brown (10YR 6/3), yellowish brown (10YR 5/4), or strong brown (7.5YR 5/6). Beds are very thin to medium, and commonly lenticular or concave-up, ribbon-shaped. Gravel is clast-supported, moderately to poorly sorted, and generally composed of cobbles and pebbles with <5% boulders (boulders are more common within or near the Sangre de Cristo Mountains). Clast composition is mostly granite to granitic gneiss, with very minor amphibolite, schist, Paleozoic siltstone-sandstone, gneiss, and quartzite. Quartzite clasts are well-rounded to subrounded; for other rock types, cobbles are rounded to subrounded, coarse to very coarse pebbles are rounded to subangular, and very fine to medium pebbles are angular to subrounded. Clasts are generally larger and more rounded in a given terrace deposit compared to underlying Santa Fe Group strata (if present). Sand is very fine- to very coarse-grained (mostly medium- to very coarse-grained), moderately to poorly sorted, subrounded to subangular, and arkosic. Two radiocarbon dates for two relatively low-level fill terraces along the Santa Fe River returned ages of 7 ka and 10 ka (Read et al., 1999). Higher level fill terraces along the Rio Tesuque and south of the Pojoaque River may be correlated to the terrace stratigraphy developed along the Rio Grande by Dethier and Reneau (1995) (e.g., Koning and Maldonado, 2001). Sediment is unconsolidated and up to 18 m-thick (generally less than 8 m-thick).

Qalm **Alluvium of La Majada Mesa (middle Pleistocene) –** Alluvial and minor eolian deposits composed of sand, silty sand, and silt, with minor lenticular gravel, that underlies a high-level surface west of the La Bajada escarpment. Contains minor amounts of pebbles and cobbles; clasts composed mainly of granite and basalt. Deposited by Galisteo Creek, Santa Fe River and, perhaps to a minor extent, the Rio Grande (Smith and Kuhle, 1998). Unit underlies a geomorphic surface between Galisteo Creek and the base of La Bajada Mesa. Unit overlies an erosion surface on unit **QTsp**. The underlying erosion surface is graded westward to a former level of the Rio Grande (~75 m above present stream grade) that is approximately equivalent to a terrace bearing the Lava Creek B tephra (640 ka). Unit **Qse** locally mantles the top of this alluvium but was not mapped separately. A near-surface stage III to IV calcic horizon is present in many places below a largely stripped Bt horizon. Exposed thickness of 2-6 m; maximum thickness of possibly 10-15 m. [Description modified from Smith and Kuhle, 1998].

QTba **Basaltic and andesitic alluvium (Pliocene(?) to middle Pleistocene) –** Interbedded sandy gravel and silty sand derived from erosion of basalt, basaltic andesite, and andesite. Sandy gravel is poorly sorted to moderately well sorted, clast-supported, commonly subangular, and contains pebbles and cobbles of basalt, andesite, and basaltic andesite. Silty sand is pink (7.5YR 7/4), very slightly pebbly, and dominated by very fine to medium sand; loose to slightly indurated. This unit locally contains carbonate-cemented white pumice fragments that are likely derived from the Bandelier Tuff (1.6- and 1.2-Ma eruptions, Izett and Obradovich, 1994). Unit QTba overlies volcanic flows and tephra associated with the Cerros del Rio volcanic field. Age is poorly constrained but post-dates Pliocene lavas associated with the Cerros del Rio field (2.2-2.7 Ma; Thompson et al., 2006). Exposed thickness is 2–4.5 m; possibly as much as 5 m thick. [Description modified from Shroba et al. (2005)].

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 coinciding 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 angular to subrounded. Clast composition is generally about 25-50% quartzite and 50-75% granite with 1-5% amphibolite, trace to 3% mica-schist, and trace to 5% 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 separated by a vertical distance of approximately 6 m. The upper two terrace straths project to at least 30 m above the scoured 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

Volcanic rocks are abundant near the western map boundary. Most of these rocks belong to the mafic to intermediate Cerros del Rio volcanic field (mostly 2.7-2.2 Ma) and two major rhyolitic ignimbrites erupted from the Valles Caldera (1.6 and 1.2 Ma). The sequence of Cerros del Rio basalt to basaltic andesite flows overlain by rhyolitic ignimbrites is a common feature on the Pajarito Plateau (west of the Rio Grande). Comparably minor volcanic rocks include a 50-65 ka rhyolitic tephra (El Cajete tephra) and early Pleistocene basalts and dacites in the southwestern Cerros del Rio volcanic field.

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. (1985) report a zircon-fission-track age of 170 ± 70 ka. Toyoda et al. (1995) and Toyodo and Goff (1996) interpret ESR ages of about 53 ± 6 ka for El Cajete and 59 ± 6 ka Battleship Rock Members. Reneau et al. (1996) obtained thermal luminescence ages of 48 ± 5 to 61 ± 5ka for soils buried beneath the El Cajete fallout pumice, and a ^{14}C 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. $^{40}Ar/^{39}Ar$ ages1.46 ± 0.06 Ma, 1.31 ± 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 surfaces 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. $^{40}Ar/^{39}Ar$ ages from single-crystal-sanidine range from 1.22-1.26 (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 $^{40}Ar/^{39}Ar$ age 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 phenocrysts in a fine-grained groundmass (Koning and Maldonaldo, 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. They look similar to the basalt flows but are thicker and the lower part of the flows is platy (Koning and Maldonaldo, 2001). Andesite flows are brownish-gray to medium-gray and occasionally flow banded (Koning and Maldonaldo, 2001).

These contain ubiquitous phenocrysts of hornblende, plagioclase, clinopyroxene, Fe-Ti oxides, and minor olivine 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 silty sand 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 from Thompson 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 in 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 0.5-15 mm. Welding of adjacent lapilli is observed in primary magmatic ejecta. 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 reverse 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 silty sand 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 maars 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 Cuarteles 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 plethora of 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 (sand having abundant potassium feldspar and granite 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 hetereolithic 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 latitic 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 Btb 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. (2005)].

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 in width. The proportion of coarse channel fills increases towards the Sangre de Cristo Mountains to the east and also towards the base of the deposit. Common colors 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 in the Ancha Formation; these consist of predominately 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 Kb) 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 Tgt, 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 $^{40}Ar/^{39}Ar$ 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 $^{40}Ar/^{39}Ar$ 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. [Modifed 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 composition 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 original top 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., 3-1.2 Ma). Thickness of 1-60(?) m. [Modifed 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 Tchicoma 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 dacitic tephra and pumiceous alluvium, and beds of fine sand and silt. Gravel beds generally 0.5-3.0 m (1.5-10 ft) thick. Debris flows are boulder-rich and range from 0.3 m (1 ft) to about 5.0 m (16 ft) thick. Clast and matrix lithology mainly dacite 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 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 northwestern 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 pre-dates overlying Cerros del Rio volcanic rocks (2.2-2.7 Ma; Thompson et al., 2006). This unit lies beneath landslide deposits, Pliocene alluvium, or phreatomagmatic deposits at most exposures. Coarse units are 0.5-3.0 m (1.5-10 ft) thick, cross-bedded, and locally planar bedded. Clasts are generally composed of >80% quartzite and other resistant lithologies from northern New Mexico, but granitic clasts from the southern Sangre de Cristo Range are common locally. Paleocurrent directions measured on channels, gravelly crossbeds, and imbricated cobbles range from 160° to 220° and average about 180°. Mainly undeformed. Unit pre-dates the overlying Cerros del Rio volcanic rocks (2.2-2.7 Ma; Thompson et al., 2006). The aforementioned stratigraphic relations indicate that preserved ancestral Rio Grande facies of the Puye Formation is 5.3-2.7 Ma. Thickness 5-45 m (16-150 ft). [modified from Dethier, 1997].

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 lithic-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].

<u>Upper Miocene Santa Fe Group</u>

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 claystone, siltstone, and clayey-silty very fine- to fine-grained sandstone. Conglomerate beds are sparse. Sandy channel-fills are broad (typically >10s 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 andesite, 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 subrounded to rounded and 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 Cuarteles Member of the upper Tesuque Fm (Ttacu and Ttacuf) and gradational overlies basin floor deposits (unit Ttb). 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 Española 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.

Ttce **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 Penasco embayment; channel-fills are up to 4 m-thick. Sand is composed of quartz, variable (mostly ~10%) potasssium feldspar, and 10-20% lithic grains that include 1-5% quartzite, 1-2% green-brown quartz grains (probably representing eroded Paleozoic sedimentary rocks, 5% mafics, and trace to 1% felsic volcanic grains. Minor floodplain 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 Cuarteles Member of the upper Tesuque Fm (Ttacu and Ttacuf) and westward with axial river sediment (Tcar).

Ttcu **Cuarteles 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% gneiss, and trace 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 Cuarteles 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 Tta and has prograded southward over fluvial deposits of unit Ttcuf. The lower gradation zone of the Cuarteles Member is over 6-12 m thick to the south and becomes thicker to the north. This coarser sediment of the Cuarteles Member grades westward into fine-grained sediment of the distal alluvial slope (included in the Cuarteles Member; unit Ttcuf). The Cuarteles 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.

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

Ttcuf **Cuarteles 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.

Finer-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 0.5 to 1%, very thin to thin, brown to light brown (7.5YR 5-6/4) claystone beds. Very thin to medium, ribbon- to lenticular-shaped, isolated channel-fills are present within the finer-grained sediment (generally 3-30% 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 Cuarteles Member is considered part of the Tesuque Formation east of the Rio Grande (Ttcu) and part of the Chamita Formation (Tccu) 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 Cuarteles Member (Ttcu). This finer-grained part of the Cuarteles 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.

Tccuf Cuarteles Member of the Chamita Formation, fine-grained, distal sediment (upper middle to upper Miocene) – Strata similar to that of fine-grained Cuarteles Member of the Tesuque Formation (**Ttcuf**), as described above.

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 intercalated 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 to least common). Sand is outside of the coarse channel-fills is generally very fine- to medium-grained, mostly moderately to well consolidated, weakly cemented, and in very thin to thick (mostly medium to thick), tabular beds. Coarse channel-fills consist of medium- to very coarse-grained sandstone, pebbly sandstone, and sandy conglomerate. The coarse channel-fills are commonly pinkish gray in color, clast-supported, weakly to strongly cemented by calcium carbonate, and ribbon- to lenticular-shaped. Bedding within a channel-fill is laminated (especially for sand) or very thin to medium and lenticular, with lesser planar-horizontal or cross-stratified beds. The proportion of coarse channel-fills increases near (within 5 km) of the modern mountain front, so that gravelly sediment dominates adjacent to the modern mountain front. The conglomerate includes pebbles with minor cobbles. Gravel is poorly to moderately sorted, subrounded to angular (larger clasts are rounded to subrounded), and composed of granite with trace to 5% quartzite, 1-5% amphibolite, and variable (mostly 1-5%) intra-formational clasts (i.e., cemented sandstone). Sand is subangular to subrounded, moderately to well sorted, and an arkose. The lower 300-500 m of lithosome A north of Tesuque consists mostly of sand and gravel and is differentiated in the cross-sections as the lower coarse unit. Near Santa Fe, a 120-210 m-thick tongue of lower lithosome A extends southward under lithosome S deposits and may interfinger southward with lithosome S; this tongue is composed of well consolidated, very pale brown to pink, very poorly sorted silty-clayey very fine- to very coarse-grained sand and pebbly sand. Beds of fine, white and gray ashes are preserved in the western part of lithosome A. Lithosome A interfingers and grades laterally southward into lithosome S and laterally westward into lithosome B. It grades upward into the Cuarteles Member of the Tesuque Formation. Smith (2000b) and Kuhle and Smith (2001) have interpreted correlative sediment to the north as alluvial slope deposits. A synthesis of radiometric ages from tephra, biostratigraphic data, and geomagnetic polarity data indicate an age of 26-13.2 Ma (Izett and Obradovich, 2001; MacIntosh and Quade, 1995; Barghoorn, 1981 and 1985; Tedford and Barghoorn, 1993; Baldridge et al., 1980). Total thickness is 550-950 m.

Ttb **Lithosome B of the Tesuque Formation (lower to middle Miocene) –** Grayish basin floor sediment that consists primarily of floodplain deposits of claystone, siltstone, and very fine- to medium-grained sandstone intercalated with sparse channel-fills of fine- to very coarse-grained sandstone. Floodplain deposits are massive or in laminated to very thin to medium, horizontal-planar beds. Common colors are light gray, pale brown, light brownish gray, and pinkish gray. Sand is well sorted, subrounded to subangular, and contains abundant lithic grains (including greenish quartz grains). The proportion of lithic grains in the sediment is comparable to the proportion of potassium feldspar. Locally, siltstone and claystone contain 20-40% calcium carbonate nodules 1 to 5 cm in length. Pebbles are very sparse and include a mix of Paleozoic sandstone, siltstone, and limestone together with quartzite and quartz. Near eastern margin of deposit are local (up to 5%), very thin- to medium-thick, arkosic channel-fills that are strongly cemented and in horizontal-planar to lenticular beds; sand in these channel-fills is very fine- to very coarse-grained and clasts included granite and intra-formational sandstone (indurated by calcium carbonate).Sediment is commonly weakly consolidated and erodes to form strike valleys. Unit deposited on a basin-floor from a river sourced in the Penasco embayment and San Luis Basin. Unit Ttb interfingers and grades eastward into unit Tta and southward into unit Tta (to the east) or Tts (to the west). Under the eastern Pajarito Plateau, this unit is inferred to interfinger westward with unit Ttc. A synthesis of radiometric ages from tephra, biostratigraphic data, and geomagnetic polarity data indicate an age of 26-13.2 Ma (Izett and Obradovich, 2001; MacIntosh and Quade, 1995; Barghoorn, 1981 and 1985; Tedford and Barghoorn, 1993; Baldridge et al., 1980). Approximately 2000 m in thickness.

Tts **Lithosome S of the Tesuque Formation (lower to middle Miocene) –** Pebbly sand channel-fill deposits and fine sandstone, siltstone, and mudstone floodplain deposits associated with a large drainage exiting the Sangre de Cristo Mountains near the modern Santa Fe River. Unit is further subdivided in the cross-sections on the basis of gross texture and stratigraphic position (see below). Lithosome S is recognized by its clast composition (35-65% granite, 3-40% Paleozoic clasts, 5-30% quartzite, including a distinctive black quartzite, and 1-8% chert), reddish color (particularly compared to the browner, distal alluvial slope facies of lithosome A), and high-energy-flow deposits in very broad, thick channel complexes that possess very thin to medium, planar to lenticular internal bedding Lithosome S is coarser-grained near the axis of its associated alluvial fan and near the mountain-front, and becomes finer-grained to the south, southwest, northwest, and north. Coarse-grained strata include pebbly sandstone (most common), sandy conglomerate, and sandstone. The coarse strata exhibit stacked channel-fill complexes. Bedding within the channel-fill complex is laminated to very thin to thick, and horizontal planar to lenticular to concave-up channel-shaped to cross-stratified (up to 1.1 m-thick but generally less than 60 cm-thick). Most commonly, beds are very thin to thin, planar-horizontal to lenticular beds, with only minor ribbon forms. Local cross-stratification up to 1.1 m-thick (generally less than 60 cm) is present but relatively minor (includes both planar- and tangential cross-stratification. There is relatively high connectivity of the channel-fills and channel-fills may fine-upwards. Gravel consists of pebbles with subordinate cobbles. Channel-fill gravel is clast-supported, poorly to moderately sorted, and mostly subrounded (but granitic clasts may be subangular). Gravel is composed of granite with 3-40% Paleozoic sedimentary clasts (limestone, sandstone, and siltstone), 1-8% chert and petrified wood, 5-30% quartzite, 0-3% amphibolite, trace intermediate to felsic hypabyssal intrusives and volcanic flow-rock, 0-5% schist, and 1-10% gneiss. The sand fraction is an arkose composed of quartz, 10-30% potassium feldspar, trace to 7% yellowish Paleozoic siltstone, sandstone, or limestone grains, and trace to 5% chert and dark quartzite grains. Channel-fill sand is commonly light brown (7.5YR 6/3), fine- to very coarse-grained, poorly to well sorted, and subrounded to subangular. Well consolidated, pink to very pale brown, silty-clayey very fine- to fine-grained sand beds like that seen in lithosome A are uncommon. Cementation of channel-fills is variable. Channel-fills are weakly to moderately consolidated and weakly to non-cemented in overall coarser strata but 10-50% of the channel-fill complexes may be moderately to strongly cemented by calcium carbonate in overall finer strata. There appears to be a gradation in clast composition in the lower 275 m (900 ft) of lithosome S. Specifically, quartzite (including a distinctive dark quartzite) becomes progressively more abundant (1-3% to 19-26%), granite decreases from 82% to 46%, and Paleozoic clasts increase from 10 to 17%. Above 500 m (1670 ft) in the stratigraphic section, there are no obvious progressive trends, although the relative proportions of Paleozoic sedimentary clasts compared to quartzite change locally. Quartzite-dominated conglomerate is abundant in the upper 60-80 m of the unit; here, the channel complexes are the thickest, epsilon cross-stratification is locally present, and the clast composition is as follows: about 50% quartzite, 20% Paleozoic siltstone and sandstone, 1% chert, 2% gneiss, and 25-30% granitic rocks. Finer-grained strata of lithosome S are in very thin to medium, tabular beds with internal horizontal-planar to wavy laminations; locally, this sediment is massive. Overbank sediment consists of light brown to reddish yellow and pink to very pale brown siltstone, very fine- to coarse-grained (generally fine-grained) sandstone, and silty to clayey sandstone. Within the fine sediment are local very thin to medium, lenticular channel-fills. There are also variable amounts of reddish brown to yellowish red to light reddish brown mudstone and sandy mudstone. In the finer-grained deposits are locally clayey deposits reflecting floodplain and localized lake or shallow pond deposition, including a 150 m- (500 ft) thick clayey section near the Santa Fe Airport. Lithosome S interfingers and grades northwards and southwards into unit Tta and northwestward into unit Ttb. This unit gradationally overlies a 120-210 m-thick tongue of lower lithosome A sediment. Lithosome S gradationally overlies lithosome E (unit **Tte**) west of downtown Santa Fe. Because this unit interfingers northward with unit Tta, its age would be similar to that of Tta (i.e., 26-13 Ma). Maximum thickness of 2400 m.

Ttsc Coarser-grained Lithosome S of the Tesuque Formation (middle Miocene), differentiated in cross-sections only – Fluvial deposits characterized by a predominance of medium- to very coarse-grained sand and gravelly sand channel fills, with subordinate fine-grained floodplain deposits.

Ttsm Medium-grained Lithosome S of the Tesuque Formation (lower to middle Miocene), differentiated in cross-sections only – Fluvial deposits characterized by clay, silt and very fine- to fine-grained sand intercalated with subequal medium- to very coarse-grained, arkosic sand and gravelly sand channel fills; deposits of medium-grained lower Lithosome S are represented by intercalated fine sand and mudstone found between 1459 and 2273 in the Yates La Mesa #2 well

Ttsf Finger-grained Lithosome S of the Tesuque Formation (lower to middle Miocene), differentiated in cross-sections only – Fluvial deposits characterized by clay, silt and very fine- to medium-grained sand intercalated with minor medium- to very coarse-grained, arkosic sandstone channel fills (locally with very fine to fine pebbles); relatively clayey. Deposits of fine-grained lower Lithosome S are represented by intercalated fine sand and mudstone found between 2273 and 3500 ft in Yates La Mesa #2 well, but in this well the sand fraction is very fine- to very coarse-grained.

Ttas Gradational zone between lithosomes A and S of the Tesuque Formation, closer to lithosome A (lower to middle Miocene) – Fine-grained lateral gradation between lithosomes A and S; unit is laterally closer to lithosome A than lithosome S; predominantly fine sandstone, silty sandstone, and mudstone. Cross-section C-C' suggests a thickness of about 275 m for this unit.

Ttsa Gradational zone between lithosomes S and A of the Tesuque Formation, closer to lithosome S (lower to middle Miocene) – Fine-grained lateral gradation between lithosomes A and S; unit is laterally closer to lithosome S than lithosome A; predominantly fine sandstone, silty sandstone, and mudstone. Cross-section C-C' suggests a thickness of about 275 m for this unit.

Tte Lithosome E of the Tesuque Formation (upper Oligocene to lower Miocene) – Gray to brown (locally pink) sandstone, clayey-silty very fine- to very coarse-grained sandstone, and pebbly sandstone in the southwestern Santa Fe embayment. It has a general gray to brownish gray color. Pebbles and sand grains are mostly composed of latite and basalt in varying proportions, but with the general trend of basalt increasing in abundance down-hole. Locally on the cross-sections, a slightly greenish subunit of lithosome E is differentiated. In wells, it is commonly observe that lithosome E grades upward into muddy volcaniclastic sand and then up into reddish brown sandy mud of lithosome S. Lithosome E appears to be well-consolidated in boreholes, based on caliper logs (e.g., the recent Jail well by the NM State Penitentiary), and commonly is weathered and slightly muddy. Unit is not exposed so bedding character has not been observed. However, we suspect it has bedding similar to a typical alluvial fan: very thin to medium, planar to broadly lenticular beds intercalated with thin to thick, lenticular to tight and concave-up channel-fills. Lithosome E is locally exposed on the La Bajada escarpment, where it consists of pink, very fine- to medium-grained sandstone, silty sandstone, and siltstone interbedded with pebble-conglomerate containing largely latite clasts. Lithosome E includes detritus from the Cieneguilla basanite, so it is younger than that lava. Volcaniclastic sediment similar to lithosome E is interbedded in Cieneguilla basanite flows in the Yates La Mesa No. 2 well. Since lithosome E lies at the base of the Santa Fe Group, it probably is no younger than lower Miocene in the Santa Fe embayment. Along the La Bajada escarpment, lithosome E may be middle Miocene in age. Wells in the Santa Fe embayment suggest a maximum thickness of 160-170 m.

Tb **Blackshare Formation (lower to upper Miocene) –** Piedmont deposits of sandstone with interbeds of lenticular conglomerate, conglomeratic sandstone, and minor mudstone in the eastern Santo Domingo Basin; derived from the Ortiz Mountains. Conglomeratic beds are lenticular, and sandstone intervals commonly fine upward into thinly bedded mudstone. Gravel is composed mostly of monzanite and latite porphyry, with sparse, rounded metaquartzite, petrified wood, iron-stained sandstone, and hornfels. The Blackshare Formation conformably overlies the Tanos Formation and is overlain with angular unconformity by the Tuerto Gravel. It contains an ash that returned a $^{40}Ar/^{39}Ar$ age of 11.65 +/- 0.38 Ma (Connell et al., 2002). Greater than 1260 m in thickness. [Description is from Connell et al., 2002].

Tab **Abiquiu Formation (upper Oliogcene) –** Light gray, ash-rich silty sandstone beds and siltstone beds that form prominent cliffs (85 m in height) immediately north of the Santa Fe River, near the town of La Bajada. Reworked ash, mixed with detrital silt-clay and arkosic sand, is common in the section and there is a few primary ash-fall beds 20-50 cm-thick. Sand is mostly very fine- to medium-grained and arkosic. Local, thin limestone beds are interbedded with gray, green, and red silt and clay; these fine-grained deposits were interpreted to be lacustrine by Stearns (1953a). The volcaniclastic deposits at La Bajada are tentatively correlated as a distal equivalent of the volcaniclastic Abiquiu Formation (Stearns, 1953a), exposed in the Abiquiu area about 70 km north of the map area. This correlation is based on the unit's ashy nature and strong consolidation near the Santa Fe River. The Abiquiu Formation to the north is generally 25.5-23 Ma (Smith et al., 2002). Unit extent and thickness is poorly constrained in the subsurface to the north of La Bajada. In an unpublished north-south seismic line that passes through the Yates No. 2 La Mesa well, an interval of prominent seismic reflectors at the base of the Santa Fe Group in the northern map area may correlate to the Abiquiu Formation. If so, then the Abiquiu Formation is 800-850 m-thick in the Canada Ancha graben. Total exposed thickness of 300 m near the Santa Fe River.

Tcb **Cieneguilla Basanite (upper Oliogcene) –** Medium to dark gray to grayish black, porphyritic, mafic volcanic rocks that include basanite, nephelinite, and basalt. Overall, the flows are fine-grained and non-vesicular, and bedding textures and flow structures are poorly preserved. We follow Koning and Hallett (2000) and Sawyer et al. (2002) in redefining the Cieneguilla limburgite of Stearns (1953a,b) as the Cieneguilla Basanite. Its type section was designated as being along the Santa Fe River between the villages of Cieneguilla (the namesake of the formation) and Canyon (Stearns, 1953b; Sun and

Baldwin, 1958, p. 15-18 and fig. 3). At the type section, the formation dips 10 degrees east and consists of four massive, cliff-forming packages of 2-5 discontinuous lava flows. These packages are separated by tuff, breccia, and vesicular to amygdaloidal flows (Sun and Baldwin, 1958). Calcite commonly fills vesicles. At the type section, the breccia is angular and probably very proximal to the vent. Such angular, near-source breccias that are minor compared to flows are placed within the Cieneguilla Basanite. This unit also includes north- to northeast-striking dikes, together with small and irregular sills, that crosscut older rocks on the west side of the La Bajada escarpment and in Santa Fe Canyon (Sawyer et al., 2002). Cieneguilla basanite flows are present in the Yates #2 well. Weathered, dark, volcanic flows north of Santa Fe and 300 m (1000 ft) to 1400 m (4500 ft) west of the present-day mountain front are also correlated to the Cieneguilla Basanite. Here, these flows consist of black to gray, coarse-grained, altered olivine basalt(?) that is vesicular and amygdaloidal.

The Cieneguilla Basanite commonly lies between the Espinaso Formation and the Santa Fe Geroup. The unit clearly overlies the Espinaso Formation at its type section. At Cerro de la Cruz, the Cieneguilla basanite flows overlie or intrude into Espinaso Formation latitic breccia, and so should be younger than the Espinaso Formation. Spiegel (1975) interpreted that the Cieneguilla basanite or similar flows were interbedded with the lower Tesuque Formation based on well data, which we also interpret for Nuclear Dynamics borehole EB-38 (cross-section D-D'. Weathered basalt flows north of Santa Fe are interbedded in the lower part of lithosome A of the Tesuque Formation or rest directly on tuffaceous mudstone of the Bishop's Lodge Member of the Espinaso Formation. The base of the Cieneguilla Basanite is sharp and may represent a disconformity, at least locally. The top of the Cieneguilla Basanite grades upward into lithosome S, E, or A of the Tesuque Formation (units Tts, Tte, or Tta), depending on location. Total thickness of the Cieneguilla Basanite is 180 m (590 ft) (Stearns, 1953b) to 220 m (720 ft) (Sun and Baldwin, 1958) near La Cienega to approximately 320 m in the Yates La Mesa No. 2 well (Myer and Smith, 2006).

Near La Cienega, the Cieneguilla basanite has been dated at 25.1 $\pm$ 0.7 Ma using K-Ar radioisotopic analyses (Baldridge et al., 1980) and 26.08 $\pm$ 0.62 Ma using $^{40}Ar/^{39}Ar$ radioisotopic analyses (Peters, 2000b; Koning and Hallett, 2000). This value is similar to a K-Ar radioisotopic date of 25.1 $\pm$ 0.6 Ma (Kautz et al., 1981) and a $^{40}Ar/^{39}Ar$ radioisotopic date of 25.41 $\pm$ 0.32 Ma (Connell et al., 2002) obtained from an olivine tholeiite at Espinaso Ridge west of Cerrillos. The northern flows in our study area are too weathered for successful radiometric dating. However, these flows appear to lie in a similar stratigraphic interval as a 24.9 $\pm$ 0.6 Ma Ma basalt flow dated by K/Ar methods on the southwest flank of Cerro Pinon (Baldridge et al., 1980), located 3 km north of the north boundary of the geologic compilation map.

Te **Espinaso Formation (upper Eocene to upper Oligocene) –** Gray, volcaniclastic alluvial fan deposits of sandstone $_{\text{and}}$ conglomerate shed from former volcanic centers near the Cerrillos Hills. The proximal reaches of the alluvial fan deposits are interbedded with near-vent volcaniclastic breccias and minor latitic to andesitic flows (Kautz et all, 1981; Smith et al., 19991; Thompson et al., 2006). The Espinaso Formation represents an extensive apron of volcaniclastic debris surrounding volcanic centers associated with the Ortiz porphyry belt (Kautz et al., 1981; Smith (1981); Smith et al. (1991). Radiometric ages for the Espinaso Formation generally range from 36-29 Ma (Sawyer et al., 2002; Baldridge et al., 1980; Sauer, 1999). Unit is thickest northeast of the Cerrillos Hills in the middle of the Santa Fe embayment (600-650 m), but progressively decreases in thickness to the north. It is 307 m thick at the Yates La Mesa No. 2 well (Myer and Smith, 2006).

Tebl **Espinaso Formation, Bishop's Lodge Member (lower(?) to upper Oligocene) –** White to light gray, tuffaceous, silty-clayey sandstone and sandstone, with subordinate gray, pebbly volcaniclastic sandstone and pebble to boulder conglomerate containing latitic clasts; member represents distal alluvial fan facies of the Espinaso Formation. This unit was originally included in the Tesuque Formation but work by Smith (2000b) demonstrated correlation with the Espinaso Formation; consequently, we include this member within that formation. Clasts are compsosed of light to dark gray pyroxene (+ biotite) latite as large as 100 cm but typically 5-20 cm. Clast size increases to the south where 50 cm and larger clasts are common in exposures near the Santa Fe River. A slightly reworked ash, 30-40 cm thick, 4 m below the top of the Bishops Lodge interval was dated at 30.45 +0.16 Ma (Smith, 2000b). In places, the Bishops Lodge Member lies directly on Paleozoic rocks, but overlies up to 100 m of non-volcaniclastic Tesuque Formation around Bishops Lodge. Up to 80m thick. [description modified from G. Smith write-up in Read et al., 1999].

Northeast of Tesuque, the Bishops Lodge Member consists of white to light gray to light brownish gray (2.5Y 6-7/2 and 8/1), slightly silty-clayey(<20% estimate), slightly tuffaceous, very fine- to very coarse-grained sand and pebbly sand. The sand consists of quartz, plagioclase, 10-15% orangish potassium feldspar, <10% intermediate(?) volcanic grains (usually 0.5-3%), and 2-8% mafics; sand is poorly to moderately sorted and subangular to subrounded. Minor and variable volcanic pebbles of latite, andesite, or rhyolite. Bedding is poorly exposed but at least locally internally massive. The tuffaceous sediment is interbedded with minor pebbly sandstone that is arkosic; gravel are granite with 3% Paleozoic limestone-siltstone clasts.

Ti **Intrusive rocks (Oligocene) –** Various intrusions in the vicinity of the Cerrillos Hills and La Cienega that are generally felsic in composition. These intrusions are stocks and generally monzonite or quartz monzonite in composition, but locally there are smaller stocks of diorite and andesite. The monzonite and quartz monzonite is light gray (N7) to light brownish gray (5YR), medium-grained, and prophyritic. Phenocrysts of subhedral hornblende or augite, potassium feldspar, and plagioclase are commonly present. Biotite, plagioclase, magnetite, and a trace of clinopyroxene are present in the groundmass. Unit includes several units near the Cerrillos Hills: 1) quartz monzonite consisting predominantly of plagioclase, in addition to 5-10% quartz and minor amounts of potassium feldspar, clinopyroxene, orthopyroxene, and biotite (Koning and Hallett, 2000); 2) andesite porphyry that is grayish green to gray on fresh surfaces, fine-to medium grained, and porphyritic; subhedral andesine plagioclase makes up about 75 percent of the phenocrysts and ranges 0.5 to 2 mm; black euhedral hornblende phenocrysts (0.6-5 mm) constitute nearly all the rest of the phenocryst assemblage; andesite porphyry forms laccoliths, sills, dikes, and irregular masses (Maynard et al., 2001); 3) feldspar-porphyry latite that is gray to tan, with tabular euhedral orthoclase phenocrysts 1.0 to 3.0 cm long in light gray groundmass (Maynard et al., 2001); 4) augite monzonite that forms the highest parts of the Cerrillos Hills; it is gray to dark gray, medium-grained, equigranular to porphyritic and composed of andesine and orthoclase. On the Galisteo quadrangle, this unit includes a dark purplish brown latite consisting of a porphyritic mixture of plagioclase, potassium feldspar, titaniferous augite, titaniferous biotite, apatite, and magnetite in a glassy groundmass (Lisenbee, 1999). $^{40}Ar/^{39}Ar$ and K/Ar dating indicates a 28-34 Ma age range for these intrusions (Maynard, 1995; Lisenbee, 1999; Sauer, 1999; Maynard et al., 2001; Baldridge et al., 1980).

Tog **Older gravel (upper Eocene to lower Oligocene) –** Limestone- and granite-bearing pebbly sandstone and conglomerate that underlies the Bishops Lodge Member (Espinaso Formation) at and north of Santa Fe. Bedding is commonly medium, tabular to lenticular. Gravel are subangular to subrounded, commonly clast-supported, moderately to poorly sorted, and consist of pebbles with varying amounts of cobbles (but cobbles are generally subordinate). Clasts are composed of granite, granitic gneiss, and yellowish Paleozoic limestone and siltstone. Concentration of limestone gravel decreases up-section (from 70% to 10-15%). Sand is light yellowish brown to light gray (2.5Y 6/3-7/2), subrounded to subangular, poorly to moderately sorted, mostly medium- to very coarse-grained, and an arkose in its upper part. Common strong cementation. Locally exceeds 400 m in thickness (Smith, 2000b).

Tg **Galisteo Formation, undivided (Eocene) –** Fluvial sediment exposed along the Rio Galisteo that is characterized by thick, laterally extensive, cemented channel-fill complexes of sandstone interbedded with reddish overbank and distal piedmont deposits. The interpreted age of the revised Galisteo Formation is early to late Eocene (Lucas, 1982; Lucas et al., 1997). The age interpretation is based on fossil studies summarized in Lucas (1982) and Lucas et al. (1997).

Tgd **Galisteo and Diamond Tail Formations undifferentiated (subcrop unit only)**

Tgu **Galisteo Formation, upper unit (Eocene) –** Tan to white, cross-bedded to massive, sandstone and pebbly sand channel-fills (non- to strongly cemented) with subordinate overbank deposits of fine sandstone and red, rose, tan, and gray-green mudstone; the gravel are predominately quartzite and chert. Contains silicified logs up to 1.2 m in diameter and up to 10 m long. This unit includes the “upper yellow pebbly sandstone member” of Gorham (1979). Interpreted by the authors to have been deposited by a east- to southeast-flowing axial river deposit. If this interpretation is correct, then in the subsurface of the Santa Fe embayment one may expect a northward, lateral transition of the upper unit to sediment similar to that of the lower unit. The upper contact of the Galisteo Formation is gradational with the overlying Espinaso Formation. Commonly weakly consolidated. 100-130 m-thick in the Galisteo quadrangle (Lisenbee, 1999) and 280 m-thick in the Picture Rock quadrangle (Maynard et al., 2002).

Tgl **Galisteo Formation, lower unit (Eocene) –** Pink to red, sandy conglomerate and arkosic sandstone channel-fills intercalated with mudstone, siltstone, and fine sandstone overbank deposits; the gravel contains mostly granite, with subordinate Paleozoic limestone and sandstone. The proportion of granite to Paleozoic sedimentary clasts in the lower unit increases up-section (Maynard et al., 2002). The lower contact corresponds with an unconformity. Interpreted to have been deposited by south-flowing streams flowing into the Galisteo Basin from the Sangre de Cristo Mountains. The upward change in clast composition in the lower unit (i.e., an upward increase in the ratio of granite gravel to Paleozoic sedimentary clasts) probably reflects unroofing of the highlands north of the Galisteo Basin (Lucas et al., 1997). 1000-1100 m-thick in the Galisteo quadrangle (Lisenbee, 1999) and 1200 m-thick in the Picture Rock quadrangle (Maynard et al., 2002).

Tdt **Diamond Tail Formation (Paleocene) –** Sandstone and pebbly sandstone, mudstone, minor conglomerate, and local limestone beds that unconformably underlies the Galisteo Formation. Proposed by Lucas et al. (1997), the Diamond Tail Formation constitutes the lower 0-442 m of what was called the Galisteo Formation by previous workers (e.g., Stearns, 1943 and 1953a, Disbrow and Stoll, 1957, Bachman, 1975, Johnson, 1975, Kelley and Northrop, 1975, Gorham, 1979, Beaumont, 1979, and Lucas, 1982). The sandstone exhibits yellow, tan, orange, and gray colors. The mudstone is variegated gray to maroon to greenish gray, and generally lacks the brick red (moderate reddish brown) colors common in the overlying Galisteo Formation (Lucas et al., 1997). Clasts in Diamond Tail Formation conglomerate beds are well-sorted and consist of dominantly white and gray quartzite and chert (minor petrified wood in small fragments and ironstone concretions) and mostly small (<0.5 cm diameter), whereas clasts in the overlying Galisteo Formation in the study area are coarser, less sorted, and include quartzite and granite with subordinate Paleozoic limestone, sandstone, and chert clasts (Lucas et al., 1997). In the area north of Madrid conglomerate is notably rare. Sandstone beds are massive, friable, commonly trough-cross bedded, and composed of medium- to coarse-grained, subrounded, poorly sorted arkose and subarkose. Kaolin, limonite, or calcite commonly constitute the matrix. Most of the Diamond Tail Formation in the Galisteo type section area is composed of brown to green to gray mudstone and medium- to coarse-grained, conglomeratic, trough crossbedded, subarkosic sandstone (Lucas et al., 1997). The Diamond Tail Formation represents the earliest deposition in the Laramide-age Galisteo Basin (Lucas et al., 1997). Gorham and Ingersoll (1979) interpret that sources of the river(s) depositing this unit were derived from primarily granitic and/or metamorphic source areas to the north and northeast. However, Lucas et al. (1997) interpret clast compositions to suggest recycling of coarse detritus from Mesozoic strata. Lucas et al. (1997) interpret a late Paleocene to early Eocene age for the upper part of the Diamond Tail Formation based on the presence of a left dentary fragment correlated to the species *Hyracotherium*. The Diamond Tail Formation thickens to the east in the Rio Galisteo area, from 120 m at the Galisteo Formation type section (Lucas et al., 1997) to 240-300 m east of Galisteo (Lisenbee, 1999). [description from (Abbott et al., 1995; Lucas et al., 1997; Lisenbee, 1999; Maynard et al., 2002].

Mzu **Mesozoic Rocks undifferentiated** (**subcrop in the Cerrillos Hills area) –** Cretaceous, Jurassic, and Triassic rocks present in the subsurface and shown bounded by concealed contacts.

K **Cretaceous strata, undivided –** Unit includes the Menefee Formation, Point Lookout Sandstone, Dakota Sandstone, and Mancos Shale. The Menefee Formation contains sandstone and siltstone with coal seems. Color range from gray to tan to orange-tan. Sediment is cross-bedded and laminated to thick-bedded. Dark-gray to olive-gray and black shale is also present. The Menefee Formation is up to 380 m-thick in the Madrid quadrangle (Maynard et al., 2001). The Point Lookout Sandstone consists of gray-tan to light-tan and drab-yellow to dark brown to olive, fine- to medium-grained quartz sandstone and interbedded thin, gray shale; its thickness varies from 0 to 150 m-thick (Maynard et al., 2002). The Mancos shale consist of thick marine shale, calcareous shale, and sandy shale, with minor beds of bentonite and limestone (Sawyer and Minor, 2006). Uppermost Mancos Shale deposits are sandy and may be a lateral equivalent to the Niobrara Member (Sawyer and Minor, 2006). The Dakota Sandstone is yellow-orange, fine- to coarse-grained, cross-bedded to tabular-bedded sandstone; it is interbedded with one or two tongues of calcareous shale and silty very fine- to fine-grained sandstone (Maynard et al., 2001; Lisenbee, 1999). Dakota Sandstone is 35-36 m-thick and Mancos shale is as much as 280 m-thick (Maynard et al., 2001) [Description modified from Maynard et al., 2001; Maynard et al., 2002; Lisenbeen, 1999; and Sawyer and Minor, 2006].

J **Jurassic strata, undivided –** Unit includes the Entrada Sandstone, Todilto Formation, Summerville, and Morrison Formation. The Entrada Sandstone is a ledge-former and variably massive to planar-bedded to cross-stratified. The Entrada can be subdivided into a reddish brown lower section, composed of very fine-grained sandstone and silty sandstone, and a yellowish-gray upper section that is composed of fine- to medium-grained sandstone (Lucas et al., 1995). Total thickness of the Entrada Sandstone is 30-60 m. The Todilto Formation is also a ledge-former and com posed of a lower thin limestone member and an upper, thicker gypsum member. The lower limestone is yellow to medium gray, thinly laminated to massive, and 5 m-thick. The gypsum member is white, massive, and typically brecciated in outcrop. Thickness ranges from 20-70 m. Grayish red, gypsiferous siltstone and sandstone characterize the Summerville Formation; these strata overlie a basal, reddish brown to red siltstone; total thickness is ~100 m. The Morrison Formation consists of fluvial strata of variable colors. [Description modified from Sawyer and Minor, 2006].

Tr **Triassic strata, undivided –** Red-orange, reddish brown, dark brown, purplish gray and green mudstone that is interbedded with dark red brown to buff, cross-bedded sandstone and limestone-pebble conglomerate. Assigned to the Chinle Group and Moenkopi Formation (Lisenbee et al., 1999; Maynard et al., 2002) and deposited in a fluvial environment. 150-560 m-thick. [Description modified from Sawyer and Minor, 2006; Lisenbee, 1999].

Pzu **Paleozoic strata, undivided –** Gray to yellowish cherty limestone, yellowish calcareous siltstone, greenish gray shale, and minor very fine- to coarse-grained arkosic sandstone. Exposures east of Santa Fe are dominantly limestones of the La Posada and Alamitos Formations that are interbedded with coarse sandstones (Miller, Montgomery, and

Southerland, 1963). Isolated thin outcrops of Mississipian Arroyo Peñasco Group sediments are also present in places. In the subsurface of the southern Santa Fe embayment, this unit includes the San Andres Formation, Glorieta Sandstone, Yeso, and Abo Formations.

XYu **Proterozoic rocks, undivided –** Granite, pegematite, metaplutonic rocks, and amphibolite comprises most of the Sangre de Cristo Mountains (Miller, Montgomery, and Southerland, 1963). Granite, both foliated and unfoliated, is mostly medium- to coarse-grained.

REFERENCES

Abbott, J.C., Cather, S.M., and Goodwin, L.B., 1995, Paleogene synorogenic sedimentation in the Galisteo basin related to the Tijeras-Cañoncito fault system: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, p. 271-278.

Aubele, J., C., 1978, Geology of Cerros del Rio volcanic field, in Hawley, J.W., *compiler*, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Circular 163, p. 198-201.

Bachman, G.O., 1975, Geologic map of the Madrid quadrangle, Santa Fe and Sandoval Counties, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map GQ-1268, scale 1:62,500.

Bailey, R.A., Smith, R.L., and Ross, C.S., 1969, Stratigraphic nomenclature of volcanic rocks in the Jemez Mountains, New Mexico: U.S. Geological Survey Bulletin 1274-P, 19 p.

Baldridge, W.S., 1979, Petrology and petrogenesis of Plio-Pleistocene basaltic rocks from the central Rio Grande rift, New Mexico, and their relation to rift structure, in Riecker, R.E., (ed.), Rio Grande rift – tectonics and magmatism: American Geophysical Union, Washington, D.C., p. 323-353.

Baldridge, W.S., Damon, P.E., Shafiqullah, M., and Bridwell, R.J., 1980, Evolution of the central Rio Grande rift, New Mexico - new Potassium-Argon ages: Earth and Planetary Science Letters, v. 51, p. 309-321.

Barghoorn, S., 1981, Magnetic-polarity stratigraphy of the Miocene type Tesuque Formation, Santa Fe Group, in the Española Valley, New Mexico: Geological Society of America Bulletin, v. 92, p. 1027-1041.

Barghoorn, S.F., 1985, Magnetic polarity stratigraphy of the Tesuque Formation, Santa Fe Group, in the Española Valley, New Mexico, with a taxonomic review of the fossil camels [doctoral]: New York, Columbia University, 489 p.

Bates, R.L., and Jackson, J.A., 1983, A Dictionary of Geological Terms (3rd edition) [prepared under the direction of the American Geological Institute]: New York, Doubleday, 571 p.

Bauer, P.W., Ralser, S., Daniel, C., and Ilg, B., 1996, revised Dec-1997, Geology of the McClure Reservoir 7.5-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-7, scale 1:12000.

Beaumont, E.C., 1979, Geology of the Cerrillos coal field, Santa Fe County, New Mexico: New Mexico Geological Society Guidebook, 30th Field Conference, Santa Fe Country, p. 269-274.

Biehler, S., Ferguson, J., Baldridge, W.S., Jiracek, G.R., Aldren, J.L., Martinez, M., Fernandez, R., Romo, J., Gilpin, B., Braile, L.W., Hersey, D.R., Luyendyk, B.P., and Aiken, C.L., 1991,

A geophysical model of the Española basin, Rio Grande rift, New Mexico: Geophysics, v. 56, p. 340-353.
Birkeland, P.W., Machette, M.N., and Haller, K.M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological and Mineral Survey, a division of the Utah Department of Natural Resources, Miscellaneous Publication 91-3, 63 p.
Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 430 p.
Black, B.A., 1984, Structural anomalies in the Española Basin: New Mexico Geological Society Guidebook, 35th Field Conference, Rio Grande Rift, Northern New Mexico, p. 59-62.
Booth, F.O., III, 1977, Geologic map of the Galisteo Creek area, Lamy to Cañoncito, Santa Fe County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-823, scale 1:12,000.
Borchert, C., Skotnicki, S., and Read, A.S., 1998, Preliminary geologic map of the Tesuque 7.5-minute quadrangle: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM 47, scale 1:24,000.
Broxton, D. E., Heiken, G.H., Chipera, S.J., and Byers, F.M., Jr., 1995, Stratigraphy, petrography, and mineralogy of Bandelier Tuff and Cerro Toledo deposit: Los Alamos National Laboratory, LA-12934-MS, p. 33-64.
Cather, S.M., 1992, Suggested revisions to the Tertiary tectonic history of north-central New Mexico: New Mexico Geological Society Guidebook, 43rd Field Conference, San Juan Basin IV, p. 109-122.
Compton, R.R., 1985, Geology in the field: New York, John Wiley & Sons, Inc., 398 p.
Connell, S.D., Cather, S.M., Dunbar, N.W., McIntosh, W.C., and Peters, L., 2002, Stratigraphy of the Tanos and Blackshare Formations (lower Santa Fe Group), Hagan embayment, Rio Grande rift, New Mexico: New Mexico Geology, vo. 24, no. 4, p. 107-120.
Dethier, D.P., 1997, Geology of the White Rock quadrangle, Los Alamos and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources in cooperation with Los Alamos National Laboratory, University of California, Geologic Map 73, scale 1:24,000.
Dethier, D.P., and Reneau, S.L., 1995, Quaternary History of the western Española Basin, New Mexico: New Mexico Geological Society, 46th Field Conference Guidebook, Geology of the Santa Fe Region, p. 289-298.
Dethier, D.P. and Koning, D.J., 2007, Preliminary geologic map of the White Rock 7.5-minute quadrangle, Los Alamos and Santa Fe Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM 149, scale 1:24,000.
Disbrow, A.E., and Stoll, W.C., 1957, Geology of the Cerrillos area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 48, 73 p.
Drakos, P., Riesterer, J., and Lazarus, J., 2002, Geohydrology and water availability for Santa Fe Canyon Ranch subdivision, Santa Fe County, New Mexico: unpublished consultant report prepared for Santa Fe Canyon Ranch LLC by Glorieta Geoscience, Inc., 47 p. plus appendices.
Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.
Gorham, T.W., 1979, Geology of the Galisteo Formation, Hagan basin, New Mexico [M.S. thesis]: University of New Mexico, Albuquerque, 136 p.
Gradstein, F.M., Ogg, J.G., and Smith, A.G., 2004, A geologic time scale: Cambridge University Press, 585 p.

Grauch, V.J.S., Phillips, J.D., Koning, D.J., Johnson, P.S., and Bankey, V., 2009, Geophysical interpretations of the southern Española Basin, New Mexico, that contribute to understanding its hydrogeologic framework: U.S. Geological Survey Professional Paper 1761, 88 p.

Griggs, R.L., 1964, Geology and ground-water resources of the Los Alamos area, New Mexico: U.S. Geological Survey Water Supply Paper 1753, 107 p.

Ilg, B., Bauer, P.W., Ralser, S., Rogers, J., and Kelley, S., 1997, revised Dec-1997, Geology of the Glorieta 7.5-minute quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-11, scale 1:24,000.

Ingram, R.L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geological Society of America Bulletin, v. 65, p. 937-938, table 2.

Izett, G.A., and Obradovich, J.D., 1994, $^{40}Ar/^{39}Ar$ age constraints for the Jaramillo Normal Subchron and Matuyama-Brunhes geomagnetic boundary: Journal of Geophysical Research, v. 99, p. 2925-2934.

Izett, G.A., and Obradovich, J.D., 2001, $^{40}Ar/^{39}Ar$ ages of Miocene tuffs in basin-fill deposits (Santa Fe Group, New Mexico, and Troublesome Formation, Colorado) of the Rio Grande rift system: The Mountain Geologist, v. 38, no. 2, p. 77-86.

Johnson, P.S., 2009, Water-level contours and ground water flow conditions (2000 to 2005) for the Santa Fe area, southern Española Basin, New Mexico, New Mexico Bureau of Geology and Mineral Resources, Open-file Report 520, CD-ROM.

Johnson, R.B., 1975, Geologic map of the Galisteo quadrangle, Santa Fe County, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map 1234, scale 1:24,000.

Kautz, P.F., Ingersoll, R.V., Baldridge, W.S., Damon, P.E., and Shafiqullah, M., 1981, Geology of the Espinaso Formation (Oligocene), north-central New Mexico: Geological Society of America Bulletin, vol. 92, Part I (p. 980-983) and Part II (p. 2318-2400).

Kelley, V.C., 1978, Geology of Española Basin, New Mexico, GM-48, Scale 1:125,000, (Reprinted 1992).

Kelley, V.C., and Northrop, S.A., 1975, Geology of the Sandia Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 29, 136 p.

Koning, D.J., and Hallett, R.B., 2000, rev. March-2001, Geology of the Turquoise Hill 7.5-min. quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 41, scale 1:24,000.

Koning, D.J., and Maldonado, F., 2001, revised Oct-2003, Geologic map of the Horcado Ranch quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-54, scale 1:24,000.

Koning, D.J., and Aby, S.B., 2005, Proposed Members of the Chamita Formation, north-central New Mexico: New Mexico Geological Society Guidebook, 56th Field Conference, Geology of the Chama Basin, 2005, p. 258-278.

Koning, D.J., Connell, S.D., Pazzaglia, F.J., and McIntosh, W.C., 2002, Redefinition of the Ancha Formation and Pliocene-Pleistocene deposition in the Santa Fe embayment, north-central New Mexico: New Mexico Geology, v. 24, no. 3, p. 75-87.

Koning, Daniel J., Connell, Sean D., Morgan, Gary S., Peters, Lisa, and McIntosh, William C., 2005, Stratigraphy and depositional trends in the Santa Fe Group near Española, north-central New Mexico: tectonic and climatic implications: New Mexico Geological Society Guidebook, 56th Field Conference, Geology of the Chama Basin, p. 237-257.

Koning, D.J., Broxton, D., Sawyer, D., Vaniman, D., and Shomaker, J., 2007, Surface and subsurface stratigraphy of the Santa Fe Group near White Rock and the Buckman areas of

the Española Basin, north-central New Mexico: New Mexico Geological Society Guidebook, 58th Field Conference, Geology of the Jemez Mountains Region II, p. 209-224.
Koning, D.J., Grauch, V.J.S., Connell, S.D., Ferguson, J., McIntosh, W., Slate, J.L., Wan, E., and Baldridge, W.S., *in press* Structure and tectonic evolution of the eastern Española basin, Rio Grande rift, north-central New Mexico: *in* Hudson, M. and Grauch V.G.S, (eds) Geological Society of America Special Paper
Kuhle, A., and Smith, G.A., 2001, Alluvial-slope deposition of the Skull Ridge Member of the Tesuque Formation, Española Basin, New Mexico: New Mexico Geology, p. 30-37.
Lisenbee, A.L., 1999, Geology of the Galisteo 7.5-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-30, scale 1:24,000.
Lucas, S.G., 1982, Vertebrate paleontology, stratigraphy, and biostratigraphy of Eocene Galisteo Formation, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 186, 34 p.
Lucas, S.G., Anderson, O.J., and Pigman, C., 1995, Jurassic stratigraphy in the Hagan basin, north-central New Mexico: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, p. 247-255.
Lucas, S.G., Cather, S.M., Abbott, J.C., and Williamson, T.E., 1997, Stratigraphy and tectonic implications of Paleogene strata in the Laramide Galisteo Basin, north-central New Mexico: New Mexico Geology, v. 19, no. 4, p. 89-95.
Manley, K., 1976, The Late Cenozoic History of the Española Basin, New Mexico [Ph.D. thesis]: University of Colorado, 1-171 pp.
Manley, K., 1979, Tertiary and Quaternary stratigraphy of the Northeast Plateau, Española Basin, New Mexico: New Mexico Geological Society Guidebook, 30th Field Conference, Santa Fe Country, p. 231-236.
Manley, K., and Naeser, C.W., 1977, Fission-track ages for tephra layers in upper Cenozoic rocks, Española Basin, New Mexico: Isochron/West, no. 18, p. 13-14.
Maynard, S.R., 1995, Gold mineralization associated with mid-Tertiary magmatism and tectonism, Ortiz Mountains, Santa Fe County, New Mexico: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe region, p. 161-166.
Maynard, S.R., Sawyer, D., and Rogers, J., 2001, Geology of the Madrid 7.5-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-40, scale 1:24,000.
Maynard, S.R., Lisenbee, A.L., and Rogers, J., 2002, Geology of the Picture Rock 7.5-minute quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-51, scale 1:24,000.
McIntosh, W.C., and Quade, J., 1995, $^{40}Ar/^{39}Ar$ geochronology of tephra layers in the Santa Fe Group, Española Basin, New Mexico: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, p. 279-284.
Miyaji, M., Izett, G.A., Naeser, C.W., Naeser, N.D., and Andreissen, P.A.M., 1985, Zircon fission-track ages on some volcanic rocks and pyroclastic flow deposits on the Jemez Mountains, New Mexico: Bulletin of the Volcanological Society of Japan, v. 30, p.90-91.
Miller, John P., Montgomery, A., and Sutherland, P. K**.**, 1963, Geology of part of the southern Sangre de Cristo Mountains, New Mexico, New Mexico Bureau Mines Mineral Resources, Memoir, v. 11, 106 p..
Miller, J.P., and Wendorf, F., 1958, Alluvial chronology of the Tesuque Valley, New Mexico: Journal of Geology, v. 66, p. 177-194.

Munsell Color, 1994 edition, Munsell soil color charts: New Windsor, N.Y., Kollmorgen Corp., Macbeth Division.

Myer, C., and Smith, G.A., 2006, Stratigraphic analysis of the Yates #2 La Mesa well and implications for southern Española Basin tectonic history: New Mexico Geology, vol. 28, no. 3, p. 75-83.

Phillips E. H., Goff, F., Kyle, P.R., McIntosh, W.C., Dunbar, N.W., Gardner, J.N., 2007, The ^{40}Ar/ ^{39}Ar age constraints on the duration of resurgence at the Valles caldera, New Mexico: Journal of Geophysical Research, v. 112, B08201, 15 p.

Read, A.S., Rogers, J.B., Ralser, S., Ilg, B.R., and Kelley, S., 1999, Preliminary geologic map of the Seton Village 7.5-minute quadrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-23, scale 1:12,000.

Read, A.S., Koning, D.J., Smith, G.A., Ralser, S., Rogers, J., and Bauer, P.W., 2000 (last revised October-2003), Geologic map of the Santa Fe 7.5-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM-32, scale 1:12,000.

Read, A.S., Koning, D.J., and Johnson, P.S., 2004, Generalized geologic map of the southern Española basin, Santa Fe County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Report 481, CD-ROM.

Reneau, S., Gardner, J., and Forman, S., 1996, New evidence for the age of the youngest eruptions in the Valles caldera: Geology, v. 24, p. 7-10.

Sauer, R.R., 1999, Petrochemistry and geochronology of plutons relative to tectonics in the San Pedro-Ortiz porphyry belt, New Mexico [M.S. thesis]: Boulder, University of Colorado, 115 p.

Sawyer, D.A., and Minor, S.A., 2006, Geologic Setting of the La Bajada Constriction and Cochiti Pueblo Area, New Mexico, *in* Minor, S.A. (ed.), The Cerrillos Uplift, the La Bajada Constriction, and Hydrogeologic Framework of the Santo Domingo Basin, Rio Grande Rift, New Mexico (U.S. Geological Survey Professional Paper 1720), p. 3-23.

Sawyer, D. A., Shroba, R. R., Minor, S. A., and Thompson, R. A., 2002, Geologic map of the Tetilla Peak quadrangle, Santa Fe and Sandoval Counties, New Mexico: U. S. Geological Survey Miscellaneous Field Studies Map MF-2352, scale 1:24,000, version 1.0.

Sawyer, D.A., Minor, S.A., Thompson, R.A., Shroba, R.R., Smith, G.A., Dethier, D.P., Grauch, V.J.S., and Brandt, T.R., 2006, Geologic Map of the Cochiti Pueblo area, New Mexico, *in* Minor, S.A. (ed.), The Cerrillos Uplift, the La Bajada Constriction, and Hydrogeologic Framework of the Santo Domingo Basin, Rio Grande Rift, New Mexico (U.S. Geological Survey Professional Paper 1720), Plate 2.

Sawyer, D.A., Koning, D.J., Smith, G.A., Goff, F., Kelley, S.A., Minor, S.A., Kellogg, K.S., Thompson, R.A., and Read, A.S., in review, Geologic map of the Los Alamos-Española Basin area, Santa Fe, Sandoval, Los Alamos, and Rio Arriba Counties, New Mexico: U.S. Geological Survey, Open-file report XX.

Shroba, R.R., Thompson, R.A., Minor, S.A., Grauch, V.J.S., and Brandt, T.R., 2005, Geologic map of Agua Fria quadrangle, Santa Fe County, New Mexico U. S. Geological Survey Investigations Map 2896, scale 1:24,000. http://pubs.usgs.gov/sim/2005/2896.

Smith, G.A., 1991, Stratigraphy and sedimentology of Espinaso Ridge (Stop 1): New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, p. 89-90.

Smith, G.A., 2000a, Oligocene onset of Santa Fe Group sedimentation near Santa Fe, New Mexico (abs.): New Mexico Geology, v. 22, p. 43.

Smith, G.A., 2000b, Recognition and significance of streamflow-dominated piedmont facies in extensional basins: Basin Research: v. 12, p. 399-411.
Smith, G.A., and Kuhle, A.J., 1998 (rev. 2000), Geologic map of the Santo Domingo Pueblo and Santo Domingo Pueblo SW quadrangles, Sandoval County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Digital Map OF-DM-15 and OF-DM-26, 1 sheet and text, scale 1:24,000.
Smith, G.A., Moore, J.D., and McIntosh, W.C., 2002, Assessing roles of volcanism and basin subsidence in causing Ologicene-lower Miocene sedimentation in the northern Rio Grande rift, New Mexico, U.S.A.: Journal of Sedimentary Research, v. 72, p. 836-848.
Smith, G.A., Larsen, D., Harlan, S.S., McIntosh, W.C., Erskine, D.W., and Taylor, S., 1991; A tale of two volcaniclastic aprons: Field guide to the sedimentology and physical volcanology of the Oligocene Espinaso Formation and Miocene Peralta Tuff, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, p. 87-103.
Smith, R.L., Bailey, R.A., and Ross, C.S., 1970, Geologic map of the Jemez Mountains, New Mexico: United States Geological Survey Map I-571, scale 1:125,000.
Soil Survey Staff, 1992, Keys to Soil Taxonomy: U.S. Department of Agriculture, SMSS Technical Monograph no. 19, 5th edition, 541 p.
Spell, T.L., Kyle, P.R., and Baker, J., 1996a, Geochronology and geochemistry of the Cerro Toledo Rhyolite: New Mexico Geological Society, Guidebook 47, p. 263-268.
Spell, T., McDougall, I., and Doulgeris, A., 1996b, Cerro Toledo Rhyolite, Jemez volcanic field, New Mexico: Ar geochronology of eruptions between two caldera-forming events: Geological Society of America Bulletin, v. 108, p. 1549-1566.
Spiegel, Z. and Balwin, B., 1963, Geology and Water Resources of the Santa Fe Area, New Mexico, U. S. Geological Survey Water-supply Paper 1525, 258p.
Spiegel, Z., 1975, Preliminary report on the hydrology of the Cienega area, Santa Fe County, New Mexico: unpublished consultant report by Zane Spiegel for Santa Fe Downs, Inc., 34 p. plus appendices.
Stearns, C.E., 1943, The Galisteo Formation of north-central New Mexico: Journal of Geology, v. 5, p. 301-319.
Stearns, C.E., 1953a, Tertiary geology of the Galisteo-Tonque area, New Mexico: Geological Society of America, Bulletin, v. 64, p. 459-508.
Stearns, C.E., 1953b, Early Tertiary vulcanism in the Galisteo-Tonque area, north-central New Mexico: American Journal of Science, v. 251, p. 415-452.
Stimac, J.A. 1996, Hornblende-dacite pumice in the Tshierge Member of the Bandelier Tuff: Implications for magma chamber and eruptive processes: New Mexico Geological Society, Guidebook 47, p. 269-274.
Sun, M. and Baldwin, B., 1958, Volcanic rocks of the Cienega area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 54, 80 p., map scale 1:15,840.
Tedford, R.H., and Barghoorn, S.F., 1993, Neogene stratigraphy and mammalian biochronology of the Española Basin, northern New Mexico: Vertebrate paleontology in New Mexico, New Mexico Museum of Natural History and Science, Bulletin 2, p. 159-168.
Thompson, R.A., Sawyer, D.A., Hudson, M.R., Grauch, V.J.S., and McIntosh, W.C., 2006, Cenozoic volcanism of the La Bajada constriction area, New Mexico, *in* Minor, S.A. (ed.), The Cerrillos Uplift, the La Bajada Constriction, and Hydrogeologic Framework of the Santo

Domingo Basin, Rio Grande Rift, New Mexico: U.S. Geological Survey Professional Paper 1720, p. 43-60.
Toyoda, S., and Goff, F., 1996, Quartz in post-caldera rhyolites of Valles caldera, New Mexico: ESR finger printing and discussion of ESR ages: New Mexico Geological Society, Guidebook 47, p. 303-309.
Toyoda, S., Goff, F., Ikeda, S., and Ikeya, M., 1995, ESR dating of quartz phenocrysts in the El Cajete and Battleship Rock Members of the Valles Rhyolite, Valles, caldera, New Mexico: Journal of Volcanology and Geothermal Research, v. 67, p. 29-40.
Turbeville, B.N., Waresback, D.B., and Self, S., 1989, Lava dome growth and explosive volcanism in the Jemez Mountains, New Mexico – evidence from the Pliocene-Pleistocene Puye alluvial fan: Journal of Volcanology and Geothermal Research, v. 36, p. 267-291.
Udden, J.A., 1914, The mechanical composition of clastic sediments: Bulletin of the Geological Society of America, v. 25, p. 655-744.
Varnes, D.J., 1978, Slope movement types and process, in Schuster, R.L., and Krizek, R.J., eds., Landslides, analysis, and control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11-33.
Walker, J.D., Geissman, J.W., compilors, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C.
Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.
WoldeGabriel, G., Warren, R., Broxton, D., Vaniman, D., Heizler, M., Kluk, E., and Peters, L., 2001, Episodic volcanism, petrology, and lithostratigraphy of the Pajarito Plateau and adjacent areas of the Española Basin and the Jemez Mountains: New Mexico Museum of Natural History and Science, Bulletin 18, p. 97-129.