Geologic Map of the Los Alamos 30 x 60-Minute Quadrangle, 1:24,000 Scale Compilation of the Los Alamos, Rio Arriba, Santa Fe, and Sandoval Counties, New Mexico

By

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Open-file Digital Geologic Map OF-GM 298

Scale 1:24,000

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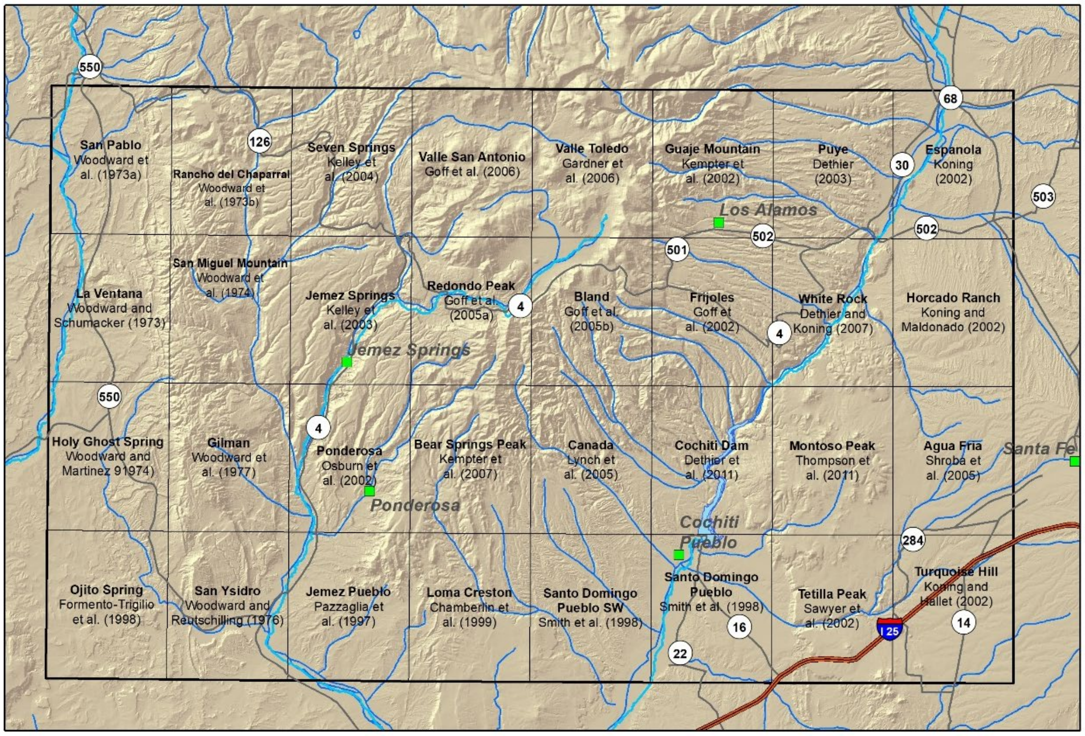

Figure 1. Quadrangles included in this compilation.

Notes about this map: The line work and symbology on the Los Alamos 1:100,000-scale map are largely derived from the original line work and symbology on the 1:24,000-scale geologic maps shown in Figure 1. Most of the mapping fieldwork in the Jemez Mountains took place between 1999 and 2006, with subsequent edge matching and field checking occurring during the 2007 to 2010 timeframe during the preparation of the Goff et al. (2011) map. More recent new mapping is presented on this compilation map. One area is along the Rio Guadalupe in the western Jemez Mountains, highlighting Otowi Member and Paliza Canyon andesite outcrops that are not shown on the original Smith et al. (1970) map. A second area is along the Pajarito fault zone between Los Alamos Canyon and Alamo Canyon, where Lewis et al. (2009) and Koning and Kelley (2016) mapped the Pleistocene to Holocene sedimentary deposits and Tshirege Member cooling units in detail to identify many previously unmapped strands of the fault zone. The third area in Santa Clara Canyon is summarized in an unpublished report submitted to the Army Corp of Engineers (Kelley et al., 2017).

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				
	Holocene			0–11,700
	Quaternary			
		Pleistocene	Late	11,700–129,000
			Middle	129,00–7774,000
			Early	774,000–2.58 million
	Neogene	Pliocene		2.58–5.333 million
		Miocene		5.333–23.03 million
	Paleogene	Oligocene		23.03–33.9 million
		Eocene		33.9–56.0 million
		Paleocene		56.0–66.0 million
MESOZOIC				
	Cretaceous			66.0–145.0 million
	Jurassic			145.0–201.3 million
	Triassic			201.3–251.902 million
PALEOZOIC				
	Permian			251.902–298.9 million
	Pennsylvanian			298.9–323.2 million
	Mississippian			323.2–358.9 million
PROTEROZOIC				
	Mesoproterozoic			1,000–1,600 million
	Paleoproterozoic			1,600–2,500 million

International Chronostratigraphic Chart (www.stratigraphy.org, 2022)

DESCRIPTION OF MAP UNITS

CENOZOIC

Quaternary

Surficial Deposits

Surficial deposits range from light-gray (10YR 7/2) to light-reddish-brown (7.5YR 6/4). In this report, the term "alluvium" includes surficial materials transported by running water confined to channels (stream alluvium) as well as running water not confined to channels (sheet-wash). The term "colluvium" includes surficial material transported down slopes by mass-wasting (gravity-driven) processes—such as creep and debris flow—aided by running water not confined to channels (sheet-wash). Metric units are used in this report. A conversion table is provided for those more familiar with English units (Table 1). The divisions of geologic time used in this report are provided in Table 2.

af **Artificial fill (Holocene)**—Silt, sand, and gravel in landfills, road beds, and check dams. Includes disturbed areas around Los Alamos National Laboratory, the Los Alamos town site, and the earthen fill of Cochiti Dam along the Rio Grande and Santa Fe River.

Qam **Modern alluvium (Subject to annual deposition)** —Unconsolidated sediment on the floors of active arroyos, generally within channels. Specific color and composition of sediment is dependent on the source area of a given drainage. Gravel is poorly to moderately sorted and the pebbles to boulders are subrounded to subangular. Sand is very fine to very coarse, subangular to subrounded, and poorly to moderately sorted. Thickness is estimated to be less than 3 m.

Qay **Young alluvium (Historical)**—Yellowish brown to pale brown, unconsolidated, pebbly sand, sandy pebbles, sand, silt, and clay that generally underlies floodplains of active drainages. Soil development is weak to nonexistent. The tread of deposit is less than 2 m above the active channel. Estimated to be 1–2 m thick.

Qal **Alluvium (Holocene to Pleistocene)—**Unconsolidated sediment deposited in active alluvial channels, on floodplains, and in Holocene terraces generally within 10 m of current channel. Specific color and composition of sediment is dependent on the source area of a given drainage. The unit includes valley-fill deposits exposed in modern arroyo channels, and is typically intercalated with active tributary-mouth fans associated with side streams. The alluvium locally includes eolian and colluvial deposits. The maximum thickness is approximately 10–15 m.

Qes Eolian sand and silt reworked by slope wash (Holocene to Pleistocene)—Tan, brown to reddish-brown, well-sorted silt and sand in reworked eolian deposits covering upland surfaces and locally filling swales that include layers and lenses of alluvium or colluvium. In the southern and southeastern Jemez Mountains, this unit commonly contains reworked pumice from the El Cajete Pyroclastic Beds, or is intercalated with, or rests on deposits of, El Cajete pumice (**Qvec**) that are too small to be mapped separately. Unit includes eolian sand-dune deposits along the lower Rio Jemez and Arroyo Chamisa. Thickness ranges from ≈1–8 m.

Qsw Sheetwash deposits (Holocene to Middle? Pleistocene)—Tan to brown, pebbly, silty, very fine- to medium-grained sand. Some of the silt to fine-grained sand fraction in these deposits may be of eolian origin that was transported by strong southwesterly winds that deflated sediment from sparsely vegetated or actively aggrading alluvial deposits (Thompson et al., 2011). Some of the silt- and clay-size fraction in **Qsw** may have been derived from more distant sources (Shroba and Thompson, 1998). Sediments in **Qsw** were primarily deposited by surface flow. Unit **Qsw** locally contains rare fragments of reworked pumice from the 1.62 Ma Guaje(?) Pumice Bed of the Otowi Member of the Bandelier Tuff, and possibly El Cajete pumice (**Qvec**). The well-developed soils in the deposits may have formed at about 120–160 ka (Shroba and Birkeland, 1983; Nelson and Shroba, 1998; Birkeland et al., 2003). Exposed thickness is 1.5–4.5 m, however, the unit may be up to 10 m thick.

Qc Colluvium (Holocene to Pleistocene)—Hillslope regolith composed of locally derived, poorly sorted silty, sandy gravel that may be clast- or matrix-supported. Specific color and composition of the sediment is dependent on the source material. Colluvium includes rock-fall talus deposits on slopes below resistant rock units, especially cliffs of Bandelier Tuff and lava flows in the Jemez Mountains volcanic field. Locally includes minor amounts of alluvial and eolian sediment, El Cajete pumice, and small-volume alluvial fans. This unit is generally mapped only in places where important bedrock contacts are obscured. These deposits are typically less than 10 m thick, although colluvial wedges up to 50 m thick are locally preserved in Cañon de San Diego in the southwestern Jemez Mountains.

Qta Talus (Holocene to Late Pleistocene)—Open-framework, mostly angular, pebble–cobble–boulder and cobble–boulder deposits typically found on steep canyon slopes below cliffs, particularly in Santa Clara Canyon in the northeastern Jemez Mountains. The unit is up to 10 m thick.

Qls Landslide deposits (Holocene to Early Pleistocene)—Locally-derived cohesive blocks of bedrock or unsorted and unstratified rock debris and sediment, characterized by hummocky topography. Specific color and composition of the sediment is dependent on the source material. Landslides commonly form on unstable slopes beneath lava flows and tuffs that cap the steep-sided mesas in the map area. Some of the landslide deposits are locally bounded upslope by arcuate headwall scarps and downslope by lobate toes. Landslides northeast and northwest of the village of Ponderosa in the southwestern Jemez Mountains rest on laminated El Cajete pumice deposits. Locally, **Qls** includes unmapped sheet-wash (**Qsw**), El Cajete pumice (**Qvec**), and colluvial deposits (**Qc**). The maximum thickness is possibly 300 m; most deposits are 5–50 m thick.

Qdf Debris-flow deposits (Holocene to Middle? Pleistocene)—Lobate and fan-shaped masses of locally-derived debris deposited by sediment-charged streams at the base of steep escarpments adjacent to the Cerros del Rio volcanic field and in steep-sided canyons in the Jemez Mountains. Specific color and composition of the sediment is dependent on the source material. Deposits are poorly sorted and poorly stratified boulders to granules supported in a sandy matrix. The maximum thickness is about 15 m.

Qtr Travertine (Holocene to Pleistocene)—Gray to white spring deposits of calcium carbonate ranging from porous tufa to well-developed crystals of aragonite. Deposits generally coincide with faults near the southern terminus of the Sierra Nacimiento, along the Rio Jemez north of Jemez Pueblo, and along Vallecito Creek near Ponderosa. At Soda Dam in Cañon de San Diego north of Jemez Springs, the travertine actively precipitates from springs that formed during the last 7 k.y. (Goff and Shevenell, 1987). Older travertine at higher elevations near Soda Dam yields U-Th disequilibrium ages between 1.0 and 0.48 Ma (Goff and Shevenell, 1987). More recent work by Tafoya (2012) indicates that the oldest travertine ranges from >500 ka to 287 ka. Travertine accumulated at Soda Dam episodically at >500 ka, 200–92 ka, and < 10 ka (Tafoya, 2012). Unit is <15 m thick.

Qfa Alluvial-fan deposits (Holocene to Pleistocene)—Tan to brown unconsolidated locally-derived gravels with abundant angular to subrounded boulders as large as 2 m, sand, and silt deposited by alluvial fans. This unit also includes floodplain and debris-flow deposits. Specific color and composition of the sediment is dependent on the source material. These deposits are located within the Valles Caldera, at the base of the La Bajada fault escarpment, and in canyons within the Jemez Mountains. Deposits in the Jemez Mountains, particularly in the eastern and southern quadrants, may contain El Cajete pumice. The alluvial-fan deposits are locally overlain by, and are interbedded with, fine-grained eolian sediment. The presence of El Cajete pumice indicates that these fans are <74 ka. Deposits range in thickness from 2 to 30 m.

Qpa **Piedmont alluvium (upper to Middle Pleistocene)** — Cobble to boulder gravel, sand, and local eolian deposits on the Puye quadrangle (Dethier, 2003). Clasts are predominantly dacite derived from the Tschicoma Formation. The deposits form boulder-capped terrace remnants and elongate ridges 20–40 m above local arroyos, mainly on upland surfaces. Several elongate ridges of this unit appear to be topographically inverted channels that were active during Cerro Toledo time. Deposits generally 0.5 to 20 m thick.

Qt **Undivided terrace deposits (Late to Middle Pleistocene)**—Terrace deposits composed of gravel and sand at a variety of elevations along both upland drainages that are located several tens of kilometers from major drainages in this area and along major drainages. Alluvial cobble- to boulder-sized gravel, sand, and minor silt underlie terrace treads along the Rio Grande, Rio Jemez, and tributary drainages. Four Pleistocene terrace levels are recognized in most of the larger drainage basins and are likely to be at least roughly contemporaneous from basin to basin, although data are insufficient to demonstrate these correlations unambiguously. A lower, fifth terrace is recognized in some locations. Presumed and established Holocene terraces are included in map unit **Qal**. Nearly all terrace surfaces are mantled with eolian sand and silt deposits ranging in thickness from 10 cm to more than 1 m; these deposits are not mapped separately.

Qt_5 **Terrace deposit (Late Pleistocene)—**Cobble gravel and sand underlying a terrace tread that is typically 5–10 m above modern stream grade, with a basal-strath elevation that is typically close to modern grade to several meters above grade. Includes the Ash terrace of Aby (1997), which contains primary fallout tephra of the El Cajete Pyroclastic Beds, suggesting an age <74 ka (see description for unit **Qvec**). The deposit is generally 1–3 m thick.

Qt_4 **Terrace deposit (Late Pleistocene)—**Cobble gravel and sand underlying a terrace tread that is typically 15–20 m above modern stream grade along the Rio Grande, and with a highly variable basal-strath elevation that is typically less than 10 m above present grade. This terrace gravel is relatively continuous along major drainages connected to the Rio Grande. Dethier and McCoy (1993) estimate an age of 95 ± 15 ka for fill terraces at a similar elevation above grade in the Española Basin. This deposit is 8–10 m thick.

Qt_3 Terrace deposit (Middle Pleistocene)—Cobble gravel and sand underlying a terrace tread that is typically 30–60 m above modern stream grade, with a highly variable basal-strath elevation relative to present channels. The deposit is also common in various smaller drainage basins where the upper tread projects to the treads along the Rio Grande and Rio Jemez. This alluvial deposit is at least 30 m thick and is utilized as a sand and gravel resource.

Qt_2 Terrace deposit (Middle Pleistocene)—Cobble gravel and sand underlying a terrace tread and overlying a basal strath that is typically 50–85 m above modern stream grade at variable but apparently correlative elevations in various smaller drainage basins. A lower alluvial deposit contains reworked tephra dated by $^{40}Ar/^{39}Ar$ at 0.55 ± 0.01 Ma, which is probably correlative to South Mountain rhyolite (Smith et al., 2001; Spell, 1993). The alluvial deposit ranges from 1 to 30 m thick along the Rio Grande, and 10 to 15 m thick along the Rio Jemez.

Qt_1 Terrace deposit (Middle Pleistocene)—Cobble gravel and sand underlying the highest recognizable terrace tread. Basal strath is typically 80–110 m above modern stream grade and is at variable, but apparently correlative, elevations in smaller drainage basins. The age and correlation of the preserved remnants is constrained by the presence of the 640 ka Lava Creek B ash (Dethier, 2001) within the terrace deposits along the Rio Grande (Smith and Kuhle, 1998a, b), the Rio Jemez (Rogers, 1996; Formento-Trigilio, 1997), and in tributary drainages to the Rio Grande on Santo Domingo Pueblo (Smith and Kuhle, 1998a, b). The deposits are commonly 3–5 m thick overlying a planar strath, but this deposit is locally as much as 30 m thick.

Qalm Alluvium of La Majada Mesa (Middle Pleistocene)—Poorly-sorted sand and silt with minor, lenticular gravel forming alluvial and eolian deposits underlying an extensive geomorphic surface extending from Galisteo Creek to near the base of La Bajada Mesa. The geomorphic surface appears to be graded toward the Rio Grande at an elevation approximately equivalent to the **Qt_1** terrace. Excavations east of Cochiti Dam reveal that the unit has a maximum thickness of about 12 m.

Qoal Older alluvial deposits (Middle Pleistocene to 74 ka)—Orangish to reddish-brown, interbedded sandy gravel and pebbly sand, grading to distal clay, silt, and very fine sand that sits on the Tshirege Member of the Bandelier Tuff in the eastern Jemez Mountains. The unit lacks clasts of El Cajete pumice and thus is inferred to predate 74.4 ± 1.3 ka (Zimmerer et al., 2016). The unit in the vicinity of Los Alamos includes pumice derived from the eruption of the Cerro del Medio domes (Kelley et al., 2007) and contains clasts of Tschicoma Formation dacite and rhyodacite, flow-banded rhyolite, black, glassy fragments of Bandelier Tuff, and obsidian. Coarse-grained facies lie within 200 m of the Pajarito fault escarpment and consist largely of sand- to clast-supported, poorly bedded debris flows in medium to thick beds. Distal deposits are fluvial. Thickness of the unit is 4–6 m. These deposits within the Valles caldera consist of coarse to fine gravel and sand, silt, and clay derived mostly from the volcanic domes, the resurgent dome and the northern caldera wall. The thickness of these deposits are not known (Goff et al., 2011).

Tewa Group

The Tewa Group includes several Pleistocene volcanic and sedimentary formations (Bandelier Tuff, Cerro Toledo Formation, and Valles Rhyolite; Gardner et al., 2010) exposed in and around the Valles and Toledo calderas in the Jemez Mountains. The ages range from 1.85 Ma to 74 ka.

Sedimentary Units

Ql Lacustrine deposits in the Valles Caldera, undivided (Late Pleistocene)—Includes deposits in the Valle Grande of coarse sand and reworked pumice from the El Cajete Pycroclastic Beds that formed when the pumice deposits dammed the East Fork Jemez River (Reneau et al., 2007). The age of the Valle Grande lake deposit is approximately 74 ka and the maximum exposed thickness is about 4 m. This undivided unit also includes South Mountain lake deposits, which are laminated to bedded, diatomaceous silty clay and mudstone with minor siltstone and sandstone found in Valle Grande (Conover et al., 1963; Griggs, 1964; Reneau et al., 2007; Fawcett et al., 2007). The lake formed when South Mountain rhyolite flows dammed drainage of the East Fork Jemez River at approximately 552–360 ka (Goff et al., 2011). The maximum drilled thickness in Valle Grande is about 95 m. The lacustrine deposits in the northern caldera are also lumped into this undivided unit. The northern deposits are finely laminated clay, silt, and very fine sand, with subordinate fine to coarse sand and gravel deposited in lakes that occupied Valle San Antonio, Valle Toledo, and Valle Santa Rosa. The deposits formed by blockage of drainages by post-resurgence eruptions from ring-fracture vents (Rogers et al., 1996; Reneau et al., 2007) approximately 400 to >800 ka. The maximum exposed thickness about 20 m.

Qms Sedimentary deposits of southern caldera moat (Late Pleistocene) —Deposits of alluvium, colluvium, debris flows, and minor lacustrine beds interbedded with lavas and pyroclastic rocks in the southern moat of Valles Caldera (Goff et al., 2005). These deposits were formed during at least three episodes of incision and blockage of the ancestral East Fork of the Jemez River and tributaries. The oldest deposit underlies the South Mountain and Cerro La Jara rhyolite (**Qvsm**) and is composed primarily of gravels containing Bandelier Tuff, aphyric rhyolite, pre-caldera volcanics and rare Permian fragments. An intermediate-age deposit overlies **Qvsm** but underlies **Qvec** and **Qvbr**; this gravel contains fragments of Bandelier Tuff and pre-caldera volcanics near the southeast edge of South Mountain and fragments of **Qvsm** further to west. The youngest deposit, which underlies **Qvb** but overlies **Qvec** and **Qvbr**, contains fragments of Bandelier Tuff, pre-caldera volcanics, Permian redbeds, Pennsylvanian limestone and Precambrian crystalline rocks in western exposures. This deposit also contains large blocks of glassy rhyolite in the area south of El Cajete vent. The thickness beneath Valle Grande is unknown.

Qcf Early caldera-fill debris flow, landslide, alluvium, and colluvium deposits (Late Pleistocene)—Dark-gray to tan, matrix-supported conglomerate with clasts of early post-caldera rhyolites, Bandelier Tuff, pre-caldera volcanic rocks, Miocene to Permian sandstone, Pennsylvanian limestone, and Proterozoic crystalline rocks that includes minor fluvial sand and gravel deposits. The finer-grained matrix is generally not exposed. The lower part of the unit displays extensive, low-grade hydrothermal alteration (Chipera et al., 2007). The fill is interbedded with, and overlies, all other units on the resurgent dome. The age is constrained to 1.23 to 1.19 Ma. The maximum exposed thickness is 70 m; the maximum drilled thickness in the well, Baca-7, on the northeast side of the resurgent dome is over 400 m (Lambert and Epstein, 1980).

Qst Sinter deposits (Late Pleistocene)—Massive to banded silica-rich hot springs deposits from early hydrothermal activity on the resurgent dome. These deposits can have iron oxide, fossil reeds and other organic remains. The maximum exposed thickness is about 3 m.

Valles Rhyolite

As defined by Gardner et al. (2010), the Valles Rhyolite comprises the East Fork Member that includes the youngest volcanic units in the Jemez Mountains, the six member-rank, post-caldera ring fracture domes, and two member-rank early rhyolites that erupted as the resurgent dome formed.

East Fork Member

The East Fork Member includes the Banco Bonito Flow, Battleship Rock Ignimbrite, and El Cajete Pyroclastic beds.

Qvb Banco Bonito Flow (Late Pleistocene)—Gray to black porphyritic rhyolite lava flows containing phenocrysts of quartz, biotite, hornblende, clinopyroxene, plagioclase, and rare sanidine in a glassy to devitrified groundmass that erupted from a lava-filled vent just north of the El Cajete crater in the southwestern Valles Caldera. The lava consists of at least two, thick flows (Manley and Fink, 1987; Gardner et al., 1986) and fills three, west-trending paleocanyons cut into the underlying Battleship Rock Ignimbrite in upper Cañon de San Diego. Zimmerer et al. (2016) determined a $^{40}Ar/^{39}Ar$ age of 68.3 ± 1.5 ka; the date was later refined to 68.9 ± 1.0 ka by Nasholds and Zimmerer (2022) for this unit. The maximum exposed thickness is approximately 140 m.

Qvbr Battleship Rock Ignimbrite (Late Pleistocene)—Tan to gray, rhyolitic ignimbrite filling upper Cañon de San Diego beneath the Banco Bonito Flow. This tuff contains crystals of plagioclase, biotite, hornblende, and sparse quartz, pyroxene, and sanidine. The ignimbrite consists of two flow units. Each flow unit has a nonwelded base, a welded center, and a moderately welded top (Ross and Smith, 1961). The lower unit is called the VC-1 tuff (Self et al., 1988). Zimmerer et al. (2016) determined a $^{40}Ar/^{39}Ar$ age of 74.1 ± 1.3 ka for this unit; this date was later refined to 74.2 ± 1.1 ka by Nasholds and Zimmerer (2022). The maximum thickness is about 120 m at Battleship Rock (Bailey et al., 1969).

Qvec El Cajete Pyroclastic Beds (Late Pleistocene)—White, moderately- to well-sorted, pyroclastic-fall lapilli and ash deposits, with a minor volume of pyroclastic-flow and surge deposits that are restricted to exposures in the southern and southeastern Jemez Mountains and in the Cerros del Rio volcanic field (Wolff et al., 1996; WoldeGabriel et al., 2016). Pumice lapilli and bombs contain phenocrysts of quartz, biotite, plagioclase, and sanidine with rare microphenocrysts of hornblende, clinopyroxene, and fayalite. Primary deposits within the caldera and reworked deposits in the southern Jemez Mountains have been extensively excavated for aggregate and industrial-grade pumice. This unit represents a nonwelded, temporally equivalent deposit of the Battleship Rock Ignimbrite. The maximum thickness is 70 m near the vent.

Qvsm South Mountain Member (Late Pleistocene)—This rhyolite dome complex in the southern Valles Caldera includes flow-banded to massive to slightly vesicular porphyritic lavas with abundant phenocrysts of sanidine, plagioclase, quartz, biotite, hornblende, and clinopyroxene in a pale-gray, perlitic to white, devitrified groundmass. The complex appears to consist of four flow units based on morphology (Goff et al., 2011). The small Cerro la Jara dome of flow-banded to massive to slightly vesicular porphyritic lava that closely resembles South Mountain rhyolite in mineralogy is included in this unit (Goff et al., 2011). Nasholds and Zimmerer (2022) determined $^{40}Ar/^{39}Ar$ ages of **Qvsm1**, **Qvsm2**, **Qvsm3**, and **Qvsm4**, are 531.2 ± 1.2 ka, 535.1 ± 0.9 ka, 533.7 ± 0.8 ka, and 529.7 ± 1.3 ka, respectively. Maximum exposed thickness is at least 450 m. Nasholds and Zimmerer (2022) determined a $^{40}Ar/^{39}Ar$ age of Cerro la Jara is 533.0 ± 1.4 ka. The maximum exposed thickness is about 75 m.

Qvsa San Antonio Mountain Member (Late Pleistocene)—This rhyolite dome complex in the northwestern Valles Caldera is composed of gray to white flow-banded to massive to slightly vesicular lavas with phenocrysts of sanidine, plagioclase, quartz, biotite, hornblende, and clinopyroxene. Based on morphology, this area consists of two main flow units: **Qvsa1** yields $^{40}Ar/^{39}Ar$ ages of 562.9 ± 1.0 ka and 562.4 ± 1.0 ka; **Qvsa2** yields a $^{40}Ar/^{39}Ar$ age of 557.8 ± 1.2 ka. A third flow (**Qvsa3**) and peripheral vent at Sulfur Point (Goff et al., 2011) has a $^{40}Ar/^{39}Ar$ age of 562.5 ± 0.9 ka, suggesting that this flow is co-genetic with the oldest flow (Nasholds and Zimmerer, 2022). The maximum exposed thickness is at least 510 m.

Qvse (Qvset) Cerro Seco Member (Late Pleistocene)—This rhyolitic dome and tuff complex in the northwestern Valles Caldera consists of gray to pale-pink flow-banded to massive to slightly vesicular lavas with phenocrysts of quartz, sanidine, biotite and rare hornblende. Based on morphology, this complex consists of two flow units; pumice lapilli in the pyroclastic deposits (**Qvset**) have the same mineralogy as the flows (Goff et al., 2011). The early lava, **Qvse1**, yields a $^{40}Ar/^{39}Ar$ age of 800.3 ± 2.7 ka. The late lava, **Qvse2**, yields a $^{40}Ar/^{39}Ar$ age of 801.7 ± 2.7 ka (Nasholds and Zimmerer, 2022). Dates for pumice in the ignimbrite and hydromagmatic deposits are 0.77 ± 0.03 Ma and 0.78 ± 0.04 Ma, respectively (Kelley et al., 2013a). The maximum exposed flow thickness is 375 m.

Qvsl Cerro San Luis Member (Late Pleistocene)—This rhyolite dome in the northern Valles Caldera is made up of gray to pale-pink flow-banded to massive to slightly vesicular porphyritic lavas that are occasionally spherulitic. The lavas contain phenocrysts of sanidine, quartz and biotite. The dome consists of two flows, **Qvsl1** and **Qvsl2**, based on morphology (Goff et al., 2011). The two flows yield $^{40}Ar/^{39}Ar$ ages of 803.4 ± 1.7 ka and 803.7 ± 2.0 ka, respectively (Nasholds and Zimmerer, 2022). The maximum exposed thickness is 325 m.

Qvsr Cerro Santa Rosa Member (Late Pleistocene)—This rhyolite dome and tuff complex in the northern Valles Caldera is composed of two temporally distinct, juxtaposed domes that have the same name. The south dome, **Qvsr1**, consists of white to gray porphyritic lava with abundant quartz, subordinate sanidine, and sparse, small biotite (Goff et al., 2011). The north dome, **Qvsr2**, consists of white, massive to flow-banded porphyritic lava with quartz, subordinate sanidine, and trace biotite. Maximum thickness is about 150 m (Goff et al., 2011). Pale-gray to pale-pink pyroclastic flow and fall deposits have pumice lapilli with phenocrysts of quartz, sanidine and biotite in a highly vesicular groundmass. Fall deposits contain abundant lithic fragments (Goff et al., 2011). The pyroclastic flow pumice $^{40}Ar/^{39}Ar$ dates are 0.91 ± 0.03 Ma (Kelley et al., 2013a) and 932.5 ± 1.1 ka (Nasholds and Zimmerer, 2022). The south dome was dated by $^{40}Ar/^{39}Ar$ at 923 ± 8 ka (Spell and Harrison, 1993), 942 ± 8 ka (Singer and Brown, 2002), and 928.2 ± 1.3 ka (Nasholds and Zimmerer, 2022). The north dome was dated by $^{40}Ar/^{39}Ar$ at 795 ± 30 ka (Spell and Harrison, 1993) and 802.7 ± 1.8 ka (Nasholds and Zimmerer, 2022). The maximum flow thickness is over 240 m.

Qvda Cerro del Abrigo Member (Late Pleistocene)—Complex of four dome and flow sequences in the northeastern Valles Caldera with white to gray, devitrified to perlitic rhyolite lava with phenocrysts of sanidine, quartz and plagioclase, and trace biotite and hornblende (Goff et al., 2011). The $^{40}Ar/^{39}Ar$ ages of **Qvda1**, **Qvda2**, **Qvda3**, and **Qvda4** are 1010.1 ± 1.7 ka, 998.2 ± 1.8 ka, 997.7 ± 1.2 ka, and 1001.8 ± 1.0 ka, respectively (Nasholds and Zimmerer, 2022). The maximum exposed flow thickness is about 405 m.

Qvdm Cerro del Medio Member (Late Pleistocene)—Dome and flow complex on the east side of the Valles Caldera consists of at least seven eruptive phases (Gardner et al., 2007). This complex included six flows and pyroclastic flow and pumice fall deposits with pumice that is sparsely phyric, with small sanidine and opaque oxides. White to gray lava flows are typically massive, devitrified, pumiceous rhyolite with sparse, small phenocrysts of sanidine and opaque oxides (Goff et al., 2011). One aphyric brown- to black-obsidian flow is massive to flow-banded, and is devitrified around unit margins. The $^{40}Ar/^{39}Ar$ age of the northern lava (**Qvdmn**) is 1158.0 ± 3.1 ka. The $^{40}Ar/^{39}Ar$ age of the southern lava (**Qvdms**) is 1148.5 ± 1.7 ka. The $^{40}Ar/^{39}Ar$ age of the western lava (**Qvdmw**) is 1139.6 ± 6.5 ka. The $^{40}Ar/^{39}Ar$ ages of Cerro del Medio 4 (**Qvdm4**) and Cerro del Medio 5 (**Qvdm5**) are 1133.6 ± 10.1 ka and 1133.5 ± 4.6 ka, respectively (Nasholds and Zimmerer, 2022). The maximum flow thickness is about 260 m.

Qrc Redondo Creek Member (Late Pleistocene)—Gray to black to pale-pink, massive to flow-banded, porphyritic rhyodacite lavas that contain 10–15% phenocrysts of plagioclase, sanidine, biotite, and pyroxene, with an absence of quartz. The groundmass is perlitic to devitrified and commonly has spherulites. The lavas are characterized by coherent and autobrecciated facies textures ranging from a glassy to a crystalline matrix with few spherulites. Multiple vents are located on the Redondo Peak resurgent dome, and a vent is located in the Sulphur Springs area. The unit consists of at least two flow units separated by a relatively thick sequence of conglomerate north of La Cueva. The $^{40}Ar/^{39}Ar$ ages on four samples range from 1199.9 ± 5.6 ka to 1186.8 ± 2.9 ka (Nasholds and Zimmerer, 2022). Thickness is up to 200 m.

Qdc (Qdct) Deer Canyon Member (Late Pleistocene)—Gray to pale-pink rhyolitic lava flows (**Qdc**) and tuffs (**Qdct**) characterized by phenocrysts of sanidine and quartz. Porphyritic lavas occur on the southwestern resurgent dome, whereas aphyric lavas occur on the central and eastern resurgent dome. Lithic and crystal-rich, thin-bedded rhyolitic tuffs are interbedded with the lavas. The pumice fragments in the tuff usually contain phenocrysts of quartz and sanidine, and lithic fragments generally consist of Bandelier Tuff and pre-caldera volcanics. The $^{40}Ar/^{39}Ar$ age of one tuff is 1231.6 ± 4.1 ka and the $^{40}Ar/^{39}Ar$ ages of four lava flows range from 1231.2 ± 2.2 ka to 1212.0 ± 5.6 ka (Nasholds and Zimmerer, 2022). The maximum exposed thickness is about 40 m.

Bandelier Tuff

As described by Gardner et al. (2010), a pyroclastic and sedimentary unit named the Cerro Toledo Formation was deposited between the eruption of the Toldeo Caldera (Otowi Member of the Bandelier Tuff) and the Valles Caldera eruption (Tshirege Member of the Bandelier Tuff). The Cerro Toledo Formation consists of the dozen rhyolite domes of the Valle Toldeo Member that were active between the caldera eruptions; this formation also includes sedimentary and pyroclastic material derived from these domes. The small volume La Cueva Member of the Bandelier Tuff is preserved in the southwestern Jemez Mountains.

Qbt Tshirege Member, Bandelier Tuff (Late Pleistocene)—Multiple cooling units of white, gray, orange, and pink, densely welded to non-welded, rhyolitic ignimbrite erupted during the collapse of the Valles Caldera (Smith and Bailey, 1966, 1968). The pumice and matrix contain abundant phenocrysts of sanidine and quartz, sparse microphenocrysts of clinopyroxene and orthopyroxene, and extremely rare microphenocrysts of fayalite (Warshaw and Smith, 1988; Warren et al., 2007). In the more welded portions, the sanidine is typically chatoyant (blue iridescence). The tuff contains accidental lithic fragments of older country rock, and has a thin (<2 m) laminated, pumice fall and surge deposit at base of unit (Tsankawi Pumice Bed) that contains roughly 1% of hornblende-bearing dacite pumice (Bailey et al., 1969). The most recent $^{40}Ar/^{39}Ar$ age determination is 1.2319 ± 0.0013 Ma (Nasholds and Zimmerer, 2022). Wu et al. (2021) determined a U-Pb zircon date of 1.271 ± 0.015 Ma. The maximum observed thickness within the caldera is greater than 900 m.

Qx Caldera collapse and vent breccia, undivided (Late Pleistocene)—This combined unit includes younger, widely scattered, lenticular to nearly circular outcrops (<300 m in diameter) of mosaic or vent breccia, and older, large caldera-wall landslide breccia (megabreccia) blocks composed of pre-Valles-Caldera bedrock that accumulated synchronously during caldera formation (Lipman, 1976). Megabreccia blocks are composed of the Otowi Member of the Bandelier Tuff, Tschicoma Formation, Paliza Canyon Formation, Santa Fe Group, Ritito Conglomerate, Abo Formation, Yeso Formation, and Madera Formation. The megabreccias contain rocks that are dated at 8.21–1.68 Ma (based on three rock types; Phillips, 2004). The maximum exposed thickness is highly variable.

Qct Cerro Toledo Formation (Middle Pleistocene)—Unit **Qct** is divided in four members: three (Pueblo Canyon, Virgin Mesa, and Alamo Canyon members) are comprised of sedimentary and pyroclastic rocks derived from the fourth member, the Valle Toledo Member rhyolite domes located in the northeastern and eastern Jemez Mountains. For the purposes of this map compilation **Qct** is a lumped unit that includes the Pueblo Canyon, Virgin Mesa, and Alamo Canyon members. The individual Valle Toledo Member domes are described in detail below. The Pueblo Canyon Member (Gardner et al., 2010) is composed of reddish-tan fluvial sandstone and gravel intercalated with primary phreatomagmatic pyroclastic deposits erupted from Valle Toledo Member domes in the Toledo embayment. These deposits are between the Otowi and Tshirege members of the Bandelier Tuff on the northern to eastern flanks of the Jemez Mountains. The clasts in the gravel are predominantly porphyritic dacite to rhyodacite lavas derived from the Tschicoma Formation, and reworked tuff from the Otowi Member of the Bandelier Tuff. The pyroclastic flow and fallout deposits contain crystal-poor pumice lapilli with <1% phenocrysts of potassium feldspar and pyroxene; fayalite is also present in some pyroclastic deposits. The $^{40}Ar/^{39}Ar$ ages for the Valle Toledo Member tephras range from 1.56 to 1.23 Ma (Stix, 1989); maximum thickness about 40 m. The Virgin Mesa Member (Gardner et al., 2010) is located in the western Jemez Mountains in cliff exposures along Virgin Canyon, Cañon de San Diego and on the west side of Mesa de Guadalupe between the Otowi and Tshirege members of the Bandelier Tuff.

The fluvial gravels contain Proterozoic granite and quartzite, Permian (Abo, Yeso, Glorieta) sandstone, Paliza Canyon Formation andesite, dacite, and basalt, flow-banded rhyolite, Pedernal chert, and lithic-rich tuff (Otowi). Much of this material was derived from erosion of the Sierra Nacimiento to the west (Osburn et al., 2002). The Alamo Canyon Member (Gardner et al., 2010) on the southeastern flank of the Jemez Mountains includes sandy fluvial conglomerate interbedded with primary tephras, block-and-ash, and debris-flow deposits derived from the collapse of the Valle Toledo Member Rabbit Mountain and Del Norte Pass domes. Fluvial deposits include clasts of Paliza Canyon Formation andesite and dacite, Canovas Canyon Rhyolite, Bearhead Rhyolite, and aphyric Rabbit Mountain obsidian. The $^{40}Ar/^{39}Ar$ dates of sanidine in tephra yield ages of 1.57 ± 0.04 Ma to 1.48 ± 0.03 Ma (Jacobs et al., 2016). Prior dating by Spell et al. (1996a, 1996b) indicate pulses of activity at 1.56 Ma, 1.49 Ma, and 1.38 Ma. Thickness is 40–60 m.

Valle Toledo Member

Rhyolite and tuff from domes active between the eruptions of the Toledo and Valles calderas.

Qcrt Rhyolite tuffs (Middle Pleistocene)—Two areas of white to gray, partially to densely welded, nearly aphyric tuff in the Toledo embayment. The microphenocrysts consist of sparse quartz, sanidine, biotite, and rare clinopyroxene. A K-Ar age determined for the western exposure (Pinnacle Peak) is 1.20 ± 0.02 Ma (Stix et al., 1988). The maximum exposed thickness is roughly 200 m.

Qcws Warms Springs rhyolite (Middle Pleistocene)—Small dome of massive to flow banded, gray to pale-pink porphyritic lava containing phenocrysts of quartz, sanidine, and biotite located on the north side of the Valles Caldera. $^{40}Ar/^{39}Ar$ age is 1.279 ± 0.022 Ma (Spell et al., 1996b). The maximum exposed thickness is 25 m.

Qcrr Aphyric rhyolite (Middle Pleistocene)—Two dome and flow complexes, and two small intrusive bodies of white to gray to black flow-banded lava in the Toledo embayment. Obsidian phases are completely aphyric. The devitrified phases contain spherulites and very sparse microphenocrysts of quartz, sanidine, and biotite. A K-Ar age determined for a dome northwest of Cerro Rubio **(Ntcr)** is 1.33 ± 0.02 Ma (Stix et al., 1988). The maximum exposed thickness is 365 m.

Qcs Sierra de Toledo rhyolite (Middle Pleistocene)—White to gray flow-banded, sparsely porphyritic lava with phenocrysts of quartz, sanidine, biotite, and tiny magnetite in the Toledo embayment. The sanidine is commonly chatoyant blue. The $^{40}Ar/^{39}Ar$ ages of two samples range from 1.394 ± 0.024 Ma to 1.350 ± 0.036 Ma (Spell et al., 1996b). The maximum exposed thickness is 365 m.

Qctr Turkey Ridge rhyolite (Middle Pleistocene)—White to gray flow-banded, porphyritic lava with phenocrysts of quartz, sanidine, biotite, and magnetite in the Toledo embayment. The sanidine is usually large and chatoyant, and this lava is generally devitrified, platy, and spherulitic. The $^{40}Ar/^{39}Ar$ age is 1.357 ± 0.030 Ma (Spell et al., 1996b). The maximum exposed thickness is 490 m.

Qctq Cerro Trasquilar rhyolite (Middle Pleistocene)—Flow-banded to massive, sparsely porphyritic lava with tiny phenocrysts of quartz, sanidine, clinopyroxene, opaque oxides, and rare biotite located on the north side of the caldera. The $^{40}Ar/^{39}Ar$ age is 1.374 ± 0.024 Ma (Spell et al., 1996b). The maximum exposed thickness 225 m.

Qcto Cerro Toledo rhyolite (Middle Pleistocene)—White to gray flow-banded, aphyric lava with microlites of quartz, sanidine, and biotite in the Toledo embayment. The obsidian phase is completely aphyric, and rarely contains spherulites and bread crust textures. This lava overlies Indian Point rhyolite, which apparently underlies Turkey Ridge rhyolite, and definitely underlies the Tshirege Member of the Bandelier Tuff. A K-Ar date on Cerro Toledo proper is 1.38 ± 0.05 Ma (Stix et al., 1988). The maximum exposed thickness is 520 m.

Qcrm Rabbit Mountain rhyolite (Middle Pleistocene)—Large dome with thick flows and flow breccias of aphyric to sparsely phyric obsidian to white, devitrified lava on the southeastern margin of the caldera. The actual vent area is probably northwest of the location shown on the map because the dome collapsed either before or during formation of Valles Caldera. A small exposure of associated bedded tuff occurs southwest of the dome. The $^{40}Ar/^{39}Ar$ age is 1.437 ± 0.007 Ma (Kelley et al., 2013a). The maximum exposed thickness is about 410 m.

Qcep East Los Posos rhyolite (Middle Pleistocene)—White to gray flow-banded to massive porphyritic lava with 5% phenocrysts of quartz, sanidine, biotite, hornblende, and opaque oxides. This rhyolite rarely contains a black glassy groundmass. The $^{40}Ar/^{39}Ar$ age is 1.462 ± 0.018 Ma (Spell et al., 1996b). The maximum exposed thickness is 165 m.

Qci Indian Point rhyolite (Middle Pleistocene)—White to gray flow-banded, sparsely porphyritic lava with phenocrysts of quartz and sanidine in the Toledo embayment. Biotite is extremely rare and most samples are devitrified and spherulitic. The $^{40}Ar/^{39}Ar$ age is 1.479 ± 0.022 Ma (Spell et al., 1996b). The maximum exposed thickness is 410 m.

Qcn Del Norte Pass rhyolite and debris flow (Middle Pleistocene)—Small dome and flow of devitrified rhyolite with sparse phenocrysts of quartz, sanidine, and biotite located south of the caldera. A layer of indurated, slightly altered, lithic-rich tuff **(Qcnpt)** underlies the dome on east and southeast. **Qcnd** is a white to pale gray debris flow that formed during two episodes of collapse of the Del Norte Pass dome. Large blocks of blocks of andesite and dacite are common. The $^{40}Ar/^{39}Ar$ age is 1.49 ± 0.08 Ma (Justet and Spell, 2001). The maximum exposed thickness of the dome is about 110 m and the debris flow is approximately 60 m thick.

Qcwp West Los Posos rhyolite (Middle Pleistocene)—White to gray to black, flow-banded to massive porphyritic rhyolite with phenocrysts of quartz, sanidine, plagioclase, biotite, and opaque oxides located on the northwestern side of the caldera. This flow commonly contains relict black glass. The $^{40}Ar/^{39}Ar$ age is 1.557 ± 0.024 Ma (Spell et al., 1996b). Maximum exposed thickness is 370 m.

Qcnr North caldera rim intrusive (Middle Pleistocene)—White flow-banded, sparsely porphyritic intrusive body and minor lava with phenocrysts of quartz, sanidine, and biotite on the north edge of the Toledo embayment. The $^{40}Ar/^{39}Ar$ age is 1.62 ± 0.03 Ma (Kelley et al., 2013a). The maximum exposed thickness is 50 m.

Qbo Otowi Member, Bandelier Tuff (Middle Pleistocene)—White, light-gray, pale-pink, and orange, mostly nonwelded but locally welded (especially on the Jemez Plateau in the western Jemez Mountains), rhyolitic ash-flow tuff consisting of multiple flow units forming a single cooling unit (Smith and Bailey, 1966; Broxton and Reneau, 1995). This tuff originated from the Toledo caldera-forming eruption. The pumice and matrix contains abundant phenocrysts of sanidine and quartz, and sparse mafic microphenocrysts. The sanidine may display chatoyancy (blue iridescence). The Otowi Member contains abundant accidental lithic fragments, particularly on the east side of the Jemez Mountains. The basal Guaje Pumice Bed is up to 5 m thick east of Los Alamos, is <1 m thick in the northern Jemez Mountains, and is absent in the western and northwestern Jemez Mountains. The $^{40}Ar/^{39}Ar$ ages range from 1.651 ± 0.022 Ma to 1.625 ± 0.020 Ma (Izett and Obradovich, 1994; Spell et al., 1996b). Wu et al. (2021) determined a U-Pb zircon date of 1.61 ± 0.02 Ma. The maximum exposed thickness is about 120 m.

Qog Older gravels (Middle Pleistocene)—Unconsolidated terrace and piedmont deposits on high level surfaces in the Sierra Nacimiento. The specific color and composition of the sediment is dependent on the source material. This unit also includes fluvial sandstone and gravel deposited between the Tshirege, Otowi, and La Cueva members of the Bandelier Tuff. The gravel clasts deposited between tuff eruptions are composed predominantly of Paliza Canyon volcanics with occasional Proterozoic granite, Permian sandstone and conglomerate, and rare Pedernal chert. The maximum thickness is 7 m.

Qblc La Cueva Member, Bandelier Tuff (Middle Pleistocene)—Previously called the Cañon de San Diego ignimbrites (Self et al., 1986; Turbeville and Self, 1988), this white, nonwelded to poorly welded, ash-flow tuff contains phenocrysts of quartz and sanidine with trace pyroxene and magnetite. This deposit was renamed La Cueva Member by Gardner et al. (2010). This tuff consists of two units (Self et al., 1986): the lower unit (A) is nonwelded with abundant lithic fragments, and the upper unit (B) is nonwelded to slightly welded with large pumice clasts. The two units are separated by reworked pumice and debris flows. The $^{40}Ar/^{39}Ar$ ages are 1.87 ± 0.04 Ma and 1.87 ± 0.07 Ma for units A and B, respectively (Spell et al., 1990). The maximum observed thickness is 80 m.

Quaternary to Neogene

Sedimentary Units

QNpg Older piedmont gravels (Pleistocene to Pliocene)—Unconsolidated piedmont gravels covering high level surfaces in the Sierra Nacimiento, containing clasts of Proterozoic granite and locally derived Paleozoic and Mesozoic sedimentary rocks (Woodward, 1987). This unit also includes high-level inset deposits on the Pajarito Plateau. The maximum thickness is 10 m.

QNdf Older debris-avalanche and debris-flow deposits (Pleistocene to Miocene?)—Unsorted tan to gray heterolithic breccias resting on Permian sandstones and overlain by the La Cueva Member of the Bandelier Tuff exposed along the west wall of Cañon de San Diego between La Cueva and Soda Dam. Clasts consist primarily of Paliza Canyon Formation porphyritic andesite and basaltic andesite. The breccia overlies a debris-flow deposit that contains clasts of Abiquiu Formation sandstone, Paliza Canyon Formation lavas, and Tschicoma Formation (?) hornblende dacite. The top of the unit exhibits as much as 60 m of relief. The maximum thickness is 180 m.

Volcanic rocks of the Cerros del Rio volcanic field

The Cerros del Rio volcanic field forms a plateau on the southeastern flank of the Jemez Mountains that is composed primarily of basalt to andesite, although dacitic and basaltic andesitic lavas are also present. The Quaternary to Pliocene lavas range in age from 1.15±0.13 to 3.06±0.21

Ma, with some of the younger lavas overlapping in time with the eruption of the Bandelier Tuff. Thompson (2006) recognized that the volcanic field formed in three phases (>2.72–2.61 Ma forming the older, large volcanoes; 2.61–2.12 Ma with small-volume eruptions filling in topographic lows, and 1.51–1.11 Ma forming younger, small volume centers on the west side of the field). The generally monogenetic eruptive centers have both lava flow and pyroclastic components that were mapped separately. All Quaternary lavas have reverse polarity and all Pliocene (Neogene) lavas have normal polarity, based on aeromagnetic and/or paleomagnetic data (Thompson et al., 2011).

Qa Andesite (Early Pleistocene)—Andesite erupted from Little Cochiti cone, Cochiti cone and Ortiz Mountain. The *Little Cochiti cone* flows are reddish brown to medium gray andesite with sparse phenocrysts of olivine, pyroxene and plagioclase in decreasing order of abundance; xenocrysts of plagioclase and lesser quartz are common. The $^{40}Ar/^{39}Ar$ age is 1.15±0.13 Ma. Maximum exposed thickness is 70 m. *Cochiti Cone lava flows* are reddish brown to medium gray with sparse phenocrysts of olivine, pyroxene, and plagioclase. The $^{40}Ar/^{39}Ar$ age is 1.52±0.05 Ma. This unit is up to 350 m thick. *Ortiz Mountain flows* are medium-gray to black and are crystal-rich, containing phenocrysts of plagioclase and pyroxene, with minor olivine, hornblende, and opaque minerals. **Qac** are andesitic cinder deposits. The$^{40}Ar/^{39}Ar$ age is 2.33±0.06 Ma. The maximum exposed thicknes is 225 m (Thompson et al., 2011).

Qd Dacite (Early Pleistocene)—The youngest dacite in the volcanic field erupted from a center in Arroyo Montoso (Dethier, 1997). The older dacite of Hill 7065 erupted from a cone on the southeast side of Cerro Micho (Thompson et al., 2011). The *Arroyo Montoso flows* are dark gray to black, and are fine grained to glassy. Lava flows are thick (up to 20 m) and massive with brecciated flow bases and flow foliated tops. Sparse phenocrysts of olivine ± pyroxene ± plagioclase occur locally in a fine-grained groundmass. Partially resorbed xenocrysts of plagioclase ± quartz are sparse but ubiquitous. A $^{40}Ar/^{39}Ar$ age of 1.32±0.08 Ma was obtained from a lava flow above the Rio Grande. This flow locally overlies the Otowi Member of the Bandelier Tuff. **Qdc** are dacitic cinder deposits. The maximum exposed thickness is 170 m (Deither, 1997). The *Hill 7065 lava flows* are medium to dark gray and are sparsely phyric containing small (less than 1 mm) olivine and pyroxene phenocrysts in a fine-grained to glassy matrix. The age of the Hill 7065 flow is 2.57±0.04 Ma. The thickness varies from 30 to 100 m (Thompson et al., 2011).

Qb Basalt (Early Pleistocene)—Basalt erupted from numerous centers on the Cerros del Rio plateau, including Hill 7033, Tetilla Hole, Colorado Peak, Hill 6929 (two centers), and Cañada Ancha . The *basalt on Hill 7033* is comprised of thin (<3 m) medium-gray lava flows with 1–2 mm olivine phenocrysts in fine-grained matrix (Thompson et al., 2011). A $^{40}Ar/^{39}Ar$ age of 2.04±0.35 Ma was obtained from a lava flow in the southern part of the field (Sawyer et al., 2002). The flows are generally 2 to 25 m thick (Thompson et al., 2011). The *Tetilla Hole flows* are medium gray and massive, with vesicular tops and aa bases. Olivine phenocrysts and small pyroxene clots are common, and the groundmass is fine grained. A $^{40}Ar/^{39}Ar$ age of 2.50±0.05 Ma was obtained from the uppermost lava flow at Tetilla Hole. The maximum exposed thickness is 80 m (Thompson et al., 2011). *Colorado Peak flows* are medium to dark gray, massive, and contain phenocrysts of olivine 1-4 mm in diameter, clinopyroxene, and olivine+clinopyroxene clots up to several millimeters across in a fine-grained groundmass. Xenocrysts of resorbed quartz and plagioclase up to several millimeters in diameter are common. A $^{40}Ar/^{39}Ar$ age of 2.55±0.01 Ma was determined from a lava flow near the base of the section in Arroyo Colorado. The maximum exposed thickness is 120 meters (Thompson et al., 2011). *Hill 6929 basalt to basaltic andesite flows* are medium to dark gray with phenocrysts of olivine, ubiquitously altered to iddingsite, and lesser amounts of pyroxene. Quartz and plagioclase xenocrysts are present locally. This unit has not been dated. The maximum exposed thickness is 30 m (Thompson et al., 2011). The *Cañada Ancha basalt to basaltic andesite flows* are medium to dark gray and contain abundant, equant olivine phenocrysts, sparse clinopyroxene phenocrysts, and plentiful resorbed plagioclase xenocrysts. This unit has not been dated. **Qbc** are basaltic cinder deposits. The maximum exposed thickness is 8 m (Thompson et al., 2011). *Tholeiitic olivine basalt flows, pillow basalt, and palagonitic breccia* are exposed west of the Rio Grande north of Chaquehui Canyon beneath the community of White Rock. These basalts originated from vents buried by Bandelier Tuff to the west and northwest. A sample from the basalt exposed near the intersection of Pueblo and Los Alamos canyons gave a $^{40}Ar/^{39}Ar$ age of 2.34 ± 0.08 Ma; flows capping Ancho Canyon and underlying the community of White Rock yielded ages between 2.5 and 2.4 Ma (Dethier, 1997).

Qba Basaltic andesite (Early Pleistocene)—Basaltic andesite erupted from the Twin Hills/Cerro Rito complex, the Arroyo Eighteen volcanic center, and from an area north of Cochiti Lake. The *Twin Hills flows* are platy near the base, and contain olivine and clinopyroxene phenocrysts (2–3 mm) and sparse glomerocrysts of olivine + pyroxene. A $^{40}Ar/^{39}Ar$ age of

2.55±0.04 Ma was obtained from a northeast-trending dike on the western flank of Twin Hills. Maximum exposed thickness is 175 m (Thompson et al., 2011). The *Arroyo Eighteen lava* is comprised of medium-gray, massive flows that are 3–5m thick. The flows contain sparse olivine ± pyroxene phenocrysts and abundant xenocrysts of plagioclase and quartz. A $^{40}Ar/^{39}Ar$ age of 2.58±0.02 Ma was determined for this unit. The maximum exposed thickness is 65 m (Thompson et al., 2011). The massive *Cochiti Lake flows* are medium-gray with sparse olivine ± pyroxene phenocrysts and abundant xenocrysts of plagioclase and quartz. A $^{40}Ar/^{39}Ar$ isotopic age of 2.54±0.04 Ma was obtained from a lava flow on the west bank of the Rio Grande southeast of the community of Cochiti Lake. **Qbac** are basaltic andesite cinder deposits. The maximum thickness is 25 m (Dethier et al., 2011).

QNbm Basaltic hydromagmatic deposits and tephra (Early Pleistocene to Pliocene)—Tan to brown, bedded tuff consisting of partly to wholly palagonitized vitric (sideromelane) grains, accessory angular blocks of basalt and abundant accessory clasts and finely comminuted fragments of basin-fill sediment ranging from silt to rounded cobbles (including quartzite). Hydromagmatic deposits are interbedded with both Quaternary and Pliocene flows. Planar and sand-wave crossbedded tuff and lapilli tuff deposited by pyroclastic surges are as much as 50 m thick in tuff rings and maar-crater-fill deposits adjacent to and within vents.

Na Andesite (Pliocene)—Andesite was erupted in the vicinity of Cerro Colorado, Cerrita Potrillo, Sanchez Canyon, Cerro Micho, and Tetilla Peak. The *Cerro Colorado flows* are dark gray with phenocrysts of olivine and pyroxene and abundant xenocrysts of resorbed plagioclase and sparse quartz. A $^{40}Ar/^{39}Ar$ isotopic age of 2.62±0.10 Ma was obtained from a lava flow near the summit of Colorado Peak. The maximum exposed thickness is 225 m (Thompson et al., 2011). The *Cerrita Potrillo flows* medium-gray and massive with phenocrysts of of hornblende, plagioclase, clinopyroxene, Fe-Ti oxides, and minor olivine. Resorbed plagioclase xenocrysts are commonly associated with glomerocrysts of altered pyroxene. A $^{40}Ar/^{39}Ar$ age of 2.62±0.10 Ma was obtained from a lava flow on the south flank of an eroded distal flow lobe. The maximum exposed thickness is 175 m (Thompson et al., 2011). The *flows of Sanchez Canyon* are medium gray to reddish brown and are exposed along the Rio Grande. The porphyritic lavas contain phenocrysts of olivine + pyroxene ± plagioclase in a fine-grained matrix. Locally, partially resorbed xenocrysts of plagioclase and quartz are present. No age data is available. The maximum thickness is 100 m (Dethier et al., 2011). Flows of *Cerro Micho andesite* are medium-gray to reddish brown with olivine and clinopyroxene phenocrysts, sparse to abundant plagioclase phenocrysts ± resorbed plagioclase xenocrysts in a fine-grained groundmass. A $^{40}Ar/^{39}Ar$ age of 2.78±0.03 Ma was obtained from a lava flow in a tributary to Arroyo Montoso. The maximum exposed thickness is 300 m; the thickness is variable (Thompson et al., 2011). *Tetilla Peak andesite* consists of massive light-gray lava flows. The flows contain plagioclase and clinopyroxene phenocrysts, sparse xenocrystic quartz, and hornblende that locally is a prominent phenocryst in upper part of lava flows at Tetilla Peak (Zimmerman and Kudo, 1979). $^{40}Ar/^{39}Ar$ isotopic age of 3.06±0.21 Ma. **Nac** are andesitic cinder deposits. Individual flows range from 50 to 70 m in thickness; aggregate thickness as much as 200 m (Sawyer et al., 2002).

Nb Basalt (Pliocene)—Basalt was erupted from the Montosa Peak, Caja del Rio, La Bajada, and Tsinat Mesa centers and from an area north of Cochiti Lake. *Montosa Peak flows* are dark gray to medium gray with phenocrysts of olivine, pyroxene and plagioclase, and locally xenocrysts of quartz and hornblende. A $^{40}Ar/^{39}Ar$ isotopic age of 2.61±0.05 Ma was obtained from a lava flow forming a prominent bench on the south side of Montoso Peak. The maximum exposed thickness is 210 m (Thompson et al., 2011). *Caja del Rio flows* are medium gray basalt to basaltic andesite with few phenocrysts of olivine in a fine groundmass. Resorbed plagioclase xenocrysts are typically 2–3 mm, but can be up to 0.5 cm. A $^{40}Ar/^{39}Ar$ age of 2.61±0.04 Ma was obtained from a lava flow on the southeast flank of the largest cinder and spatter remnant. The maximum exposed thickness is 135 m (Thompson et al., 2011). *La Bajada Rim flows* are medium to dark gray lavas with olivine+pyroxene±plagioclase and lesser iron-titanium oxides. No age data is available for this unit. The maximum exposed thickness is 40 m (Thompson et al., 2011). The *basal flow on the La Bajada escarpment* dated by $^{40}Ar/^{39}Ar$ yields an age of 2.66±0.08 Ma; a dike cutting a cinder cone gave an age of 2.70±0.08 Ma (Sawyer et al., 2002). These results are consistent with an earlier age determination of 2.8±0.1 Ma (Bachman and Mehnert, 1978) on a Mesita de Juana flow at the southern rim of the Cerros del Rio volcanic field. The basalt of Tsinat Mesa is medium gray with small olivine phenocrysts and resorbed plagioclase and quartz xenocrysts. Cinder deposits are locally quarried for decorative landscape material. An $^{40}Ar/^{39}Ar$ age of 2.70±0.03 Ma was obtained from a dike that locally intrudes a cinder cone (Sawyer and others, 2002). The *Cochiti Lake lavas* are dark gray basalt flows preserved as prominent benches west of the Rio Grande, northeast of the community of Cochiti Lake. The basalt contains small (<1 mm) phenocrysts of olivine and pyroxene in a fine grained groundmass. The flows locally contain xenoliths of rounded Proterozoic pebbles, likely recycled from underlying Santa Fe Group sediments. **Nbc** are basaltic cinder deposits.The flows have normal polarity based on magnetic fluxgate determinations. The maximum exposed thickness is 70 m (Dethier et al., 2011). Basalt was also erupted from two centers outside the main Cerros del Rio field. Dark gray, porphyritic olivine basalt is intercalated with the Sierra Ladrones Formation (unit QTsa) in *Peña Blanca–Cochiti Dam* area to the southwest of the main field. Two lava flows overlie and are separated by hydromagmatic tuff that is too thin to map separately in most places. The flows are sparsely phyric containing phenocrysts of olivine±pyroxene. Probable source of lava flows was a low spatter cone or shield cone located near the Cochiti Dam spillway; this feature was partly excavated and then buried during the construction of the dam (Smith, 2001b). Smith and Kuhle (1998a) report a whole rock age of $^{40}Ar/^{39}Ar$ date of 2.73 ±0.04 Ma Maximum thickness is about 25 m just below Cochiti Dam along the Santa Fe River; more typically the thickness of the unit is 4–8 m thick. A second center is located to the north of the main field. The *basalt of Black Mesa* is dark gray to black basalt that appears to have crystallized in a volcanic neck. This basalt yielded a $^{40}Ar/^{39}Ar$ age of 2.75 ± 0.27 Ma (WoldeGabriel *et al*., 2001). Up to 55 m exposed.

Nba **Basaltic andesite (Pliocene)**—Basaltic andesite erupted from the Thirty-One Draw, Arroyo Calabasa, and Cerro Micho volcanic centers. The *Thirty-One Draw* flows are medium gray to dark gray lavas that are generally aphyric, but occasionally contain small olivine phenocrysts in a fine-graned matrix. No age data is available for this unit. Maximum exposed thickness is 50 m. The medium to dark gray lavas of *Arroyo Calabasas* contain few olivine phenocrysts. A $^{40}Ar/^{39}Ar$ age of 2.55±0.20 Ma was obtained from a lava flow in Arroyo Calabasas, but a normal magnetic polarity based on the measured paleomagnetic signature of the same sample suggests the age must be greater than 2.59 Ma. Maximum exposed thickness is 90 m at Cerrito Pelado; outflow thickness in Arroyo Calabasas is typically 25 m or less. The medium to dark gray lavas of *Cerro Micho* contain abundant olivine and few pyroxene phenocrysts, as well as plagioclase and quartz xenocrysts. A $^{40}Ar/^{39}Ar$ isotopic age of 2.75±0.03 Ma was obtained from a lava flow interbedded with scoria on the larger of the two cinder cones. **Nbac** are basaltic andesite cinder deposits. The maximum thickness is 115 m.

Nd **Dacite (Pliocene)**—The dacite of Tetilla Peak is a thin, cone-forming, small-volume, light-grayish-tan low-silica dacite lava capping Tetilla Peak. Dacite represents the most-differentiated magma composition in the eastern Cerros del Rio volcanic field. Phenocrysts of hornblende and plagioclase are conspicuous. The age is estimated to be 2.62 to 2.67 Ma (Sawyer et al., 2002).

Volcanic rocks of Santa Ana Mesa

The porphyritic olivine basalts capping Santa Ana Mesa erupted as spatter, scoria, and low lava shield volcanoes along two fault-controlled, north-trending vent alignments An outlying vent west of the primary alignments is defined by aeromagnetic data (Grauch et al., 2006) and isolated outcrops of lava and hydromagmatic tephra (Chamberlin et al., 1999). Hydromagmatic tephra also underlies the basaltic lava immediately below the north rim of Santa Ana Mesa (Smith and Kuhle, 1998a). Aeromagnetic data (Grauch et al., 2006) imply that the surficial lava flows have reverse magnetic polarity. The Santa Ana flows were not mapped in detail on the Loma Creston quadrangle (Chamberlin et al., 1999); these flows are shown a lumped unit on this compilation map.

Qbs3 Youngest flow on Santa Ana Mesa (Pleistocene)– Poorly exposed basalt, probably only one flow, with sparse olivine and plagioclase phenocrysts to 3 mm, erupted from vents south of the southern map boundary.

Qbs2 Middle flow on Santa Ana Mesa (Pleistocene)–A single, inflated basalt flow that consists of ~20-25% iddingsitized olivine phenocrysts (to 3.0 mm) and glomerphenocrysts (to 5.0 mm) in a coarse-grained intergranular groundmass of plagioclase, clinopyroxene and oxide minerals. Overlies hydromagmatic tuff (QNbm). The lava flow overlies and is inset against the older lava of Nb1 where it was eroded by the ancestral Rio Grande. $^{40}Ar/^{39}Ar$ plateau age is 2.41 ±0.03 Ma (Smith and Kuhle, 1998a). The flow is generally 4–6 m thick but thickens toward source, erupted from the northernmost volcano on Santa Ana Mesa, which is marked by a pyroclastic cone of spatter and cinder (circular feature labeled **Qbs2c**).

QNbs Santa Ana Mesa basalt flows, undivided (Pleistocene to Pliocene)—Thin subhorizontal olivine basalt flows and cogenetic basaltic tephra that cap the northern end of Santa Ana Mesa. Olivine basalt lava and associated hydromagmatic basaltic tephra erupted from a small isolated eruptive center on the northwest corner of Santa Ana Mesa. The medium dark gray olivine basalt contains rare (<0.5%) fine to medium grained (0.5–2 mm) greenish olivine and traces of plagioclase in a finely vesicular aphanitic groundmass. The unit is up to 18 m thick.

Nbs1 Oldest flows on Santa Ana Mesa (Pliocene)–Sequence of 1-4(?) lava flows that consist of 10% olivine (1-3 mm) and 20% plagioclase phenocrysts (0.6 -1 mm), including olivine+plagioclase glomerphenocrysts to 5.0 mm across, in a fine grained intergranular groundmass of plagioclase, clinopyroxene, and oxide minerals. Distinguished from Qbs2 by a greater abundance of plagioclase and lower abundance of olivine, which are also reflected geochemically by higher CaO and lower MgO. The flows were erupted from a linear chain of low shield volcanoes and cinder cones (cones are circular features labeled **Nbs1c**). The eroded eastern margin of the flows is associated with scattered quartzite pebbles, indicating a former course of the Rio Grande following the eruption of the lava flows. $^{40}Ar/^{39}Ar$ plateau age is 2.62 ±0.15 (Smith and Kuhle, 1998a) Ma. The total thickness of the flows more than 15 m.

Pliocene to Miocene

Keres Group (Older rocks of the Jemez Mountains volcanic field)

Tschicoma Formation. The Tschicoma Formation includes dacitic domes and flows forming the Sierra de los Valles just west of Los Alamos and hills in the eastern and northeastern Jemez Mountains. This episode of volcanism occurred between 5.4 and 2.9 Ma.

Ntqc Upper Quemazon Canyon dacite (Pliocene)—Bluish-gray to pinkish gray flow-banded to massive, crystal-poor (3%) lava with phenocrysts of large plagioclase and small resorbed quartz in a trachytic groundmass of plagioclase, orthopyroxene, clinopyroxene, biotite and opaque oxides. $^{40}Ar/^{39}Ar$ date is 2.94 ± 0.05 Ma (Kelley et al., 2013a). The maximum exposed thickness is roughly 65 m.

Ntpm Pajarito Mountain dacite (Pliocene)—Dome and flow complex of massive to sheeted, bluish-gray to pale pink porphyritic lava containing phenocrysts of plagioclase, hypersthene, clinopyroxene, and opaque oxides in a devitrified groundmass. $^{40}Ar/^{39}Ar$ ages on widely separated samples range from 3.11±0.06 to 2.95±0.08 Ma (Broxton et al., 2007). The maximum exposed thickness is about 365 m.

Ntcm Caballo Mountain dacite (Pliocene)—Dome and flow complex of massive to sheeted, dark gray to red porphyritic lava containing phenocrysts of plagioclase, clinopyroxene, rare rounded quartz, opaque oxides and oxidized biotite. $^{40}Ar/^{39}Ar$ date is 3.08 ± 0.15 Ma (Broxton et al., 2007). The maximum exposed thickness is about 200 m.

Ntu Tschicoma Formation lava south of Santa Clara Canyon, undivided (Pliocene)—Tschicoma Formation lavas that appear to underlie the Caballo Mountain dacite flows. Tschicoma Formation lavas are undifferentiated where exposed on the Santa Clara Indian Reservation outside of Santa Clara Canyon, representing unmapped territory since access to this region was not allowed. Contacts were drawn using Lidar imagery. Although the majority of these highlands are believed to be Tschicoma Formation, older and younger rocks may be present.

Nt Tschicoma Formation lava north of Santa Clara Canyon, undivided (Pliocene)—Tschicoma Formation lavas that appear to lie above the andesite of Santa Clara Canyon. Tschicoma Formation lavas are undifferentiated where exposed on the Santa Clara Indian Reservation outside of Santa Clara Canyon, representing unmapped territory since access to this region was not allowed. Contacts were drawn using Lidar imagery.

Ntsca Andesite of Santa Clara Canyon (Pliocene)—Three intervals of andesitic lava are exposed in Santa Clara Canyon. The upper interval, which lies above Caballo Mountain dacite is gray, massive to flow-banded lava containing 15–25% plagioclase with sparse pyroxene and quartz. Plagioclase laths are typically less than 0.5 cm long. This unit appears to consist of two flows that form impressive cliffs at the rim of the canyon. The upper andesite is 380 m thick in the Narrows and 100 m thick toward the west. The middle andesite is black to dark-gray, massive to flow-banded lava with 10–25% phenocrysts of plagioclase and pyroxene. This flow lies above the quartz-poor lava of Santa Clara Canyon. The plagioclase laths are up to 1.5 cm long; higher in the section, the matrix is gray, and the plagioclase are up to 3.5 cm long. The lava contains ≈1% xenoliths. A 10–15 m thick breccia commonly occurs at the base of the flows. This unit is 110 m thick in the Narrows and thins toward the west. The lowest flow lies below the rhyodacite of Santa Clara Canyon. This unit is a gray, thin, crystal-poor lava flow with 5–7% phenocrysts of quartz and plagioclase with trace biotite and hornblende. The plagioclase is 2–4 mm long. Contains felsic crystal clots and a few enclaves. This unit is 5–12 m thick.

Ntcg Cerro Grande dacite (Pliocene)—Extensive dome and flow complex of massive to sheeted, gray to pale-pink porphyritic lava containing phenocrysts of plagioclase, hypersthene, and (usually) conspicuous hornblende. The latter two phases commonly show oxidized rims and may be difficult to see in hand sample. Dates on widely separated samples range from 3.37 ± 0.17 Ma to 3.09 ± 0.02 Ma (Broxton et al, 2007). The maximum exposed thickness is about 750 m.

Ntsd Sawyer Dome dacite (Pliocene)—Dome and flow complex of massive, gray to pale-pink porphyritic lava containing phenocrysts of plagioclase, hypersthene, opaque oxides, and conspicuous hornblende. This lava contains occasional mafic clots of plagioclase and hornblende up to 10 cm in diameter. The $^{40}Ar/^{39}Ar$ age of the summit is 3.46 ± 0.30 Ma (Kelley et al., 2013a). The maximum exposed thickness is 245 m.

Ntcr Cerro Rubio dacite (Pliocene)—Gray to pink to black, massive to sheeted, fine-grained lava with phenocrysts of plagioclase, hornblende, orthopyroxene, biotite, and rare quartz. Resembles **Ntcd** (described below). The K-Ar age is 3.56 ± 0.36 Ma (Stix et al., 1988). The maximum exposed thickness is 440 m.

Ntcd Dacite intrusive north of Cerro Rubio (Pliocene)—Massive to sheeted, white to gray, fine-grained intrusive with small phenocrysts of plagioclase, hornblende, orthopyroxene, sparse biotite, and rare quartz. Columnar jointing is visible around margins and top of the intrusive body. The $^{40}Ar/^{39}Ar$ age is 4.24 ± 0.12 Ma (Kelley et al., 2013a). The maximum exposed thickness is 365 m.

Ntdqp Quartz-poor dacite lava and flow breccia in Santa Clara Canyon (Pliocene)—Gray to light-gray, massive to flow-banded lava with 5–15% phenocrysts of plagioclase, biotite, hornblende, and quartz. This unit contains more mafic minerals and less quartz compared to the underlying dacite (**Ntscrd**). The plagioclase laths are up to 1.5 cm long and the quartz is clear. The mafic minerals biotite and hornblende are usually abundant and tend to become larger (hornblende up to 1 cm long) near the top of the unit. A 10–15 m thick flow breccia forms the base of the unit and is well exposed in the Narrows section of Santa Clara Canyon. A discontinuously exposed flow breccia is also preserved at the top of the unit. The lava forms tall cliffs and the fracture density within the lava is low. This unit is 240 m thick in the Narrows and pinches out toward the west.

Ntt Tuff in Santa Clara Canyon—White to tan tuff with <1% crystals, 70% glassy pumice, and 3% lithic fragments. The only phenocryst observed was a trace of hornblende in the pumice. Generally 3 m thick; can be up to 20 m thick.

Ntscrd Rhyodacite of Santa Clara Canyon—Gray to light-gray, massive, flow-banded lava that contains 7–15% phenocrysts of plagioclase, quartz, biotite, hornblende, sanidine, and trace pyroxene. The plagioclase laths are up to 1 cm long. Quartz is common; the quartz is clear in eastern exposures and is pink to clear toward the west. The mafic minerals biotite and hornblende are variably abundant to sparse, and tend to be concentrated near the top and base of the unit. Flow breccia, which can be 10s of meters thick, commonly occurs at the base of this dacite, although in a few places, a breccia is also present near the top. This lava generally forms spires rather than cliffs and the fracture density is moderate to high. The $^{40}Ar/^{39}Ar$ yields ages are 4.265 ± 0.004 Ma and 4.549 ± 0.003 Ma. The unit is 340 m thick in the west and pinches out in the Narrows.

Ntsc Santa Clara Canyon dacite (Pliocene)—Faulted, plug-like to dike-like, bodies of massive to sheeted, gray to white porphyritic lava containing phenocrysts of plagioclase (commonly resorbed and up to 1 cm), sanidine, hornblende, biotite, and sparse quartz. The flow foliation in the dike dips steeply southeast. This lava resembles dacite on and near Cerro Rubio. The maximum exposed thickness is 160 m.

Ntd Porphyritic dacite, undivided (Pliocene)—Massive to sheeted, porphyritic gray lava containing abundant phenocrysts of plagioclase, and sparse phenocrysts of biotite and hornblende. These dacites are exposed in the western wall of the Valles Caldera, and in the northern and northeastern parts of the Jemez Mountains. On the north rim of Santa Clara Canyon, dacitic lavas cap the ridgeline above the upper andesite of Santa Clara Canyon. The $^{40}Ar/^{39}Ar$ date for the western caldera flow is 4.39 ± 0.18 Ma (Kelley et al., 2013a). The $^{40}Ar/^{39}Ar$ date on lava erupted from a dome northwest of Tschicoma Peak is 5.37 ± 0.36 Ma (Kempter et al., 2007). The maximum exposed thickness is 100 m.

Ntrc Rendija Canyon rhyodacite (Pliocene to Late Miocene)—Dome and flow complex of massive to sheeted, gray to reddish porphyritic lava with phenocrysts of quartz (commonly pink), sanidine, plagioclase, hornblende, and biotite. An outcrop of breccia and intercalated tephra and ash labeled **Ntrcbt** is exposed below **Ntrc** flows on the north side of Guaje Canyon. The$^{40}Ar/^{39}Ar$ dates on widely separated samples range from 5.01 ± 0.05 Ma to 5.39 ± 0.02 Ma (Broxton et al., 2007). The maximum exposed thickness is approximately 500 m.

Bearhead Rhyolite

The Bearhead Rhyolite is 6 to 7 Ma and consists of two members: the Peralta Tuff and Bearhead Rhyolite flows. Intrusive rocks were mapped in detail in the southern Jemez Mountains. Most of the volcanic centers are located in the south to southeastern quadrant of the Jemez Mountains, and a few are preserved in the northeastern wall of the Valles Caldera.

Nbp Peralta Tuff Member (Late Miocene)—White, nonwelded pyroclastic-flow, fall, and surge deposits genetically related to and associated with Bearhead Rhyolite domes, flows, and intrusions in the southeastern Jemez Mountains. The pyroclastic material is interbedded with white, pink, and tan tuffaceous sand and gravel composed mostly of perlitic rhyolite (Smith, 2001a, 2001b; Smith and Katzman, 1991). These sediments are laterally adjacent to and above the Arroyo Ojito Formation (**Nao**), and below the Cochiti Formation (**QNc**) in the Borrego Canyon drainage basin between the Santa Ana and Mesita Cocida faults. Pyroclastic units contain less than 5% crystals of sanidine and quartz, with less abundant biotite and rare plagioclase. Peralta Tuff Member fall deposits correlate to tephra layers in the Chamita Formation north of Española (McIntosh and Quade, 1995) and to 200 m of "pumice-rich volcaniclastic rocks" in the subsurface below the Pajarito Plateau (Broxton and Vaniman, 2006). Peralta Tuff dates are 7.15 ± 0.04 Ma to 6.87 ± 0.05 Ma (McIntosh and Quade, 1995; Smith, 2001a; Justet and Spell, 2001; Lynch et al., 2005). The younger Cerrito Yelo vent area has an associated pyroclastic-flow apron and is correlated to slightly reworked fall deposits within the Cochiti Formation (**QNc**) dated at 6.27 ± 0.06 Ma (Smith et al., 2001) and 6.33 ± 0.08 Ma (Chamberlin et al., 1999). The maximum thickness is about 700 m north of Tent Rocks.

Nbr Bearhead Rhyolite (Late Miocene)—Domes and flows of gray to white, aphyric to slightly porphyritic, devitrified to completely silicified rhyolite, containing sparse phenocrysts of quartz, sanidine, plagioclase, biotite, and opaque oxides in the southeastern and northeastern Jemez Mountains. Some domes and flows at and near Cerrito Yelo contain the same phenocrysts in greater abundance (≈20%) and are slightly younger and compositionally distinct from the more common sparsely-phyric rhyolites (Justet and Spell, 2001). The $^{40}Ar/^{39}Ar$ dates on widely separated samples range from 7.1 to 6.0 Ma (Justet and Spell, 2001; Kempter et al., 2007, Kelley et al., 2013a). The main group of rhyolites that erupted between 7.14 to 6.59 Ma have extraordinarily similar compositions, suggesting eruption from a single magma chamber. Younger ages of 6.11 to 6.23 Ma are reported from the compositionally distinct domes near Cerrito Yelo (Justet and Spell, 2001). The maximum observed thickness is about 100 m.

Nbi Bearhead Rhyolite intrusive centers (Late Miocene)–White to light-gray rhyolite dikes, plugs, and stocks that contain 1–3% phenocrysts of quartz, sanidine, biotite ± minor plagioclase. These intrusions are located in the southern Jemez Mountains. The intrusions commonly display intense, vertically oriented, platy cleavage. Vitrophyre is typical near the margins. The intrusions are along, and at the intersection of, N-S and NE-SE striking faults.

La Grulla Formation (Miocene)

The La Grulla Formation is exposed on the La Grulla Plateau, which is an elevated N-trending volcanic plateau that extends northwards from the Valles Caldera rim, capping strata and structures at the boundary of the Rio Grande rift and the Colorado Plateau. Age data from volcanic centers and the thick andesite to dacite flow sequence in this area indicates that most of the volcanic activity occurred between ≈7 and 8.5 Ma (Kelley et al., 2013a).

Ngbhd Porphyritic biotite, hornblende rhyodacite (Miocene)—Gray**,** massive to sheeted, crystal-rich lava on the north caldera rim with phenocrysts of sanidine, plagioclase, resorbed quartz, biotite, hornblende, clinopyroxene, orthopyroxene, and opaque oxides. The lava contains rare iddingsitized olivine crystals and plagioclase-pyroxene-biotite clots. The $^{40}Ar/^{39}Ar$ date is 7.45 ± 0.05 Ma (Kelley et al., 2013a). The maximum exposed thickness is about 135 m.

Nghd Hornblende dacite and rhyodacite (Miocene)—Gray, massive to sheeted, porphyritic lavas of diverse texture capping Cerro de la Garita and other hills. The flows have distinctive hornblende, plus plagioclase, sanidine, biotite, and minor clinopyroxene phenocrysts. This unit erupted from several vents on southeastern La Grulla Plateau. The $^{40}Ar/^{39}Ar$ dates range from 7.68 to 7.32 Ma (Kempter et al., 2007; Kelley et al., 2013a). The maximum exposed thickness is 30 m.

Nga Porphyritic andesite, undivided (Miocene)—Brownish-gray, massive to sheeted, porphyritic andesite lavas with phenocrysts of plagioclase, biotite, clinopyroxene, orthopyroxene, and opaque oxides, which may contain plagioclase-pyroxene-biotite clots. This unit erupted from multiple vents. The $^{40}Ar/^{39}Ar$ dates on widely separated samples range from 7.86 to 7.48 Ma (Justet, 2003; Kempter et al., 2007; Kelley et al., 2013a) The maximum exposed thickness is about 330 m on the north caldera wall.

Ngb Olivine basalt (Miocene)—Two exposures of massive, dark-gray lava on the northwestern caldera rim that is informally correlated with the basalt of Encino Point (Kempter et al., 2007; Lawrence, 2007). The lava contains small phenocrysts of olivine, plagioclase, and clinopyroxene. The flows are interlayered with La Grulla Formation andesite. The $^{40}Ar/^{39}Ar$ dates are 7.85 ± 0.13 Ma (lower basalt) and 7.84 ± 0.09 Ma (Kelley et al., 2013a). The maximum exposed thickness is roughly 35 m.

Paliza Canyon Formation

For those rocks that have been geochemically analyzed (e.g., Gardner, 1985; Chamberlin et al., 1999; Justet, 2003; Wolff et al., 2005; Rowe et al., 2007; Thompson et. al., 2017), Paliza Canyon Formation compositions straddle the boundary between subalkaline and alkaline compositions, following LeBas et al. (1986). As a result, many of the rocks are more accurately called trachybasalt, trachyandesite, and trachydacite, rather than basalt, andesite, and dacite. However, geochemical data are not available for all the units within the Paliza Canyon Formation, so the common field names basalt, andesite, and dacite are applied here.

Npv Volcaniclastic deposits (Late Miocene)—Gray to brown volcaniclastic conglomerate, breccia, sandstone, and tuff, interbedded with Paliza Canyon Formation lava flows. The debris-flow and fluvial deposits contain locally derived clasts of andesite, dacite, basalt, basaltic andesite, and rhyolite lavas (Lavine, 1996; Lavine et al., 1996). This unit includes andesitic to dacitic block-and-ash flow deposits, dacitic pyroclastic flows, rare andesite scoria deposits, and primary and reworked andesitic-dacitic tephra deposits. The unit is intercalated with the ≈10 Ma basalt of Chamisa Mesa, and is overlain by the ≈7 Ma Peralta Tuff Member near Tent Rocks. A widespread andesitic tephra (Smith, 2001a), and a single outcrop of dacitic tephra within the Peralta Tuff Member that is between rhyolitic pyroclastic deposits, yielded dates of 6.95 ± 0.13 Ma and 7.00 ± 0.06 Ma, respectively. Smith (2001a) suggests the possibility of Paliza Canyon volcanism temporally overlapped the eruption of Bearhead Rhyolite. Maximum exposed thickness is >200 m on the slopes of St. Peters Dome (Goff et al., 1990).

Npba Basaltic andesite lava flows and domes (Late Miocene)—Medium-gray to black lava flows containing 1–10% phenocrysts of plagioclase, typically accompanied by pyroxene and/or olivine (commonly replaced by iddingsite). This unit includes the olivine andesite of Goff et al. (1990), and a lava flow that caps Loma Canovas and Mesita Cocita with a $^{40}Ar/^{39}Ar$ date of 7.18 ± 0.26 Ma (Chamberlin et al., 1999). Basaltic andesite exposed in Paliza Canyon is 9.43 ± 0.12 Ma (Kelley et al., 2013a). Several porphyritic basaltic andesite flows are exposed in Capulin Canyon and west of St. Peters Dome (Goff et al., 1990). Individual flows are generally 5–35 m thick.

Npd Dacite and rhyodacite lava flows and domes (Late Miocene)—Light- to dark-gray or pink, porphyritic lava flows, domes, and small intrusive plugs, containing 1–10% phenocrysts of plagioclase and biotite ± hornblende. Some flows contain pyroxene and some contain sparse phenocrysts of quartz. Feldspar phenocrysts are commonly as much as 1 cm long. This unit includes nearly aphyric, plagioclase and pyroxene-bearing, glassy dacite exposed in upper Capulin Canyon (Goff et al., 1990). Large continuous outcrops of hornblende and/or biotite dacite, that can be more than 100 m thick, are interbedded with volcaniclastic deposits. This dacite forms a large part of the Paliza Canyon Formation section on the southeastern and southern flanks of the Jemez Mountains (Gardner, 1985; Goff et al., 1990; Chamberlin et al., 1999; Kempter et al., 2003). Dacites yield $^{40}Ar/^{39}Ar$ and K-Ar ages that range from 9.48 ± 0.44 Ma to 7.86 ± 0.14 Ma (Gardner and Goff, 1984; Justet, 2003; Kelley et al., 2013a). Thickness of the unit is highly variable; typical flows and domes are 100–180 m thick.

Npa Andesite lava flows and domes (Late Miocene)—Medium- to dark-gray, brown, and purplish-gray porphyritic lava flows and domes, including minor amounts of interbedded fluvial conglomerate, gray ash, and poorly sorted debris-flow deposits in some locations. This map unit includes small plugs and dikes. Most flows contain 5% to as much as 20% phenocrysts of plagioclase, clinopyroxene, orthopyroxene and, less commonly, hornblende or biotite. Flow breccias are common and form most of the thickness of some outcrops, particularly in Cañon de San Diego. Justet (2003) reports $^{40}Ar/^{39}Ar$ ages of 9.11 ± 0.06 Ma to 8.29 ± 0.15 Ma for andesites. Most andesite lava flows are 10–30 m thick, with domes exceeding 150 m thick. Successions of multiple flows rarely exceed 300 m thick; an exception is the 500-m-thick stack of Paliza Canyon Formation andesite exposed in the north wall of the caldera at Cerro de la Garita (Kelley et al., 2013a).

Npob Olivine basalt (Late Miocene)—This unit includes an olivine basalt that contains up to 6% olivine altered to iddingsite. The basalt has a distinctive red-speckled appearance on weathered surfaces and is aerially extensive, covering an area from Church Canyon near Jemez Springs, to Bodega Butte on Zia Pueblo. This flow was informally named the basalt of Bodega Butte by Chamberlin and McIntosh (2007). A stack of at least four 1–2-m-thick trachyandesite and trachybasalt flows, dipping south-southwest, intercalated with volcaniclastic sediment and rhyolitic tephra, are exposed in Hondo Canyon below the basalt of Bodega Butte. Chamberlin and McIntosh (2007) determined a weighted mean age of 9.20 ± 0.12 Ma from four samples of the basalt of Bodega Butte. The $^{40}Ar/^{39}Ar$ date from the basalt of Bodega Butte collected at the confluence of Hondo and West Fork Canyons is 9.17 ± 0.13 Ma (Kelley et al., 2013a).

Npb Basalt lava flows (Late Miocene)—Black to dark-gray, sparsely porphyritic lava flows with small (<2–3 mm) phenocrysts of olivine and plagioclase ± clinopyroxene. A lava below the olivine basalt is 9.64 ± 0.08 Ma (Kelley et al., 2013a). The individual flows Hondo Canyon are 1–2 m thick.

Npbc Basalt of Chamisa Mesa and related lava flows (Late Miocene)—The basalt of Chamisa Mesa (Bailey et al., 1969) consists of sparsely porphyritic basalt flows with a distinctive ophitic texture with 2% small (<2 mm) phenocrysts of olivine (replaced by iddingsite) and pyroxene. The basalt of Chamisa Mesa, the stratigraphically lowest flows in the southwestern Jemez Mountains, consists of extensive flows that are present as far east as Borrego Dome, as far south as the south end of Borrego Mesa, and as far north as Paliza Canyon. A flow that is texturally similar to the basalt of Chamisa Mesa sits on Abiquiu Formation in Church Canyon northeast of Jemez Springs. Chamberlin and McIntosh (2007) determined an average $^{40}Ar/^{39}Ar$ age of 10.0 ± 0.9 Ma for the basalt of Chamisa Mesa. The basalt of Chamisa Mesa samples analyzed by Kelley et al. (2013a) are 9.45 ± 0.31 Ma to 9.51 ± 0.07 Ma. The succession of flows is 8–30 m thick.

Npi Intrusive rocks (Middle Miocene)—Variable composition stocks and dikes. Unit is primarily present in the Cochiti Mining District north of Bearhead Peak (Goff et al., 2005; Lynch et al., 2005) and includes the "volcanic and intrusive rocks of the Bland District" of Smith et al. (1970). Basaltic andesite, andesite, and dacite dikes and stocks are porphyritic, pervasively fractured, and hydrothermally altered. Dikes and fractures in the area commonly strike north. Light- to very dark-gray to dark-green to black diorite and monzonite dikes and stocks contain phenocrysts and locally glomerocrysts of plagioclase and augite within a phaneritic to aphanitic groundmass of plagioclase, orthoclase, and quartz, with biotite and/or hornblende. This unit is pervasively hydrothermally altered. Xenoliths of sandstone are present. Stein (1983) reported a feldspar-separate K-Ar age of 11.2 ± 0.3 Ma on a monzonite sample. Subsequent mapping (Stein, 1983; Lynch et al., 2005; Goff et al., 2005) and the K-Ar age support an interpretation that this intrusive complex is co-genetic with the Paliza Canyon Formation. This unit includes a light- to dark-gray, fine-grained andesitic intrusion with sparse plagioclase and pyroxene phenocrysts located east of the village of Ponderosa. Pieces of Canovas Canyon dacite are included in the intrusive along the margin and the older dacite is altered and iron-stained along the contact. The maximum exposed thickness is 275 m.

Canovas Canyon Rhyolite

This unit, which is preserved in the southwestern Jemez Mountains, includes rhyolite flows, domes, and intrusives, as well as tuff and sedimentary deposits. A dacite and rhyolite plug and flow form a notable landmark east of the village of Ponderosa.

Nccr Canovas Canyon Rhyolite lava flows, domes, and intrusive rocks (Late Miocene)—Tan, pink, light-gray, and white, sparsely porphyritic rhyolite forming lava flows, domes, and plugs. Most rhyolite is devitrified but gray to gray-green perlitic vitrophyre is present around the margins of some domes. Phenocrysts of plagioclase, biotite, less common sanidine, and sparse quartz, are rarely more than 2 mm across and compose less than 5% of the rock. Bear Springs Peak, Borrego Dome, and an area south and west of Tres Cerros in the south-central Jemez Mountains are among the largest centers for these lavas (Chamberlin et al., 1999; Kempter et al., 2003). Rhyolite flows and domes are also present in the southeastern Jemez Mountains in lower Cochiti Canyon and nearby Sanchez Canyon (Goff et al., 1990; Lynch et al., 2005). Several Canovas Canyon rhyolite domes were dated at 12.0 to 8.4 Ma by Padmore and Spell (2008), with the ages clustering between 9.4 and 10.1 Ma. Kelley et al. (2013a) and Justet (2003) report ages of 9.85 ± 0.09 Ma to 8.10 ± 0.60 Ma for Canovas Canyon Rhyolite flows. The thickness varies greatly from place to place, with a maximum thickness exceeding 300 m near Bear Springs Peak.

Ncct Canovas Canyon Rhyolite tuff and interbedded sedimentary deposits (Late Miocene)—White, tan, and pink, massive and bedded, crystal-poor rhyolitic tuff, tuff breccia, sandstones, and tuffaceous conglomerate, intercalated with rhyolite lava flows and domes of unit **Nccr**. Generally contains less than 5% crystals of biotite, plagioclase, and sanidine, with sparse quartz. One widespread ignimbrite is pink and contains ≈10% lithic fragments of flow-banded rhyolite and obsidian. Obsidian Apache tears are common in the tuff. This tuff in Paliza Canyon yielded a hornblende $^{40}Ar/^{39}Ar$ age of 9.28 ± 0.36 Ma. Most outcrops consist of massive to crudely bedded pyroclastic-flow deposits as much as 150 m thick, including rare welded tuff. Bedded tephra deposits that are more than 30 m thick are present close to vent areas.

Nccd Canovas Canyon dacite/rhyolite intrusion and flow (Late Miocene)—Small plug and associated flow of dacite with feldspar phenocrysts. The dacite grades into pink to reddish-brown flow-banded rhyolite (**Nccr**), which forms a prominent knob east of Ponderosa.

The crystal-poor rhyolite contains biotite, feldspar, and forms a small rhyolite flow on the east side of the knob. The $^{40}Ar/^{39}Ar$ ages of 9.41 ± 0.24 Ma to 9.37 ± 0.16 Ma were determined for the intrusion and glassy margin, respectively.

Lobato Formation

Nlb Lobato Formation basalt (Late Miocene)–Small exposures of this unit are in Santa Clara Canyon and in the fault scarp of the Pararito fault zone just north of the Pine Spring area (Smith et al., 1970). These lava flows contain microphenocrysts of plagioclase and olivine. Ages from this area are10.1 to 13.1 Ma (WoldeGabriel et al., 2006).

Quaternary to Neogene

Santa Fe Group

The Santa Fe Group is designated for basin-fill sediments that were deposited in the Rio Grande Rift during the Late Oligocene through Early Pleistocene. This stratigraphic group includes thin, lenses of volcanic rocks and tephra deposits too small to map at this scale. This unit excludes small exposures of correlative sediment in volcanic terrains (i.e., the Jemez Mountains volcanic field) as well as terrace alluvium and valley floor alluvium deposited during net regional incision in the past 780 ka (exact timing of incision is variable, depending on location). The name “Santa Fe” was first applied to poorly consolidated sediments north of Santa Fe and between Santa Fe and Galisteo Creek (Hayden, 1873). The term “Santa Fe Formation” was first used near Española for sediment containing Miocene fauna (Denny, 1940; Galusha and Blick, 1971). Spiegel and Baldwin (1963) elevated the term “Santa Fe” to group status and considered the Santa Fe Group to include the sedimentary rocks and volcanic rocks related to the Rio Grande trough [rift]. In the map area, the Santa Fe Group is differentiated into a coarser, weakly cemented upper part and a finer, better-cemented lower part. These two parts are separated by an unconformity across practically the entire Española Basin, with possible exceptions located 6–7 km south of Los Alamos and in the middle part of Santa Clara Canyon about 8–17 km west of its mouth (Dethier, 2003). However, an equivalent unconformity has not been recognized at the base of the upper Santa Fe Group in the Santo Domingo sub-basin. Below, we treat the Santa Fe Group separately for the northern Albuquerque Basin (in which we include the Santo Domingo sub-basin) and the Española Basin.

Upper Santa Fe Group, Santo Domingo basin

The upper-Late Miocene through the Early Pleistocene Santa Fe Group is preserved only in the Santo Domingo sub-basin of the northern Albuquerque Basin. This stratigraphic interval is several hundred meters thick and includes the gravel of Lookout Park, Cochiti Formation, and the Sierra Ladrones Formation. The gravel of Lookout Park overlies the Cochiti Formation. The Cochiti Formation represents a former volcaniclastic alluvial apron surrounding the southern Jemez Mountains. The Cochiti Formation interfingers eastward with the axial facies of the Sierra Ladrones Formation, which in turn interfingers eastward with piedmont facies of the Sierra Ladrones Formation.

Qglp Gravel of Lookout Park (Early Pleistocene)—Gray to tan, cobble to boulder gravel underlying high-level geomorphic surfaces in the Santo Domingo basin and southern slopes of the Jemez Mountains. The gravel overlies the Cochiti Formation with angular unconformity. West of the Mesita Cocida fault zone, the gravel of Lookout Park forms inverted-topographic ridges where gravel filled paleocanyons. Clasts are dominantly Paliza Canyon Formation andesite, basalt, and dacite, and the remainder are varieties of rhyolite and rhyolite-tuff rock types. The surface projects below the northern edge of the Pliocene basalts of Santa Ana Mesa, indicating a depositional age for the gravel younger than 2.4 Ma (Smith and Kuhle, 1998a). The gravel is older than 1.62 Ma because the Otowi Member of the Bandelier Tuff is present above the gravel of Lookout Park (Smith and Kuhle, 1998a; Lynch et al., 2005). Generally this unit is 4–15 m thick.

QNc Cochiti Formation (Middle Pleistocene to Late Miocene)—Gray, brown, and pale-orange volcaniclastic fluvial sand and gravel in poorly to moderately sorted, tabular beds. The deposit conformably overlies and interfingers with the late Miocene Peralta Tuff Member of the Bearhead Rhyolite (Smith and Lavine, 1996), and interfingers eastward with axial facies of the Sierra Ladrones Formation. Vitric-rhyolite clasts, which are the dominant clast type in texturally similar gravel in the Peralta Tuff Member of the Bearhead Rhyolite, generally represent less than 30% of Cochiti Formation clasts. This clast type abruptly decreases in abundance upsection. Devitrified rhyolite, and silicified and altered rhyolite clasts, are dominant in the Cochiti Formation. The concentration of these clasts increases in abundance upsection. The basal contact of this unit at Tent Rocks is located about 10 m above a 6.79 ± 0.05 Ma pyroclastic deposit (McIntosh and Quade, 1995). A 6.16 ± 0.07 Ma rhyolitic tephra is preserved in the lower part of the formation at Tent Rocks. The 1.62 Ma Otowi Member of the Bandelier Tuff is intercalated in the uppermost Cochiti Formation east of Tent Rocks. Maximum exposed section near Tent Rocks is 600 m (Smith et al., 2001).

QNsa Sierra Ladrones Formation, axial-river deposits (Early Pleistocene to Late Miocene)—Gray, unconsolidated sandy gravel with local yellow sand, along with minor pink to tan siltstone. This deposit interfingers westward with the Cochiti Formation and the Peralta Tuff Member of the Bearhead Rhyolite, and interfingers eastward with eastern piedmont deposits of the Sierra Ladrones Formation. Clasts include approximately 25–40% metaquartzite, 30–40% mafic and intermediate volcanic rocks, 0–8% felsic volcanic rocks, 2–8% granitic and supracrustal metamorphic rocks, ≈1–3% Pedernal chert, and traces of Amalia Tuff. The clast compositions are consistent with deposition by the ancestral Rio Grande with headwaters that include the modern Rio Chama (Smith et al., 2001) and the Tusas Mountains-Abiquiu area. The oldest exposed strata is intercalated with the Peralta Tuff Member of the Bearhead Rhyolite south of Kasha Katuwe Tent Rocks National Monument (Smith et al., 2001; Lynch et al., 2005). This yields a $^{40}Ar/^{39}Ar$ age on sanidine of 6.81 ± 0.02 Ma (Smith et al., 2001). An ash bed within the gravel is 6.88 ± 0.01 Ma (Smith et al., 2001). Exposures east of the Rio Grande upstream of the Cochiti Dam spillway and at Santo Domingo Pueblo contain ash and pumice bombs from the Otowi Member of the Bandelier Tuff (Smith and Kuhle, 1998a, b). Age range is ≈6.9–1.62 Ma. The total thickness is unknown since the base is not exposed, but it exceeds 300 m.

QNsl Sierra Ladrones Formation, lacustrine limestone, mudstone and minor sandstone (Early Pleistocene to Late Miocene)—Consists of 1 to 3 beds of vuggy limestone, travertine, and marl interbedded with green calcareous mudstone and local beds of axial-composition sand. Gastropod and ostracod fossils locally abundant. Abundance of precipitated calcite suggests bodies of water that were at least partially spring fed. The large extent of this deposit, however, suggests an areally extensive shallow lake. These deposits might speculatively relate to disruption of surface flow and consequent water-table rise caused by impoundment of the Rio Grande behind lava dams of the San Felipe volcanic field located south of the southern map boundary. Total thickness is 4 to 12 m; thickest outcrops form prominent east -dipping cuesta along north side of Galisteo Creek north of Santo Domingo and in unnamed valley southeast of Peña Blanca. In the latter area, limestone fills channels incised through basalt (**Nb**).

QNsp Sierra Ladrones Formation, eastern piedmont-stream deposits (Early Pleistocene to Late Miocene)—Tan, pink, and red lithic-arkosic sand, mud, and gravel deposited by west and southwest flowing streams in the eastern Santo Domingo basin. Pebbles and cobbles consist mostly of Proterozoic granite, white-vein quartz, and basalt in northern outcrops and Espinaso Formation lavas and petrified wood from the Galisteo Formation in southern outcrops (Smith and Kuhle, 1998a). Contains an eroded layer of the 1.62 Ma Otowi Member of the Bandelier Tuff, including the Guaje Pumice Bed, that is as much as 3 m thick and crops out almost continuously for 4 km along the north side of Galisteo Creek (Smith et al., 1970; Smith and Kuhle, 1998a). The unit is interbedded with axial-river gravel (**QNsa**) east of the Rio Grande between Cochiti Dam and Galisteo Creek. Base is not exposed, so the thickness exceeds 300 m.

Lower Santa Fe Group, Santo Domingo basin.

The lower Santa Fe Group is exposed along the southern margin of the Jemez Mountains west of the Santo Domingo sub-basin. This unit consists of several hundred meters of predominantly fluvial sand, with minor fines and gravels. This sediment was initially deposited by rivers flowing southeastward off of the Colorado Plateau, but later was largely derived from erosion of the emerging Sierra Nacimiento and the Jemez Mountains volcanic field (Connell et al., 1999; Chamberlin et al., 1999). Eolian sand intervals are present in the lower part of this unit.

Nao Arroyo Ojito Formation (Late Miocene)—Buff to pale-pink, pebble- to cobble- (rarely boulder) conglomerate and arkosic sandstone. The coarser lenticular layers are preferentially cemented by calcite to form distinctive ledge-and-slope outcrops. South of the map area, Connell (2008) recognizes three members in the Arroyo Ojito Formation (from youngest to oldest): Picuda Peak, Loma Barbon, and Navajo Draw. More than half of the clasts in the Arroyo Ojito Formation on the Loma Creston quadrangle are pink granite, pegmatite, white-vein quartz, and Pedernal chert. The remainder are a mixture of Keres Group volcanic rocks and basalts of unknown origin. The mixture of rock types indicates deposition by streams flowing eastward from the slopes of the Sierra Nacimiento and possibly draining parts of the adjacent San Juan Basin. This unit is exposed between the Santa Ana and Mesita Cocida faults in the southwestern Jemez Mountains. This formation rests with disconformity and local angular unconformity on the Cerro Conejo Formation west and southwest of Mesita Cocida, and is locally interbedded with tuffaceous sediment containing Peralta Tuff ash beds (**Nbp**). The exposed unit shares many of the same gravel types as the Loma Barbon Member of Connell (2008) and, like the Loma Barbon Member, the gravel is intercalated with Peralta Tuff beds. Thus, considering that the two likely interfinger, the unit in the Loma Creston quadrangle correlates temporally with the Loma Barbon

Member and perhaps the Navajo Draw Member (Connell, 2008). The age range is 10–6.5 Ma (Connell, 2008). The maximum exposed thickness is approximately 65 m.

Ncc Cerro Conejo Formation (Late to Middle Miocene)—Pink to brown to red, mostly well sorted, fine- to medium-grained quartz-rich sand and sandstone, with local conglomeratic intervals and rare pink siltstone and mudstone. Pebbles, cobbles, and boulders (to 50 cm) are mostly Keres Group volcanic rocks, although small pebbles (typically 0.5–2 cm) of granite, chert, and vein quartz are common. Most of the well-sorted sandstones are likely of eolian origin and conglomeratic sandstones represent fluvial redistribution of eolian sand by streams that also transported locally derived volcanic and distant older detritus. The unit is silicified and strongly reddened in the footwalls of faults in the Mesita Cocida fault zone. The Cerro Conejo Formation is interbedded with volcaniclastic sediment deposited contemporaneously with Keres Group volcanism (unit **Npv**) and is interbedded with Paliza Canyon Formation basalt. The unit is unconformably overlain by a 7.13 ± 0.26 Ma Paliza Canyon Formation basaltic andesite, Peralta Tuff Member of the Bearhead Rhyolite, and Arroyo Ojito Formation, which suggests that deposition ceased between 8 and 9 Ma. Age range is ≈14.6–9.0 Ma (Connell, 2008). The maximum thickness is approximately 200 m.

Upper Santa Fe Group in the Española Basin

The upper Santa Fe Group in the Española Basin consists of three intertonguing formations differentiated by provenance-based compositional criteria. Compared to underlying Santa Fe Group basin fill, this suite of formations is relatively thin (10–100 m thick). To the south, the Tuerto Formation surrounds the northern Cerrillos Hills and consists of sand and monzonite-dominated gravel shed from these uplands. The Ancha Formation consists primarily of granitic detritus derived from the southern Santa Fe Range portion of the Sangre de Cristo Mountains. South of the Buckman well field, the Ancha Formation is intercalated with the gravelly Puye Formation, which includes volcaniclastic gravel shed from the Jemez Mountains and axial ancestral Rio Grande fluvial sediment.

QNt Tuerto Formation (Early Pleistocene to Late Pliocene)—Yellowish-brown to light-yellowish-brown to tan to brownish-yellow, silty-clayey sand interbedded with coarse channel fills of sandy gravel and gravelly sand derived from the Cerrillos Hills (Koning and Hallett, 2000). The unit grades northward and northeastward into the Ancha Formation. The silty sand is massive or very thinly to thinly bedded, and mixed with 1–10% pebbles that occur in discrete thin beds. The gravelly sediment increases towards bedrock hills and commonly occurs in: 1) thin to medium beds dominated by pebbles, or 2) thick, extensive, indurated beds with subequal cobbles and pebbles. Gravel composition is dominated by monzonite, with less than 20% granite derived from the Sangre de Cristo Mountains. This unit has an age range of ≈3–1.3 Ma, and a thickness of 1–60(?) m.

QNa Ancha Formation (Early Pleistocene to Late Pliocene)—Alluvial slope deposits are pink to brownish-yellow to light-yellowish-brown to yellowish-brown, and contain two distinct types of intercalated sediment: 1) silty-clayey sand that is mostly very fine to medium grained with subordinate coarse- to very coarse-grained sand, containing a few scattered pebbles, and 2) coarse channel fills of gravelly sand, sandy gravel, and medium- to very coarse-grained sand. The alluvial slope deposits were derived from the southwestern Sangre de Cristo Mountains (Koning and Hallett, 2000; Koning and Read, 2010). The unit includes subordinate ancestral Santa Fe River deposits, mostly coarse-grained with minor clayey-silty sand that are located approximately between Interstate 25 and the modern Santa Fe River. South of Interstate 25, coarse channel fills are generally subordinate to silty-clayey sand, but strata coarsens down-section. Alluvial slope gravel consists of subrounded pebbles with minor cobbles, composed of 85–95% reddish granite with minor metamorphic and gabbroic-dioritic clasts. The gravel is similar to the ancestral Santa Fe River deposits except that quartzite and cobble concentrations are higher. Ancha sand is arkosic and subangular to subrounded. Unit **QNa** includes minor interbeds of basaltic hydromagmatic deposits, which increase in abundance to the west. The age range is ≈3–1.3 Ma (Koning et al., 2002). The unit averages 5–75 m thick, but locally is as much as 90–100 m thick.

QNp Puye Formation (Late Pleistocene to Early Pliocene)— Light- to dark-gray, moderately lithified pebble to cobble gravel, boulder-rich debris flows, massive to planar-bedded sand, thin (<2.0 m) beds of dacitic and rhyolitic tephra, ignimbrite, and pumiceous alluvium, lacustrine beds containing fine sand, silt, and clay, and local beds of basaltic scoria (Waresback, 1986). The unit was deposited in the northern to eastern quadrant of the Jemez Mountains. Rounded to subrounded clasts in the debris flows are dacitic to rhyodacitic lavas derived from Tschicoma Formation domes and flows in the Sierra de los Valles to the west. Paleocurrent azimuths range from 40º to 160º. The unit includes at least 25 primary pyroclastic deposits (Turbeville et al., 1989; Waresback and Turbeville, 1990), and is weakly to moderately cemented.

The age range of 5.3–1.9 Ma is based on dating of a basal pumice-lapilli bed, interbedded lava flows, and the La Cueva Member of the Bandelier Tuff in uppermost strata (WoldeGabriel et al., 2001; Waresback and Turbeville, 1990; Smith, 2007; Samuels et al., 2007; Broxton et al., 2007). Outcrops have a thickness of 5–140 m (mostly 60–140 m), but locally exceeds 330 m in boreholes (Broxton and Vaniman, 2005).

Lower Santa Fe Group, Española Basin.

Underlying a Plio-Miocene unconformity, Neogene basin-fill strata of the Española Basin is 3 km thick (Grauch et al., 2009; Cole et al., 2009) and consists of the Chamita Formation and underlying Tesuque Formation of the Santa Fe Group (Spiegel and Baldwin, 1963; Galusha and Blick, 1971). The Chamita Formation is overlain generally with angular unconformity by the Puye Formation. Koning and Aby (2005) and Koning et al. (2007b) subdivide the Chamita Formation into the Hernandez, Vallito, Cejita, and Cuarteles Members. The time-transgressive Cejita and Cuarteles members extend from the Chamita Formation west of the Rio Grande into the Tesuque Formation east of the Rio Grande. The Chamita Formation is generally coarser grained than the Tesuque Formation, with the coarsening beginning at 13.3–13.2 Ma (Koning, 2002, 2003; Koning and Manley, 2003; Koning et al., 2005, 2013). Both formations contain tephra beds, but those of the Chamita Formation are characteristically coarse ash- to lapilli-size, whereas fine ashes dominate in the Tesuque Formation (Galusha and Blick, 1971; Koning et al., 2007; Koning et al., 2013). Both the Chamita and Tesuque formations are subdivided into internal stratigraphic units. The Tesuque Formation generally overlies late Oligocene volcanic and volcaniclastic strata (e.g., Cieneguilla Basanite) with interfingering present in the lowermost Tesuque strata (Koning and Read, 2010). The Tesuque and Chamita formations were deposited in the following paleo-depositional environments (Cavazza, 1986; Ingersoll et al., 1990; Smith, 2004; Koning and Read, 2010; Koning et al, 2013): (1) west-sloping piedmont alluvium shed from the Sangre de Cristo Mountains located on the east side of the basin (**Nta**, **Ntacu**, and **Nts**); (2) distal piedmont alluvium (transitioning to basin-floor) that slopes toward the south and southeast, derived from sources to the north and northwest (**Ntc,** not exposed on this compilation map); (3) a 10–20 km, south-sloping basin floor with converging, south-flowing rivers (**Ntb**, **Nch**, **Ntbce**); and (4) alluvial fans surrounding uplands on the immediate footwall of the La Bajada fault (**Nte,** exposures too small to show at this scale). In the east-central Española Basin, the Tesuque Formation has been differentiated into the following members, listed from oldest to youngest:

Nambé, Skull Ridge, and Pojoaque members (Galusha and Blick, 1971). However, lithologic contrasts in this part of the Tesuque Formation are better represented by delineation of two provenance-based, intertonguing lithosomes (Cavazza, 1986): 1) lithosome A, derived from the Sangre de Cristo Mountains, located to the east of the Española Basin, and 2) lithosome B, derived from the Peñasco Embayment and San Luis Basin, located to the northeast and north of the basin. Recent mapping efforts in this part of the basin incorporate both nomenclature schemes. To the south, near Santa Fe, Koning and Read (2010) differentiated two additional lithosomes in the Tesuque Formation: lithosome S and lithosome E. These two lithosomes are time-equivalent to lithosomes A and B mapped in the Nambe, Skull Ridge, and Pojoaque members of Galusha and Blick (1971), and are readily distinguished from the northern lithosomes by their clast composition. Lithosome E is volcaniclastic and is derived from Cerros del Rio volcanic field on the immediate footwall of the La Bajada fault. Lithosome S represents deposition by an ancestral Santa Fe River.

Nch Chamita Formation, undivided (Middle to Late Miocene)—Fluvial strata comprised of pink to tan to light-gray, coarse-grained channel fills (sand and gravelly sand) intercalated with subordinate, brown, fine-grained floodplain deposits (clay, silt, and very fine- to fine-grained sand). Minor cross-stratified eolian layers are present in the lower part of the unit (Koning and Aby, 2005; Koning et al., 2007b; Koning, 2007). The unit was deposited on a south-sloping basin-floor by two converging paleo-drainages: one exiting the San Luis Basin (Vallito Member) and another representing an ancestral Rio Chama (Hernandez Member). Locally, this includes unit **Ntbce** west of NM-30. The axial sediment interfingers eastward with the Cejita (**Ntbce**) and Cuarteles members (**Ntacu**) and westward with Miocene-age alluvial fans derived from the Jemez Mountains volcanic field. Channel fills are amalgamated (as much as 20 m thick) and laterally extensive (>10s of m). Gravel consists of subrounded to rounded pebbles, with abundant cobbles in the Hernandez Member. Felsic-intermediate volcanic rocks dominate in both members, with minor mafic types. The Hernandez Member, which was derived from the San Juan volcanic field, contains high concentrations of dark-gray to brown porphyritic dacites to andesites, 2–26% quartzite, and 0–15% granite. The Vallito Member, in addition to the volcaniclastic component, contains diverse types of Paleozoic sedimentary rocks with minor granite and quartzite. Channel-fill sand is subrounded (lesser subangular and rounded), fine- to very coarse-grained, and dominated by quartz (especially the Vallito Member) with minor feldspars and lithic grains. The Vallito Member northeast of St. Peters Dome, in the southeastern Jemez Mountains, has bedding in the lower, coarser half that is laminated to very thin, horizontal-planar to cross-laminated, with bedding less cross-stratified and more massive in the upper half. The lower half contains two light-gray to white chert beds, each ≈1.5 m thick. Pebbles are very fine to medium, subrounded, and composed of rhyolite (including silicified rhyolite) with 1–30% andesite-dacite clasts. Sand is tan to pink, subrounded to rounded, and composed of quartz, minor feldspar, 1–5% volcanic grains, and 1–5% mafic grains. Minor coarse ash-lapilli beds exist in the upper 10 m. The unit is generally poorly cemented. The unit has a maximum age of 13.2 Ma for Vallito Member (Koning and Aby, 2005) and 12.3 Ma for Hernandez Member (Koning et al., 2016), and a minimum age of 7 Ma. Collective thickness of the unit is 900–1000 m.

Ntacu Cuartales Member, undivided, Chamita and Tesuque Formations (Middle to Late Miocene)—This unit has a coarse facies and a fine-grained facies. The coarse facies is reddish-yellow to pink, arkosic, sandy pebble-conglomerate and pebbly-sandstone channel-fill complexes that locally fine upwards to sand-dominated sediment (Koning and Read, 2010). Fine deposits are subordinate. The coarse facies was derived from the Sangre de Cristo Mountains and deposited on a west-sloping piedmont. This facies interfingers westward with the fine facies, and overlies either the fine facies or **Nta**. The gravel consists of pebbles and cobbles that are subangular to angular, composed predominantly of granite and granite-derived quartz and feldspar. Channel-fill sand is mostly medium- to very coarse-grained and subangular and variably cemented by calcium carbonate. The age range is 13.2–8 Ma (Koning et al., 2005; Koning and Aby, 2005; Koning et al., 2013). The coarse facies is up to 350 m thick. The fine facies is pink to light-brown to reddish-yellow to light-yellowish-brown, arkosic, silty-clayey very fine- to medium-grained sandstone that was deposited outside of confined channels and in very thin to thick, tabular beds (Koning and Read, 2010). Subordinate (3–30%) coarse channel-fills are composed of pebbly sandstone and sandy-pebble-conglomerate. These are commonly lenticular to ribbon-shaped, but locally composed of thick, multistory complexes that were derived from the Sangre de Cristo Mountains and deposited on the distal part of a west-sloping piedmont. This unit interfingers eastward with the coarse facies and westward with **Nch**. Pebbles are subangular to subrounded, and predominantly composed of granite with trace to 1% Paleozoic siltstone and limestone, quartzite, and gneiss. Channel-fill sand is fine- to very coarse-grained, and subangular to subrounded. Isolated channels tend to be strongly to moderately cemented, whereas laterally extensive and thick channel complexes are generally not as cemented. The age range is 13.2–8 Ma (Koning et al., 2005; Koning and Aby, 2005; Koning et al., 2013). The fine facies is 350–400 m thick.

Ntbce Cejita Member, Tesuque Formation (Middle to Late Miocene)—Tan, cross-stratified, multistory channel-fill complexes composed of sandstone and gravelly sandstone with minor floodplain deposits of silt and silty-clayey very fine- to fine-grained sand. The unit was deposited on a basin-floor by a river flowing south-southwest, sourced in the Sangre de Cristo Mountains east of the Peñasco embayment (northeast of the city of Española). This member interfingers westward with unit **Nch,** and eastward with the fine-grained facies of **Ntacu**. This unit is conformably overlain by the fine-grained facies of **Ntacu**, underlain by unit **Ntb**, and subsumed into unit **Nch** in bluffs west of NM-30. Gravel consists of pebbles to cobbles with compositions that are dominated by Paleozoic sandstone, limestone, and siltstone, with minor quartzite (5–8%) and granite (10–50%). The latter clast types increase in abundance to the east. Variable (10–90%) felsic to intermediate composition volcanic rocks increase in abundance to the west. Local cementation by calcium carbonate was observed. The age range is 13.2–10(?) Ma. In the eastern Buckman well field, the thickness is 125–135 m (Koning et al., 2007b).

Nto Ojo Caliente Sandstone, Tesuque Formation (Middle to Late Miocene)—Tan to white to light-gray, fine- to medium-grained sandstone that is cross-laminated to horizontal-planar laminated (Koning, 2002). The sandstone intertongues southward with lower Chamita Formation (**Nch,** Vallito Member) and is conformably overlain by the Vallito Member. Sand is mostly subrounded, moderately to well sorted, and subarkosic (quartz with minor potassium feldspar and ≈10–15% volcanic and mafic grains). Locally, sand is intercalated with minor mudstone beds. The unit was deposited in an eolian dune field between 13.2 and 11 Ma (Galusha and Blick, 1971; May, 1980, 1984; Tedford and Barghoorn, 1993; Aldrich and Dethier, 1991; Koning et al., 2011). This unit has a poorly constrained thickness of 200–300 m.

Ntalc Unnamed alluvium in lower Capulin Canyon, Tesuque Formation (Middle to Late Miocene)—Tan, medium- to coarse-grained sand that is massive to bedded (tabular to cross-stratified) on the east side of St. Peter's dome. Sand is well sorted, subrounded, and composed of quartz, lesser clear feldspar (plagioclase and sanidine), minor (mostly 10-20%) orange-colored grains (e.g., orange-stained quartz, chert, Kspar), and minor volcanic lithics. Locally, there are 1-5% pebbles composed of rhyolites and metarhyolites. Weakly to moderately consolidated, with local strong cementation. This sand was laid down by an alluvial system that was the source of the sand for the Ojo Caliente Member; the NE-prevailing wind blew the sand out of the sandy alluvial plain and transported toward the NW.

Nts **Lithosome S of the Tesuque Formation (Oligocene to Miocene)** —Pink to light-brown to reddish to tan sandstone with subordinate siltstone, mudstone, and 1–15% conglomeratic beds (Koning and Maldonado, 2001; Koning and Read, 2010). Deposited on a large fan associated with a west-flowing ancestral Santa Fe River (Koning et al., 2004). The unit intertongues northward with units **Nta** (to east) and **Ntb** (to west). Laterally extensive, amalgamated channel-fill complexes contain fine- to very coarse-grained sandstone and conglomerate beds that are generally very thin to medium, and horizontal-planar to lenticular; cross-stratification is rare. Finer sediments are in very thin to thick, tabular beds and were mostly deposited outside of confined channels; these strata contain local very thin to medium, lenticular channel fills composed of coarse sandstone and conglomeratic sandstone. The proportion of coarse channel fills versus finer-grained deposits changes down-fan. The former clearly dominates near Agua Fria (the western Santa Fe metropolitan area), but beyond 15 km to the NW, the proportion of the two is approximately subequal. The gravel is comprised of subrounded pebbles with minor cobbles and is composed of 35–65% granite with 3–40% Paleozoic clasts (sandstone, siltstone, limestone), 5–35% quartzite, and 1–8% chert. Sand is subrounded to subangular, arkosic, and contains trace to 7% Paleozoic sedimentary grains and trace to 5% quartzite and chert grains. The channel-fill complexes may be moderately to strongly cemented by calcium carbonate. The age range is 16–13 Ma, based on ages of interfingering strata. The maximum thickness is 2400 m.

Nta **Lithosome A of the Tesuque Formation (Oligocene to Middle Miocene)** — Pink-tan arkosic sand, silty-clayey very fine- to medium-grained sand, and minor siltstone and mudstone, deposited on a west-sloping piedmont in mostly medium to thick, tabular beds (Koning and Maldonado, 2001; Koning and Read, 2010). The very fine- to medium-grained sand and finer strata, primarily deposited outside of confined channels, are intercalated with minor, coarse-grained channel-fills that are ribbon- to lenticular-shaped, and composed of medium- to very coarse-grained sandstone and conglomerate. This unit interfingers westward with lithosome B and southward with lithosome S of the Tesuque Formation; **Nta** grades upward into the Cuarteles Member (**Ntacu**). The gravel is subrounded to angular, and the composition is dominated by granite derived from the Santa Fe Range portion of the Sangre de Cristo Mountains, with minor intraformational clasts of cemented sandstone and sparse (≤5% each) amphibolite and quartzite. The sand lacks lithic grains with an average of 3% lithics, with very few volcanics (Cavazza, 1986). This unit is lithologically similar to the overlying Cuarteles Member of the Tesuque Formation. Coarse channel fills are commonly cemented by calcium carbonate. The age range is 26–13.2 Ma (Izett and Obradovich, 2001; McIntosh and Quade, 1995; Barghoorn, 1981, 1985; Tedford and Barghoorn, 1993; Baldridge et al., 1980). The total thickness is 550–950 m.

Ntb Lithosome B, basin-floor facies, Tesuque Formation (Oligocene to Middle Miocene)—Light-gray to pale-brown to light-brownish-gray fluvial deposits comprised of floodplain deposits (claystone, siltstone, and very fine- to medium-grained sandstone) that are intercalated with a few channel fills of fine- to very coarse-grained sandstone (Koning and Read, 2010). This unit was deposited on a basin floor by a southward flowing river sourced in the Peñasco embayment and San Luis Basin (Cavazza, 1986). The deposit intertongues eastward with **Nta,** and southward with unit **Nta** (to the east) or **Nts** (to the west) and is inferred to interfinger westward with **Ntc** under the Pajarito Plateau. Pebbles are very sparse and include Paleozoic sedimentary clasts (sandstone, siltstone, and limestone) in addition to quartzite and quartz. Channel fill sand is subrounded to subangular, has sparse greenish quartz grains (presumably eroded from Paleozoic strata), and the proportion of lithic grains (mostly sedimentary and volcanic clasts per Cavazza, 1986) is comparable to potassium feldspar grains. This unit is lithologically similar to the overlying Cejita Member of the Tesuque Formation. Sediment is commonly weakly consolidated and erodes to form strike valleys. The age ranges is 26–13.2 Ma (Izett and Obradovich, 2001; McIntosh and Quade, 1995; Barghoorn, 1981, 1985; Tedford and Barghoorn, 1993). The unit is approximately 2000 m in thickness.

Ntm Intercalated Lithosomes A and B of the Tesuque Formation (Middle Miocene).—See descriptions for each unit.

Lower Santa Fe Group, western Jemez Mountains

Nz Zia Formation, undivided (Early Miocene)—White to tan, fine- to medium-grained, moderately sorted sandstone composed of well-rounded to subrounded to angular grains of quartz and minor feldspar and magnetite. This unit is exposed in the southwestern Jemez Mountains. The Zia Formation consists of three members (from oldest to youngest): Piedra Parada Member (dune deposits), Chamisa Mesa Member (fluvial deposit), and Canada Pilares Member (dune deposits; Tedford and Barghoorn, 1999). Lithic grains make up 1–5% of the sandstone, and are commonly coarse-grained sand to granule in size. Lithic fragments include quartzite, porphyritic volcanic rock, white aphyric pumice, and Proterozoic metamorphic rocks. The sandstone is generally weakly cemented, but the unit can be locally well-cemented in the vicinity of faults. Sandstones contain cross-beds as tall as 2–3 m and record eastward transport by eolian processes (Gawne, 1981). Silty sandstones and mudstones represent interdune ponds and streams, which become more abundant upsection. The age range is 19–16 Ma (Connell, 2008). The unit is 300 m thick at the type section (Galusha, 1966) and 485 m thick in the Tamara 1 well, which is immediately south of the map area (Connell et al., 2007).

Nab Abiquiu Formation (Late Oligocene to Early Miocene)—The Abiquiu Formation crops out in two widely separated areas. The first is located in the southwestern Jemez Mountains, where the unit includes discontinuous exposures of the Pedernal chert. Here, the Abiquiu Formation is composed of white to tan, medium-grained, medium-bedded, volcaniclastic sandstone that is alternately well cemented and poorly cemented. The deposit contains white fine-grained ash beds that are <0.3 m thick and sparse thin red mudstone intervals. The Pedernal chert is a white to varicolored chert that occurs as stringers or beds; this replacement deposit is up to 1 m thick. A biotite-rich ash bed from the upper Abiquiu Formation in Cañon de la Cañada yielded a $^{40}Ar/^{39}Ar$ age of 20.74 ± 0.07 Ma (Kelley et al., 2013b). The maximum thickness of the Abiquiu Formation in the southwestern Jemez Mountains is 40 m. The Abiquiu Formation also forms prominent cliffs immediately north of the Santa Fe River in the La Bajada escarpment. White to gray, very fine- to medium-grained, arkosic sandstone and primary ash-fall beds 20–50 cm thick are exposed in the cliffs. Local, thin limestone beds are interbedded with gray, green, and red siltstone and claystone on the south side of the river; these fine-grained deposits were interpreted to be lacustrine by Stearns (1953a). The Abiquiu Formation is 25–19 Ma (Connell et al., 2007; Kelley et al. 2013b; Koning et al. 2013). The total exposed thickness along the Santa Fe River is 300 m.

Nr Ritito Conglomerate (Late Oligocene)—Weakly-indurated arkosic fluvial conglomeratic sandstone with abundant pebble-sized Proterozoic granite, quartzite, and schist clasts, and few Pennsylvanian limestone and Permian sandstone clasts, exposed in the northwestern margin of the Valles Caldera. The age of this unit is ≈27–25 Ma (Kelley et al., 2013b). The maximum exposed thickness 10 m.

Ngc Gilman Conglomerate (Late Oligocene)—Consists of debris-flow deposits that are greenish-gray, matrix-supported, pebble- to cobble-conglomerate with cobbles of volcanic rocks, granites, quartz, and sedimentary rocks exposed near the Pueblo of Jemez. Proterozoic clasts are concentrated at the base and at the top of the unit. Most of the clasts are intermediate composition volcanic rocks from an uncertain source, containing phenocrysts of plagioclase and pyroxene, and are <15 cm in diameter. A few clasts have hornblende and rare clasts contain quartz as phenocrysts. Paleocurrent data and a decrease in thickness toward the north suggest a proximal source to the south (Kelley et al., 2013b). Clast ages are 29.63 ± 0.09 Ma and 28.92 ± 0.08 Ma (Kelley et al., 2013b). The thickness is 1–60 m.

Neogene to Paleogene

Volcanic Rocks, La Bajada escarpment

Ncb Cieneguilla Basanite (Late Oligocene)—Medium- to dark-gray to grayish black, porphyritic, mafic volcanic rocks that include basanite, nephelinite, and basalt that typically have moderate to abundant amounts of olivine (10–15%), and lesser clinopyroxene (5%) phenocrysts; sparse, small plagioclase phenocrysts occur in the basalt. The volcanic rocks are exposed along the Santa Fe River in the La Bajada escarpment. Basanite lava flows locally contain small (as large as 10 cm) ultramafic inclusions of harzburgite and minor granulite, and megacrysts of titaniferous magnetite, and both green and black clinopyroxenes. We follow Koning and Hallett (2000) and Sawyer et al. (2002) in redefining the Cieneguilla limburgite of Stearns (1953a, 1953b) as the Cieneguilla Basanite. This unit also includes north- to northeast-striking dikes and thin, irregular sills that crosscut older rocks on the west side of the La Bajada escarpment and in Santa Fe Canyon (Sawyer et al., 2002). Near La Cienega, the $^{40}Ar/^{39}Ar$ ages of the Cieneguilla basanite are 26.25 ± 0.62 Ma to 25.57 ± 0.32 Ma (Connell et al., 2002; Peters, 2000b; Koning and Hallett, 2000).

Nbd Basaltic dikes (Oligocene)—Local dikes, sills and plugs in the La Bajada escarpment that may be related to the Cieneguilla Basanite.

NPEim Monzonite and monzonite porphyry intrusions (Late Eocene to Oligocene)— Pinkish-brown to medium-gray intrusions and dikes of monzonite porphyry and monzonite exposed at Cerro Bonanza, Cerro Seguro, Las Tetillitas in the Cerillos Hills, and along the Cañada de Santa Fe. The Cerro Seguro and Cerro Bonanza intrusions are augite-biotite monzonite

(Stearns, 1953a; Sun and Baldwin, 1958). Phenocrysts are plagioclase and augite (8%) in a fine-grained groundmass of orthoclase, plagioclase, biotite, and magnetite. The augite-biotite monzonite in Cerro Bonanza and Los Cerrillos, and the augite-biotite monzonite porphyry of Cerro Seguro, differ primarily in texture. Turquoise Hill is composed of 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). The augite monzonite porphyry intrusion at Cerro Seguro has a biotite $^{40}Ar/^{39}Ar$ age of 29.59 ± 0.05 Ma (Sauer, 1999). The $^{40}Ar/^{39}Ar$ and K/Ar dating indicate a 34–28 Ma age range for these intrusions (Maynard, 2005).

NPEe Espinaso Formation (Late Eocene to Late Oligocene)—Gray, volcaniclastic alluvial fan deposits of sandstone and conglomerate shed from former volcanic centers near the Cerrillos Hills. The proximal alluvial fan deposits are interbedded with near-vent volcaniclastic breccias and minor dacitic to andesitic flows (Kautz et al., 1981; Smith and Lowe, 1991; Thompson et al., 2006). The Espinaso Formation in the La Cienega area was subdivided into three units—a lower andesite unit and two compositionally distinct trachydacitic units exposed northeast of La Cienega (Sun and Baldwin, 1958). The andesite unit is gray to red-brown and includes some fragmental lava clasts consisting of porphyritic hornblende-plagioclase andesite. The andesite typically has conspicuous hornblende phenocrysts, and the dominant lithology consists of fragmental breccias (locally welded) and proximal volcaniclastic deposits. The andesite was deposited prior to the intrusion of the Cerro Seguro augite monzonite. Both trachydacite compositions (the "calcic latite" and "glassy latite" of Sun and Baldwin, 1958) are brownish-gray fragmental trachydacite breccias with little intact lava-flow morphology preserved. 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. The unit is 307 m thick at the Yates La Mesa No. 2 well (Myer and Smith, 2006).

Paleogene
Sedimentary Rocks

PEg Galisteo Formation (Eocene)—Red to brownish-yellow sandstone, red mudstone, and conglomerate exposed in the La Bajada escarpment in the vicinity of Cienega Creek, on the east side of St. Peters Dome, and just southwest of Chamisa Mesa. Sandstones are well- to moderately-sorted, and are fine- to coarse-grained. Conglomerate clasts include white, gray, and black chert pebbles, gray limestone cobbles and pebbles, red granite, schist, and rare petrified wood (Lucas et al., 1997). The Galisteo Formation contains Wasatchian (55.5-50 Ma) to Duchesnean (40-37 Ma) fossils (Lucas and Kues, 1979; Lucas, 1982) and the Duchesnean section appears to correlate with Chrons C17r1 to C17r (38.5–37.5 Ma; Prothero and Lucas, 1996). The Galisteo Formation along Cienega Creek is 400 m thick (Sun and Baldwin, 1958) and is 630 m thick on St. Peters Dome (Cather, 1992).

PEn Nacimiento Formation (Paleocene)—Interbedded shale and sandstone with minor coal, with varying proportions of sandstone and shale that consist of light-brown, yellowish-gray, or white sandstone, and gray to olive-gray shale, in the east-central San Juan Basin (Fassett, 1966, Baltz, 1967, and Scott et al., 1980). The lower part is mainly shale, often carbonaceous, but includes minor siltstone, marl, and bentonites that were deposited in lacustrine and marshy environments. Near the base, the lower shale is interbedded with the upper Ojo Alamo Sandstone. The upper part of the deposit is mainly soft, poorly consolidated variegated maroon, gray, and olive-green clay and siltstone, and yellow, white, and brown trough-cross bedded fluvial sandstone. Beds are often discontinuously color-banded. Locally the unit has beds containing terrestrial faunas of early Paleocene age (Williamson and Lucas, 1993) and is ca. 65–58 Ma, based on magnetostratigraphy (Williamson et al., 2008). A $^{40}Ar/^{39}Ar$ sanidine date of 65.49 ± 0.01 Ma has been determined for an ash within the basal Nacimiento (10.5 m above the Ojo Alamo Sandstone; Cather et al., 2019). The Nacimiento Formation ranges from about 167 to 305 m thick in the east-central San Juan Basin (Baltz, 1967; Fassett, 1966).

PEoa Ojo Alamo Sandstone (Early Paleocene)—Massive beds of light- to rusty-brown, fine- to coarse-grained, cross-bedded sandstone that contain scattered silicified wood and conglomerate. The sandstone beds are separated by light- to dark-gray or greenish-gray shale. Sandstone beds are discontinuous sheets, and merge with adjoining sandstone bodies, or grade into shale. Large-scale channels are common at the base of the Ojo Alamo, and extend as much as 15 m in the underlying Kirtland and Fruitland Formations. These lower fluvial sandstones are quartzose, locally pebbly conglomerate, with clasts of quartzite and chert (Fassett, 1966; Baltz, 1967; Scott et al., 1980, 1984). The Ojo Alamo Sandstone was deposited at ca. 65 Ma, based on magnetostratigraphy

(Williamson et al., 2008). The thickness in the region ranges from 24 to 64 m, but typically is 25–30 m (Fassett, 1966; Baltz, 1967; Scott et al., 1980, 1984).

MESOZOIC SEDIMENTARY ROCKS

Late Cretaceous

Kkf Kirtland/Fruitland Formation (Late Cretaceous)—Interbedded sandstone, siltstone, and mudstone, containing only minor coal in the eastern San Juan Basin. Sandstone and siltstone in the Kirtland Formation are mainly white to brown, and the sandstone is coarse grained. Mudstone beds in the Kirtland Formation are light olive-gray to greenish gray, and are locally carbonaceous. The fluvial Kirtland Formation is Late Campanian to Early Maastrichtian (73.5–71.5 Ma; Pecha et al., 2018). The lower coal-bearing Fruitland Formation includes lenses of sandstone, siltstone, mudstone, carbonaceous shale, and coal deposited on a coastal alluvial plain environment during the Late Campanian (75.5–73.5 Ma; Pecha et al., 2018; Molenaar et al., 2002; Hunt and Lucas, 1992). Siltstone and mudstone in the Fruitland Formation are yellow to brown and the medium-grained sandstones are white to yellow gray. Total unit thickness ranges from 50 to 80 m thick (Fassett, 1966; Scott et al., 1984; Baltz, 1967; Hunt and Lucas, 1992; Cather, 2004).

Kpc Pictured Cliffs Sandstone (Late Cretaceous)—Light-gray to yellowish-gray to dark-brown marine sandstone; the basal part is interbedded with gray shale. Sandstone is thick-bedded to cross-bedded, very fine- to fine-grained, and is composed of well-sorted quartzose to lithic-rich sand that locally forms low bluffs. The Pictured Cliffs Sandstone represents the final regressive marine shoreface sand deposited as the Western Interior Seaway shoreline that migrated northeast out of the San Juan Basin area of northwestern New Mexico. The sandstone contains Late Campanian (76.5–73.5 Ma; Pecha et al., 2018) marine invertebrate fossils and abundant *Ophiomorpha* trace fossils (Molenaar et al., 2002). The Pictured Cliffs Sandstone grades at the base into the Lewis Shale, and varies in thickness from less than 8 m up to 43 m, but is typically about 12–15 m thick. (Fassett, 1966; Baltz, 1967; Scott et al., 1980).

Kl Lewis Shale (Late Cretaceous)—Olive-gray to dark-gray calcareous to sandy marine shale and thin interbeds of yellowish-gray light-brown sandstone. Beaumont and Hoffman (1992) correlated two distinct sandstone beds in the middle of the Lewis Shale to the Chacra Mesa tongue of the Cliff House sandstone. The unit is more sandy and calcareous near the top, dominantly claystone and siltstone in the middle, and sandy shale in the lower part that interfingers with the

La Ventana Sandstone Tongue of the Cliff House Sandstone. This unit was deposited between Early and Late Campanian time (79.5–76.5 Ma; Pecha et al., 2018; Molenaar et al., 2002). The thickness between the basal Lewis Shale tongue intercalated with the Cliff House Sandstone to the base of the Pictured Cliffs Sandstone is about 400 m.

Kch Cliff House Sandstone (Late Cretaceous)—White, tan, or buff to dark-yellowish-orange, thin- to thick-bedded, typically very fine-grained, but locally coarse-grained, lenticular and cross-bedded or massive, cliff-forming, calcareous well-cemented quartzose sandstone, interbedded with shale. Locally, the unit contains lenses of gray or brown carbonaceous shale. The sandstone contains middle Campanian (80.5–79.5 Ma; Pecha et al., 2018) marine fossil invertebrates and casts of *Ophiomorpha* trace fossils (Molenaar et al., 2002), and was mainly deposited as shoreface sand in a nearshore marine environment (Palmer and Scott, 1984). The thickness varies from south to north as this unit interfingers over an extended interval with the Lewis Shale (Beaumont and Hoffman, 1992), ranging from as little as 9–53 m to as much as 200–210 m.

Kmf Menefee Formation (Late Cretaceous)—Heterogeneous sequence of grayish-yellow to brown or white, fine- to medium-grained, thick, lenticular, cross-bedded sandstone interbedded with dusky-yellow to olive-gray siltstone, sandy shale, and mudstone. This unit contains lenticular beds of greenish-gray claystone, gray shale and siltstone, black carbonaceous shale, and thin beds of shaley coal (O'Sullivan et al., 1979). Coal beds occur in the upper and lower parts of the formation, and the coal is commonly burned at the outcrop. The Menefee Formation was deposited between Santonian and middle Campanian time (84–80 Ma; Molenaar et al., 2002). The lower coal-bearing unit is the Cleary Coal Member, and is typically 35–60 m thick. The barren Allison Member that consists of fluvial sandstone, siltstone, mudstone, carbonaceous shale and only thin lenticular coals overlies the coal interval. The Allison Member is commonly 150–180 m thick. The overlying informal upper coal member ranges from thin (15–45 m) to moderately thick (up to 140 m thick; Beaumont and Hoffman, 1992).

Kpl Point Lookout Sandstone (Late Cretaceous)—Gray to yellowish-gray and grayish-orange-pink, fine- to very fine-grained, well-sorted angular to subangular, calcareous well-cemented quartzose sandstone. Sandstone beds in the upper part are consistently fine- to very fine-grained, well sorted and thin- to medium-bedded. Some beds are highly bioturbated, others display wedge-planar, tabular-planar, or low-angle trough cross-bedding. Vertical to inclined feeding burrows of the trace fossil *Ophiomorpha* are common. Lower part includes gray carbonaceous siltstone, claystone, and shale interbedded with fine- to medium-grained, poorly sorted sandstone. The Santonian to middle Campanian (85–84 Ma; Molenaar et al., 2002) Point Lookout Sandstone was deposited as regressive coastal linear strandline and barrier island shoreface sand bodies (Wright-Dunbar, 1992; Robertson, 1990). The Point Lookout Sandstone ranges in thickness from 9–67 m.

Mancos Shale (Late Cretaceous)

The Mancos Shale in the southeastern San Juan Basin has been divided into six members, from youngest to oldest: Niobrara, Gallup Sandstone, an unnamed member, Juana Lopez, Bridge Creek Limestone, and Graneros. Overall, the Mancos Shale consists of thick deposits of shale, calcareous shale, sandy shale, and minor limestone and bentonite beds, deposited in marine conditions. We use the terminology of Molenaar et al. (2002), although we apply the name "Montezuma Valley Member" based on a proposed principal reference section for the Mancos Shale located north of Mesa Verde National Park in Colorado (Leckie et al., 1997) to the unnamed shale member just above the Juana Lopez Member. These members of the Mancos Shale correlate with formal stratigraphic units for the Cretaceous Western Interior Seaway deposits of Colorado and western Kansas (that is, Bridge Creek Limestone Member rather than Greenhorn Limestone Member of the Mancos Shale).

Kmn Niobrara Member (Late Cretaceous)—Consists of dark-gray shale, calcareous shale, and mudstones, intercalated with thin sands belonging to the El Vado Sandstone Member near the base (Fassett, 1974). This unit lies above a regional-scale unconformity on the Gallup Sandstone and Montezuma Valley Member in the southeastern San Juan Basin, and on the Juana Lopez Member in the La Bajada escarpment. The basal part of the Niobrara Member in the eastern San Juan Basin is yellow-brown to gray, thin-bedded sandy marine shale with large brown calcareous concretions that includes gray, coarse-grained sandstone beds that are 5–10 m thick. Along the La Bajada escarpment, the upper part of the exposed section consists of yellowish-brown to olive-gray silty or sandy shale with interbedded sandstone beds, containing yellowish-brown ovoid calcareous concretions as large as 0.6–0.9 m in diameter. This sandy interval grades downward into lower Niobrara equivalents. These sandstone beds in the upper Niobrara may be correlative with the Hosta Tongue of the Point Lookout Formation in the Hagan Basin (Black, 1979). The lower part of the Niobrara-equivalent Mancos Shale in the La Bajada area is a medium- to light-olive-gray chalky/limy calcareous shale and mudstone, with scattered marlstone beds. This unit is Coniacian to Santonian in age (≈87–85 Ma; Molenaar et al., 2002). There is 370 m of the unit exposed along the Cañada de Santa Fe and about 400 m is encountered in the subsurface of the eastern San Juan Basin (Fassett, 1974).

Kg Gallup Sandstone (Late Cretaceous)—Upper shoreface deposits are yellowish-gray and very pale-gray to white, very fine-grained to fine-grained, well-sorted sandstone deposited in a zone of wave action below mean low tide level, characterized by wedge-planar, tabular-planar, and low-angle trough cross bedding interspersed with horizontally bedded strata. Some strata are bioturbated, with *Ophiomorpha* burrows and flat *Thalassinoides* burrows are common. The deposits in the lower shoreface facies are pinkish-gray to yellowish-gray, generally very fine-grained to fine-grained, well-sorted sandstone. Bedding is thin and flat, commonly laminated, and faintly defined to massive. Upper Turonian to lower Coniacian in age (≈90–89 Ma). Thickness is 5–15 m (Robertson, 1990; Molenaar et al., 1996).

Kmz Montezuma Valley Member of the Mancos Shale (Late Cretaceous)—The Montezuma Valley is a variably thick, non-calcareous dark-gray shale equivalent to the uppermost unit of the Carlile Shale. Upper Turonian in age (≈91 Ma; Molenaar et al., 2002). This unit ranges in thickness from 45–105 m, depending on whether the Gallup Sandstone is present.

Kmj Juana Lopez, Carlile Shale, and Semilla Sandstone members of the Mancos Shale, undivided (Late Cretaceous)—This combined unit includes the Juana Lopez Member, the underlying calcareous shale and clay shale members of the lower Carlile Shale (Blue Hill and Fairport members), and the Semilla Sandstone Member. The Juana Lopez Member consists of an orangish-brown-weathering calcarenite made up of calcareous fossil material. Identified species include the ammonite *Scaphites whitfieldi*, the oyster *Nicaisolopha lugubris*, and the bivalve *Inoceramus perplexus* (Dane et al., 1966). The Blue Hill and Fairport members are composed of noncalcareous olive-gray to dark-gray shale and silty shale that is underlain by medium-gray calcareous shale. The Semilla Sandstone is massive, medium-grained, dark-yellow-brown calcareous sandstone underlain by poorly bedded, very-fine-grained sandstone interbedded with siltstone (Dane et al., 1968). The combined interval is middle to upper Turonian in age (≈93–92 Ma; Molenaar et al., 2002). This combined map unit is 110 m thick in the La Bajada escarpment and is about 100 m thick in the eastern San Juan Basin (Woodward, 1987). The Semilla Sandstone is up to 21 m at its type section in the eastern San Juan Basin, but is only 0.6 m thick in the La Bajada escarpment.

Kmgr Bridge Creek Limestone and Graneros Members, undivided (Late Cretaceous)—This combined unit is exposed in the eastern San Juan Basin and along the La Bajada escarpment. The unit includes calcareous shales below the base of the Semilla Sandstone, thin, medium-gray limestone (Bridge Creek Limestone; also called Greenhorn Limestone), and light- to dark-olive gray calcareous shale (Graneros Member) with thin bentonite beds. The Graneros Shale is Cenomanian (≈95 Ma) and the Bridge Creek is Early Turonian (≈94 Ma; Molenaar et al., 2002). Along the La Bajada escarpment, the Bridge Creek limestone beds are about 11 m thick. The total combined unit thickness is about 50 m in the La Bajada escarpment (Bachman, 1975) and about 200 m in the eastern San Juan Basin.

Kd Dakota Formation (Late Cretaceous)—Yellow-brown to yellowish-gray, fine- to medium-grained quartz sandstone with feldspar, intercalated with gray to black marine tongues of Mancos Shale in the eastern San Juan Basin and in the La Bajada escarpment. The lowest discontinuous sandstone is coarse-grained to conglomeratic, and cross-bedded with fossil plant material and thin coal beds deposited in a fluvial setting (Encinal Canyon Member). Stratigraphically higher sandstones (Cubero and Paguate members) are commonly bioturbated fine-grained marine sandstones with local cross bedding. The Dakota Formation is Cenomanian in age (≈97 Ma; Molenaar et al., 2002), and is about 10–80 m thick. The unit thins to the north in the eastern San Juan Basin.

KJj Jackpile Sandstone (Late Jurassic to Early Cretaceous)—White to pale-orange, kaolinitic, predominantly fine- to medium-grained, massive to cross-bedded fluvial sandstone (Owen et al., 1984; Aubrey, 1992) exposed west of the village of San Ysidro. Generally, moderately to poorly sorted subarkosic sandstone with matrix clay with iron-rich staining and concretions common. Sandstone predominates, but discontinuous, thin, pale-olive to red-brown, clay-rich mudstone interbeds are locally present. The maximum depositional ages, based on U/Pb zircon dating for the youngest stratigraphic horizons within the unit, indicate a latest Jurassic–Early Cretaceous age for the Jackpile Sandstone (143–147 Ma; Ridl et al., 2022). Unit thickness is about 70 m.

Jurassic

Morrison Formation (Late Jurassic)—Sandstones and mudstones deposited in a north-flowing fluvial system that are exposed in the La Bajada escarpment, and in the eastern San Juan Basin.

The Morrison Formation was deposited during Kimmeridgian–Tithonian time (Anderson and Lucas, 1996, 1997).

Jmb Brushy Basin Member (Late Jurassic)—Variegated mudstone, silty mudstone, and minor sandstone that form strike valleys and slopes. Characteristic greenish-gray, pale-olive, grayish-brown, and pale-brown variegated thick and laterally continuous clay-rich beds with minor interbedded sand lenses. Subarkosic sand beds are yellowish-gray and 25–80 cm thick. The proportion of sand to mud beds increases upward; thicker, more continuous sand beds in the upper part of the Brushy Basin Member form small hogbacks. Age is Late Kimmeridgian to Tithonian (≈152 Ma). The unit thickness is about 120 m.

Jmw Westwater Canyon Member (Late Jurassic)—Thick-bedded to massive grayish-yellow fluvial sandstone and subordinate interbedded pale-brown to pale-olive mudstone. Sandstones are trough cross-bedded to massive, subarkosic, and vary from fine- to medium-grained, moderately sorted sandstone, to coarse-grained, poorly sorted sandstone in the upper part. The unit has a gradational contact with mudstones of the overlying Brushy Basin Member. The age of the unit is Kimmeridgian (≈155 Ma), and the sandstone is approximately 65 m thick.

Jb Beclabito Formation (Late Jurassic)—Heterogeneous set of beds that has a medial red to red-brown and grayish-red sequence of gypsiferous siltstones and sandstones, which conformably overlies the gypsum member of the Todilto Formation. This unit is exposed in the San Juan Basin in the southwest corner of the map and in the La Bajada escarpment. In the San Juan Basin, this unit is composed of thin beds of variegated maroon and gray sandstone interbedded with gypsiferous siltstone, sandy siltstone, or mudstone (Anderson and Lucas, 1992). The sandstone channels are lenticular and are less than 15 m thick. A grayish pink carbonate bed interpreted to be a pedogenic carbonate occurs at the top of the formation (Anderson and Lucas, 1996). Stearns (1953a) described this sequence of beds in the La Bajada escarpment as “100–150 feet of maroon shale.” Lucas et al. (1995) and Lucas and Anderson (1997) have assigned this sequence of beds to the Beclabito Member of the Summerville Formation for the adjoining Hagan Basin and west to the Four Corners. Cather (2021) recommends the use of the term Beclabito Formation. This unit is Oxfordian (≈160 Ma) in age (Lucas, 2004). This unit is 30 m thick in the La Bajada escarpment, and up to 134 m thick in the eastern San Juan Basin (Woodward, 1987).

Jte Todilto Formation and Entrada Sandstone, undivided (Middle Jurassic)—The Todilto Formation is a gray to white, ledge-forming unit consisting of a lower thin limestone member

(Luciano Mesa) and an upper thick (often discontinuous) gypsum member (Tonque Arroyo; Kirkland et al., 1995; Lucas and Anderson, 1997). The lower limestone member is medium-gray to brown to yellow, thinly laminated to massive, fetid, and is about 5 m thick. The gypsum member is white and massive, and pervasively brecciated when exposed at the surface. The contact between the Entrada and the Todilto is conformable. Based on fish fossils (Lucas and Anderson, 1997; Cather, 2021), the unit is Callovian (≈164 Ma). The original thickness is difficult to estimate due to surface weathering and dissolution; exposed thickness is about 30 m. The underlying Entrada Sandstone is a reddish-brown to white to yellowish-gray, medium- to fine-grained, well-sorted and rounded quartzose sandstone. The Entrada Sandstone is exposed in the southwestern Jemez Mountains and in the San Juan Basin. The Entrada Sandstone commonly has a reddish-brown lower section and a predominantly yellowish-gray upper section. The Entrada Sandstone is a resistant ledge former, massive to planar bedded, and displays meter-scale cross-bedding. The Entrada is Callovian (≈166 Ma) in age. In the eastern San Juan Basin, the Entrada Sandstone is 90 m thick in the north, and is 30 m thick toward the south.

Triassic

TRc Upper Chinle Group, undivided (Late Triassic)—The upper Chinle Group includes the Salitral, Poleo, and Petrified Forest formations consisting of primarily brick-red to maroon, poorly exposed mudstone and thin sandstone beds. The Petrified Forest Formation of the Chinle Group is red mudstone with minor thin, tan thin-bedded, ripple-laminated to cross-laminated micaceous sandstones. This unit is exposed in the La Bajada escarpment, in the southwestern Jemez Mountains, and in the eastern San Juan Basin. Thin (<5 m) beds of black conglomerate with well-rounded chert and quartz pebbles, or brown to tan sandstone belonging to the Poleo Formation are exposed south of the East Fork of the Jemez River, east of the village of Ponderosa in the southeastern Jemez Mountains, and in the eastern San Juan Basin. The Salitral Formation is maroon mudstone that locally contains thin-bedded, ripple-laminated micaceous sandstone at the base that can be found on the Pueblo of Jemez and in the eastern San Juan Basin. The upper Chinle Group is Late Carnian to Norian in age (≈205 Ma; Lucas, 2004). The maximum thickness of this unit is 650 m (Woodward, 1987).

TRaz Agua Zarca Member, Chinle Formation (Late Triassic)—White to yellowish-brown, medium- to coarse-grained quartzose sandstone and conglomerate that is exposed in the southwestern Jemez Mountains and in the eastern San Juan Basin. The sandstones and conglomerates are usually cross stratified, often in trough geometries, and are usually well cemented with dark-brown ferruginous material, making the unit a consistent ridge former. The coarse conglomerate beds, up to several feet thick, contain siliceous pebbles and cobbles up to 15 cm are common near the base. Clasts are predominantly white, gray, or red quartzite, chert, sedimentary rip-up clasts, and petrified wood. This unit was deposited at ≈225 Ma, with a maximum thickness of 64 m.

TRm Moenkopi Formation (Late Triassic)—Brown to reddish-brown, micaceous shale, silty shale, and cross-bedded arkosic sandstone. The unit is shale-rich at the base and sandy at the top. The Moenkopi Formation on the Pueblo of Jemez is unique in that it contains an approximately 1-m-thick layer of fossiliferous sandy limestone with poorly preserved pelecypod fossils concentrated near the base of the limestone. Both the basal and the top contacts of the Moenkopi Formation are sharp. The Moenkopi Formation is Early Anisian (≈245 Ma; Perovkan) in age (Lucas, 2004). The unit is up to 24 m thick.

PALEOZOIC SEDIMENTARY ROCKS

Permian

Pg Glorieta Sandstone (Middle Permian)—White to gray to red, fine- to medium-grained, medium-bedded, usually well sorted, quartz arenite preserved in the southwestern Jemez Mountains and along the southern margin of the Sierra Nacimiento. Bedding varies from massive to planar to cross stratified. Some red, feldspathic sandstone and subordinate shale occurs in this unit. The Glorieta Sandstone is Leonardian (≈275 Ma) in age. The unit is approximately 15–30 m thick.

Py Yeso Formation, undivided (Middle Permian)—Red-orange to dark-red, fine- to medium-grained, quartzose sandstone exposed in the southwestern Jemez Mountains and in the Sierra Nacimiento. The Yeso Formation has traditionally been divided into two members in the southwestern Jemez Mountain region: the lower Meseta Blanca Member, and the upper San Ysidro Member (Wood and Northrop, 1946; Stanesco, 1991; Mack and Dinterman, 2002). The Meseta Blanca Member is an eolian sandstone with meter-scale, tabular-planar, wedge-planar, and trough cross-beds that record a paleo-transport direction generally to the south (Stanesco, 1991). This sandstone contains a thin (0.1–0.3 m thick), discontinuous pedogenic carbonate horizon that is present in the cliffs just below the contact with the San Ysidro Member. The San Ysidro

Member of the Yeso Formation is primarily medium-bedded, tabular sandstone that is orange-red near the base and red near the top. A continuous (1–2 m thick) limestone bed is present near the top of the unit. The sandstone under the limestone is altered and bleached due to weathering of the sandstone prior to the deposition of the limestone. The contact between the upper part of the Yeso Formation and the overlying yellow-white Permian Glorieta Sandstone is gradational. This unit is Leonardian (≈280 Ma) in age. The Yeso Formation is 170 m thick in Cañon de San Diego (Stanesco, 1991).

Pa Abo Formation (Early Permian)—Red to dark-red, medium- and thin-bedded arkose or feldspathic, medium- to coarse-grained, fluvial channel sandstone, intraformational conglomerate, and fine-grained overbank mudstone and shale exposed in the western Jemez Mountains and the Sierra Nacimiento. The sandstones are cross-stratified and the finer grained rocks commonly have ripple cross-laminations. Thin pedogenic carbonate beds, mud-chip rip-ups, plant debris, and green reduction spots and layers are common. The basal portion of the Abo Formation is dominated by mudstones. Channel sands become thicker and more abundant in the upper part of the formation (Lucas et al., 2005). Abo Formation sandstone contains pebbles of quartz, quartzite, potassium feldspar, and granite, derived in part from the Peñasco highland to the west and from the Uncompahgre uplift to the north. The contact between the Abo Formation and the overlying Yeso Formation is usually conformable (Woodward, 1987; Stanesco, 1991). The Abo Formation was deposited by a south-flowing river system during the latest Virgilian through Wolfcampian time (≈280–300 Ma). Lucas et al. (2005) measured 150 m of Abo Formation (base not exposed) south of Jemez Springs. The thickness of the Abo Formation varies due to the burial of the Pennsylvanian Ancestral Rocky Mountain Peñasco uplift during the Wolfcampian, and is preserved in the Sierra Nacimiento (Woodward, 1987).

Pennsylvanian

IPm Madera Group (late and Middle Pennsylvanian)—Interbedded gray marine limestone, light-yellowish-gray to dark-gray shale, and occasional white to buff sandstone and arkosic limestone beds. The lower, more limestone-rich part, is equivalent to the Desmoinian Gray Mesa Formation of Kues (2001) and Kues and Giles (2004), and can locally be distinguished in the Sierra Nacimiento and western Jemez Mountains. The upper part of the Madera marine limestone is intercalated with arkosic sandstone, conglomerate, and arkosic limestone. The upper Madera in the Sierra Nacimiento is equivalent to the Atrasado Formation and is Missourian–Virgilian in age

(Kues, 2002; Kues and Giles, 2004). Following Woodward (1987), the top was mapped at the uppermost limestone bed that is ≈1 m thick. The gradational contact between the Madera Group and the overlying Abo Formation is exposed north of Soda Dam near Hummingbird Music Camp on the Jemez Springs quadrangle (Kelley et al., 2007). The thickness of the Madera Group varies from 0 m to 230–240 m due to the rise of the Pennsylvanian Ancestral Rocky Mountain Peñasco uplift that is preserved in the Sierra Nacimiento (Woodward, 1987). Krainer et al. (2005) measured 155 m of the Atrasado Formation (upper Madera) and 20 m of Gray Mesa Formation at Guadalupe Box.

Mississippian and Pennsylvanian

IPMu Pennsylvanian Sandia and Osha Canyon Formations, Mississippian Log Springs Formation and Arroyo Peñasco Group, undivided (Pennsylvanian to Mississippian)—The Sandia Formation is brown to tan to white, fine- to coarse-grained, quartzose sandstone interbedded with brown, green, gray, or yellow shale, and thin-bedded fossiliferous limestone. Minor arkosic sandstones are also present. The contact with the overlying Madera Group was mapped at the abrupt increase in the proportion of limestone beds. The Atokan (≈308 Ma) Sandia Formation is 68 m thick at Guadalupe Box, but thins to the south and is absent towards the north and west (Woodward, 1987). The Osha Canyon Formation is fossiliferous gray to white limestone interbedded with light-gray fossiliferous shale, overlain by gray to tan shale with fewer fossils and nodules of gray limestone (DuChene at al., 1977). The Morrowan Osha Canyon Formation is locally preserved at Los Pinos Canyon and at Guadalupe Box in the Sierra Nacimiento (with a maximum thickness of 21 m) and is absent elsewhere. The late Visean and Namrian (Chesterian; ≈320 Ma) Log Springs Formation rests on a karsted unconformity that developed atop the Arroyo Peñasco Group, and is comprised of red shale overlain by red to orange arkosic to conglomeratic sandstone (Woodward, 1987); this unit is generally less than 24 m thick (Armstrong et al., 2004). The Arroyo Peñasco Group includes the basal Del Padre Sandstone Member composed of white to gray, medium-grained sandstone, and gray calcareous shale overlain by the dolomitic Espiritu Santo Formation, which consists of carbonates intercalated with gray calcareous shale. The Tournaisian (Osagean; ≈345 Ma). The Arroyo Peñasco Group is ≈12 m thick at Soda Dam (Armstrong, 1955; Armstrong and Mamet, 1974). The Sandia and Osha Canyon formations are described above. Generally, this lumped unit is exposed in cliffs or is too thin to differentiate on the map.

PROTEROZOIC

Plutonic and Metamorphic Rocks

Yg Granitic rocks, undivided (Middle Proterozoic)—Pinkish-tan, fine- to medium-grained, equigranular, massive monzogranite, consisting of microcline, oligoclase, quartz, and about 2% muscovite. Muscovite granite underlies Pajarito Peak and has sharp contacts with the adjacent rocks. This unit includes the leucogranite of Woodward (1987), which forms small irregularly shaped intrusions as wide as several hundred meters. In the southern part of the Sierra Nacimiento, mainly in the Gilman (Woodward et al., 1977) and San Ysidro (Woodward and Ruetschilling, 1976) areas, this unit may include dikes and zones of pegmatite and aplite. This unit is undated, although these rocks intrude Middle Proterozoic units and are probably also Middle Proterozoic in age.

Ygj Joaquin Granite (Middle Proterozoic)—Pink, fine- to medium-grained, monzogranite or syenogranite that contains microcline megacrysts in a few areas. Subtle foliation is present locally and is more prevalent in the southern exposures. The predominant lithology is monzogranite, composed of "40–50% microcline-microperthite, 18–21% plagioclase (An_{24}; locally myrmekitic), 24–37% quartz, 2–3% biotite, 1% muscovite," and trace amounts of opaque minerals, apatite, titanite, zircon, and epidote (Woodward, 1987). The intrusive contacts with older rocks are sharp, and locally chilled. Numerous dikes and apophyses of Joaquin Granite extend into adjacent units and the Joaquin Granite contains numerous inclusions and/or roof pendants of gneissic rocks (Woodward, 1987). The Joaquin Granite is named for exposures in Joaquin Canyon, and is a widespread unit in the southern Sierra Nacimiento. A U/Pb zircon age for the Joaquin Granite is 1424 ± 9 Ma (Premo and Kellogg, 2005).

Yggb Granite of Guadalupe Box (Middle Proterozoic)—Pinkish-gray to brick-red, coarse-grained, massive to strongly foliated, equigranular to porphyritic monzogranite, locally containing microcline phenocrysts as long as 2.0 cm. Average composition is "33% plagioclase (An_{27}; locally myrmekitic), 24% microcline, 23% quartz, 4% hornblende, 4% biotite", and minor amounts of sphene, opaque minerals, zircon, and apatite (Woodward, 1987). The foliation is due both to flow during emplacement and to post-emplacement shearing. The U/Pb zircon age is 1449 ± 10 Ma (Premo and Kellogg, 2005)

Ygd Granodiorite (Middle Proterozoic)—Dark-gray, massive to weakly foliated, medium- to coarse-grained rocks containing "about 50% plagioclase ($An_{27\text{-}33}$), 20 % quartz, 12% hornblende, 12% biotite, 5 percent microcline" and minor amounts of opaque minerals, sphene, zircon, and apatite (Woodward, 1987). Locally the rocks contain microcline megacrysts as long as 5 cm. Foliation, defined by elongate clusters of mafic minerals, trends approximately 20º. The granodiorite is clearly intruded by the granite of Guadalupe Box. Most exposures are strongly weathered and grusy. This intrusive rock is exposed in the southwest part of the Sierra Nacimiento (Woodward et al., 1977). The U/Pb zircon age is 1453 ± 9 Ma (Premo and Kellogg, 2005).

Xg Granite (Early Proterozoic)—Pink to gray, coarse- to medium-grained, massive to weakly foliated, porphyritic monzogranite composed of blue-gray (locally opalescent) quartz, pink microcline, greenish-gray sodic plagioclase, and minor biotite. Euhedral to anhedral pink microcline megacrysts are up to 1.5 cm long and locally display a rapakivi texture. Monzogranite in the northeast part of the San Pablo quadrangle (Woodward et al., 1973) is equigranular, lacking megacrysts. Short, discontinuous, east-northeast-trending, presumed Proterozoic mylonitic zones, including the Nacimiento Creek shear zone of Kellogg and Premo (2005), cut the granite. The U/Pb zircon ages reported for the granite are 1730 ± 20 Ma (Woodward, 1987; oral communication from L.T. Silver, 1972) and 1696 ± 10 Ma (Premo and Kellogg, 2005).

Xgn San Miguel gneiss (Early Proterozoic)—Pink to gray, fine- to coarse-grained, weakly to strongly foliated, gneissic monzogranite or granodiorite composed of "16–32% microcline, 29–36% plagioclase ($An_{27\text{–}33}$; locally myrmekitic), 25–30% undulatory quartz, 2–9% dark-brown biotite, and minor amounts of opaque minerals, muscovite, zircon, apatite, and sphene" (Woodward, 1987). Foliation is defined by a northeast-trending alignment of biotite lenses, elongate quartz lenses, and aligned feldspar megacrysts. The San Miguel gneiss is widely exposed in the Sierra Nacimiento and is named for outcrops on San Miguel Mountain. The U/Pb zircon age on a gneiss sample correlated with the San Miguel Gneiss is 1695 ± 14 Ma (Premo and Kellogg, 2005).

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