Geologic Map of the Cañones Quadrangle, Rio Arriba County, New Mexico

By

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May, 2005

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 107

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 06HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.

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Abstract

The Cañones quadrangle lies at the boundary between the Rio Grande rift and the Colorado Plateau, and includes the Cañones fault zone, an important down-to-the-east structure (among many) that marks the transition between these two provinces. This transition zone between provinces extends to the west into the Youngsville and Coyote area (Lawrence, 1979: Kelley et al., 2005). The northern part of the Miocene to Pleistocene Jemez volcanic field covers about 35 percent of the southern and eastern portions of the area. A wonderfully complex history of late Paleozoic to Mesozoic deposition, Laramide-age deformation, erosion, and deposition, Rio Grande rift deposition and faulting, as well as Jemez volcanic field eruptive activity and subsequent deformation is preserved in this special place.

The most significant findings made during this project include (1) the recognition of previously unmapped Pliocene Tschicoma lava domes and flows; (2) establishing that Cañones Mesa is formed by a ~2.8 Ma basaltic andesite that overlies the ~3.0 Ma dacite of Cerro Pelon and underlies El Alto basalt; (3) discovery of a dacitic pumice layer within the Miocene Lobato Formation; (4) observation that the Hernandez member of the Miocene Tesuque Formation is interbedded with Miocene Lobato Formation basalt and andesite on Mesa Escoba; (5) mapping of a low-angle (25 to 30°), north-dipping, possible intraformational unconformity within the Oligocene to Miocene upper Abiquiu Formation; (6) observation of Eocene El Rito Formation cutting through Cretaceous Dakota Sandstone into the underlying Cretaceous Burro Canyon and Jurassic Morrison Formation along the west side of the area; (7) discovery of an outcrop of possible Jackpile member of the Jurassic Morrison Formation, a unit not usually found in the Chama Basin.

Physiography

The Rio Chama, a west-southwest tributary of the Rio Grande, dissected the transition between the Colorado Plateau and the Rio Grande rift prior to the building of the Abiquiu Dam in 1963. Now Abiquiu Reservoir occupies the northwestern corner of the area. The northeast-flowing Cañones Creek, north-flowing Chihuahueños Creek and Canoncito Seco, northeast to north-flowing Polvadera Creek, and northeast-flowing Arroyo de las Frijoles provide important windows into this critical boundary and into the volcanic stratigraphy of the northern Jemez Mountains. The landscape between the drainages in the southern two-thirds of the area is dominated by mesas that dip gently to the north that are capped by lava flows and ash-flow tuffs of the Jemez volcanic field. Cerro Pedernal, a flat-topped (9862 ft.) peak capped by 9 Ma Lobato Formation basalt, is an important landmark along the western boundary of the quadrangle.

Basin-fill sediments of the Rio Grande rift are present across the southern two-thirds of the area; the rift-fill sediments thicken and Paleozoic to Mesozoic sedimentary rocks are not exposed at the surface east of the northeast-trending Cañones fault zone. West of the Cañones fault zone and across the northern third of the quadrangle , the landscape is underlain by mainly Triassic rocks of the Chinle Group, giving rise to the characteristic the red and white mesa country of the Colorado Plateau. This area is part of the Laramide-age Chama Basin. The northwestern part of the area is a large pediment, the La Joya del Pedregal, that basically formed at the contact between the top of the sandstone in the Poleo Formation of the Chinle Group and the overlying soft, mudstone-rich Petrified Forest member of the Chinle Group.

Previous Work

The Cañones quadrangle has been mapped by several workers over the years due to its key location at the boundary between the Colorado Plateau and the Rio Grande rift. The area was originally described by H.T.U. Smith in 1935. Smith et al. (1970) included the area on their geologic map of the Jemez Mountains. Bailey returned to the Jemez Mountains after that map was completed to concentrate on the volcanic rocks in the southeastern portion of the quadrangle as part of a Ph.D. dissertation that he never finished (unpublished mapping). Kelley (1978) broke out the various members of the Santa Fe Group on his regional scale map of the Española Basin. Lawrence (1979) included the southwestern corner of the area on his thesis map and Broomfield (1977) mapped the central part of the area for her master's project. Manley (1982) produced a reconnaissance map of the entire quadrangle. Singer (1985) mapped the Lobato andesite and basalt flows on Mesa Escoba. Baldridge et al. (1994) published a seismic line along Highway 84 across the northern portion of the area. Most recently, Moore (2000) and Smith et al. (2002) measured detailed sections through the Abiquiu Formation across the Cañones fault zone to document the beginning of Rio Grande rift deformation across the fault zone; they mapped the members of the Abiquiu Formation in the central part of the quadrangle.

In light of the good previous work that has been completed in the Cañones area, one might wonder what this project might add to our understanding of this critical spot. Our approach has been to use a refined stratigraphy of both the Mesozoic section (e.g. Lucas and Anderson, 1998; Lucas et al., 2003) and the Cenozoic section (Moore et al., 2002; Koning, 2004), which has allowed us to recognize previously unmapped geologic structures. In addition, we have refined the volcanic stratigraphy of the area.

Most Significant Contributions

Tschicoma Domes and Flows

Smith et al. (1970) did not attempt to map individual Tschicoma lava domes and flows, but instead lumped all of the units into a single formation. In our previous STATEMAP efforts in the Jemez Mountains (e.g., Kempter et al., 2004), we are subdividing the Tschicoma Formation and we continue that process here. We have identified at least four distinct Tschicoma flows, three of which correlate with flows on the Polvadera Peak quadrangle to the south (Kempter et al., 2004), and one that is unique to Cañones (see unit descriptions, dacite of Cañones Mesa).

Basaltic Andesite of Cañones Mesa

Smith et al. (1970) and Manley (1982) mapped the lava capping Cañones Mesa as Tschicoma Formation. This lava is generally more crystal poor than a typical Tschicoma lava, containing < 5% phenocrysts of plagioclase, pyroxene, and olivine. The lava is composed of at least two flows, characterized by basal block and ash features, and is platy in outcrop. Previous mappers have distinguished a different flow, in addition to their Tschicoma lava, at the northwest end of the mesa, calling the lava there El Alto Basalt; however we did not find a distinctly different lava flow in this place. Manley and Mehnert (1981) and Manley (1982) obtained two K-Ar ages of 2.8 Ma on the "El Alto Basalt." We think they dated the basaltic andesite of Cañones Mesa.

El Alto Basalt clearly overlies the basaltic andesite of Cañones Mesa on the northern flank of Cerro Pelon in the southeastern corner of the quadrangle. The basaltic andesite of Cañones Mesa clearly rests on the dacite of Cerro Pelon, which has a K-Ar age of ~3 Ma (Goff, personal communication). The basaltic andesite of Cañones Mesa may have come from the same vent area as the El Alto Basalt. Geochemistry and thin section work are needed to clarify the evolution of the magmas that gave rise to the dacite of Cerro Pelon, the basaltic andesite of Cañones Mesa, and the El Alto basalt. Geochronology is needed to determine the amount of time between eruptions.

Miocene Lobato Formation Dacitic Pumice

A poorly-exposed dacitic pumice is interbedded with Lobato Formation basalt flows on the northeastern side of Polvadera Mesa. Dacite lava interbedded with basalt has been reported in the Rio del Oso drainage on the Vallecitos quadrangle to the east (Bailey et al., 1969) and in the Encino Point area to the west (Singer, 1985); however, Lobato Formation dacitic volcanism had not been reported in this particular area.

Hernandez member of the Miocene Tesuque Formation

Koning et al. (2004) recently described a fluvial unit in the Tesuque Formation, the Hernandez member, above the eolian Ojo Caliente member in the northwestern Española Basin. We found a fluvial unit containing well-rounded volcanic pebbles below the Lobato Formation basalt on the east end of Mesa Escoba and above the Ojo Caliente member of the Tesuque Formation that we have assigned to the Hernandez member. In addition, we found significant pockets of gravel sitting on top of the basalt on top of the mesa. The gravel is dominated by intermediate composition volcanic rocks with a few basalt and tuff clasts, along with rare quartzite and orthoclase. This gravel may be a lag from Hernandez member that has was interbedded with the Lobato Formation that has since eroded from the top of the mesa.

Possible Syn-Orogenic Deformation in Upper Abiquiu Formation

A northwest-trending, low angle feature that dips 25 to 30 toward the northeast is located between 375380 E 4008960 N and 376120 E 4008315 N (NAD 27). This surface separates rocks that dip fairly steeply to the south (30 to 40°) below the surface from rocks that dip less steeply or dip to the north above the surface. This feature could be an intraformational unconformity (Figures 1 and 2), which has not been described in the literature prior to this work.

Figure 1. Photograph of north-dipping surface in the Upper Abiquiu Formation at 375380 E 4008960 N, looking toward the west. Arrows highlight the location of the surface

Figure 2. Photograph of north-dipping surface at 376120 4008315, looking toward the west. Arrows highlight the position of the surface.

Eocene El Rito Formation

Previous workers have mapped northeast-trending (Manley, 1982) or northwest-trending faults (Lawrence, 1979) to explain the distribution of rocks in an outcrop that includes Jurassic Morrison, Cretaceous Burro Canyon Formation and Dakota Sandstone, and Eocene El Rito Formation located due east of Cerro Pedernal. In this study, we recognize that part of the outcrop distribution is related to the fact that a channel in the Eocene El Rito Formation has cut down through the Dakota Sandstone into the underlying Burro Canyon Formation. In one place the El Rito Formation ends abruptly against an exposure of Jurassic Morrison Formation, apparently marking the edge of a channel that cut all the way through the Cretaceous section.

Possible Jackpile member of the Jurassic Morrison Formation

Lucas and Anderson (1998) note that only the Brushy Basin member of the Jurassic Morrison Formation is present in the Chama Basin. We may have found an outcrop of the Jackpile Sandstone member of the Morrison Formation at UTM coordinates 373740 4008620 (NAD 27). This sandstone is orange red, fine-grained, poorly to moderately sorted with angular to subround quartz. The sandstone, which is medium to thin-bedded with planar to trough cross-stratification, is cemented by carbonate and contains clay in the matrix. A basal granule sandstone to pebble conglomerate contains reworked Morrison mudstone clasts, chert, and quartzite. Red and green shale that is 2 m thick is present above the ~ 4 m thick sandstone. The shale is overlain by an additional 3 m of thin bedded sandstone and shale.

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Unit Descriptions for Cañones 7.5 Minute Quadrangle

Qal Alluvium (Holocene). Unconsolidated clay, silt, sand, and gravel deposits deposited in major drainages and tributaries; up to 5 m thick; locally includes organic-rich sediments.

Qe Eolian silt (Holocene). Unconsolidated windblown tan to brown silt and clay deposited in low-elevation spots and on pediment surfaces. Usually 1 to 3 m thick, but can be 10 m thick.

Qt Terrace deposits (middle Pleistocene to Holocene). Alluvial silt, sand, cobble, and boulder deposits of volcanic, granitic, and Mesozoic sandstone provenance overlying distinct straths and underlying discrete treads related to the large modern drainages of the Rio Chama (Gonzalez and Dethier, 1991; Gonzalez, 1993). Gonzalez (1993) recognizes as many as six terrace levels along Rio Chama between Ghost Ranch and the map area.

Qp Pediment gravels (middle Pleistocene to Holocene). Unconsolidated deposits of angular to subangular pebble to boulder size blocks of Lobato Formation, Pedernal Chert, Mesozoic sandstone, as well as rounded recycled Proterozoic quartzite, granite, and metamorphic pebbles from the Oligocene Lower Abiquiu Formation resting on surfaces graded to the level of the highest terraces. The largest surface, covering several square kilometers, is on La Joya del Pedregal, which is cut on the approximate contact between the Poleo Formation and Petrified Forest Formation of the Chinle Group. Most of the pediment surfaces are covered with eolian silt (**Qe**). Approximately 1 to 10 m thick.

Qsp Spring deposits (Quaternary?). White, fine-grained quartz sandstone, well-sorted, angular grains, no reaction to HCl. Associated with a northeast-trending fault and characterized by "popcorn" concretions. Appears to have formed on colluvium; < 1 m thick

Qc Colluvium (Quaternary). Hillslope colluvial deposits composed of pebble to boulder size unconsolidated, unsorted debris derived from local volcanic and sedimentary rocks. **Qcb** designates colluvium composed mainly of Lobato basalt, **Qcbt** is Bandelier Tuff colluvium. **Qc** refers to colluvium made up of a variety of lithologies. Up to 35 m thick.

Qls Landslide deposits (Quaternary). Unconsolidated, unsorted deposits composed of locally derived, cohesive blocks of bedrock. The large landslide on the south side of Mesa Escoba is composed of unconsolidated Ojo Caliente sandstone overlain by blocks of Lobato basalt and andesite. In areas to the south of Cañones Creek, many landslides are made entirely of Bandelier Tuff blocks. Large landslides that cover many square kilometers blanket the shoulders of Cerro Pedernal and the edges of Cañones Mesa. Sometimes the slides are associated with a head scarp in the source area and the top of the deposit is typically hummocky; up to 35 m thick.

Qoa Old Alluvium (Quaternary). Older alluvial deposits of gravel, sand and silt that were deposited after the eruption of the Tshirege Member of the Bandelier Tuff along Polvadera Creek. Dominant clast lithology is Tschicoma dacite, with subordinate amounts of rhyolite lava, obsidian, and rare rounded pieces of Tshirege Member, Bandelier Tuff. These deposits are also located further south along Polvadera Creek on the Polvadera Creek quadrangle (Kempter et al., 2004). Maximum thickness is approximately 10 meters.

Qb Bandelier Tuff (Pleistocene) - pumaceous air-fall tephra, nonwelded to weakly welded rhyolitic ash-flow tuff, and local volcaniclastic sediments; divided into two members, from younger to older:

Qbt Tshirege Member - White to orange to pink non-welded to weakly welded rhyolitic, ash-flow tuff (ignimbrite). The tuff contains abundant phenocrysts of sanidine and quartz, rare microphenocrysts of black clinopyroxene, trace microphenocrysts of hypersthene and fayalite, and pumice fragments in a fine-grained matrix of vitric ash. The sanidine typically displays blue iridescence. The tuff is composed of multiple flow units in a compound cooling unit (Smith and Bailey, 1966; Broxton and Reneau, 1995). Upper flows are generally more welded than lower flows; includes basal white pumiceous tephra deposits (1-2 m thick) of the Tsankawi Pumice. Qbt forms conspicuous orange to tan cliffs on both sides of Cañones Canyon in the southwest corner of the quadrangle and along the southern .edge of the area. $^{40}Ar/^{39}Ar$ age is 1.22 ± 0.01 Ma (Izett and Obradovich, 1994; Spell et al., 1996). Up to 60 m thick.

Qbo Otowi Member - White to pale pink, generally poorly welded rhyolitic ash-flow tuff containing abundant phenocrysts of sanidine and quartz, and sparse mafic phenocrysts; sanidine may display a blue iridescence. This tuff is welded in the thick section exposed in Canoñes Canyon. Contains abundant accidental lithic fragments; consists of multiple flow units in a compound cooling unit. The stratified pumice fall and surge deposit at base of unit (Guaje Pumice) is generally not found in this area, but 3 cm of Guaje Pumice is preserved at the confluence of Chihuahueños and Canoñes canyons. Qbo discontinuously fills in rugged topography on a pre-Toledo caldera age volcanic surface and can form spectacular tent rocks; upper surface quite undulatory due to erosion. Very difficult to distinguish from upper Bandelier Tuff in hand samples; best distinguished by poorer degree of welding, greater tendency to form slopes instead of cliffs, more abundant lithic fragments, less abundant iridescent sanidine, and stratigraphic position beneath the Tsankawi Pumice. $^{40}Ar/^{39}Ar$ ages 1.61± 0.01 to 1.62±0.04 Ma (Izett and Obradovich, 1994; Spell et al., 1996). Up to 180 m thick where Qbo infilled a paleo-Cañones Canyon.

QTg Old alluvial gravels – late Pliocene(?). Alluvial to fluvial gravel and sandstone deposits underlying the Bandelier Tuff or at unconstrained positions in the landscape. Gravel at the base of Qbo on the west side of Chihuahueños Canyon and in Cañones Canyon includes rounded cobbles to boulders of Lobato Formation basalt, El Ranchuelos rhyolite, Tschicoma andesite and dacite, and Ojo Caliente sandstone. Gravel on the east side of Chihuahueños Canyon does not have Qbo directly above it and appears to rest on Ojo Caliente sandstone. This gravel is characterized by clasts of rounded Proterozoic granite and quartzite (recycled from lower Abiquiu Formation?), basalt, Pedernal Chert, and sandstone. Old gravel along Polvadera Creek sits on Tschicoma andesite and underlies Qbo. This gravel contains pebble to boulder-sized rounded Tschicoma andesite and dacite, basalt, Pedernal chert (up to 0.5 m across), obsidian, rhyolite, and minor Proterozoic granite and quartzite. In places along Polvadera Creek, a tan sandy matrix is dominant with respect to the conglomerate. **Gravel on top of the west end of Mesa Escoba** contains rounded Lobato Formation and Tschicoma lavas, as well as angular clasts of upper Abiquiu sandstone and Pedernal Chert. 1 to 3 m thick.

QToc Old colluvium (late Pliocene(?)). Angular blocks of Lobato Formation basalt beneath and incorporated into the base of the Otowi member of the Bandelier Tuff south of Mesa Escoba. This unit also includes Tschicoma andesite boulders beneath the Otowi member in Chihuahueños Canyon. 1 -2 m thick.

Teb El Alto Basalt (Pliocene). Dark brown to black, vesicular basalt with phenocrysts of plagioclase, pyroxene and olivine. Overlies the basaltic andesite of Cañones Mesa and appears to emit from a vent on the north side of Cerro Pelon. K-Ar age of 3.1 ±0.7 Ma (Manley and Mehnert, 1981). Up to 120 m thick.

Tbai Andesite dike. Medium to light gray, porphyritic with aphanitic groundmass, phenocrysts (5-7% by volume) white subhedral zoned plagioclase, subhedral to resorbed dark green and brown pyroxene; matrix vuggy but nonvesicular. Intrudes Tba on the west margin Cañones Mesa.

Trdi Ryhodacite dike. Medium gray to pinkish gray, porphyritic with aphanitic groundmass, flow banded, phenocrysts (12-15% by volume) of subhedral k-spar and plagioclase, green pyroxene and resorbed quartz; locally occurs as a matrix-supported intrusive breccia. Intrudes Tba on the west margin Cañones Mesa.

Tba Basaltic andesite of Cañones Mesa. (Pliocene). Very dark gray, weakly to moderately vesicular, weakly porphyritic with aphanitic groundmass, phenocrysts (1-3% by volume) of plagioclase, amber-brown pyroxene and minor small pale green olivine. Plagioclase is zoned and commonly anhedral to resorbed. The massive to blocky basaltic andesite flow caps the northwestern part of Cañones Mesa where it is exposed as a single lava,. Along the east mesa edge, the lava exhibits undulatory layering, slabby structure and densely spaced subhorizontal "sheeted" jointing. This lava is generally more crystal poor than a typical Tschicoma lava. K-Ar ages are 2.8 ± 0.7 Ma and 2.8 ± 0.5 Ma on Cañones Mesa (Manley and Mehnert, 1981). The basaltic andesite is overlain by El Alto basalt and by dacite (Ttd3); it is underlain by dacite of Cerro Pelon. The base of the basaltic andesite on Cañones Mesa, which is ~380 m above the Chama River, corresponds to the T4 erosion surface of Gonzalez and Dethier (1991) and Gonzalez (1993). Estimated to be 15 m to 20 m thick, along the mesa's western edge

Tg Tertiary alluvial gravels (Pliocene). Gravel at the northern tip of Cañones Mesa, apparently under the basaltic andesite of Cañones Mesa and above the Jurassic Summerville Formation; contains a mix of Proterozoic quartzite cobbles, with minor granite, Pedernal Chert, and volcanic pebbles. Approximately 3 m thick.

Tt Tschicoma Formation (3 Ma to 5 Ma). Includes andesites and local dacites occurring as massive lavas, domes, vents, and shallow intrusives on Cañones Mesa and the northern flanks of Cerro Pelon; informally divided into two members:

Ttd Tschicoma dacites (Pliocene). Includes hornblende- and hornblende-biotite porphyritic rocks of diverse texture and lithology that generally overlie Tschicoma andesites. The dacitic flows on Cerro Pelon are 2.96±0.27 Ma and contain minor augite and orthopyroxene as hydrous phases (Goff et al., 1989). Both coarsely porphyritic and fine-grained, flow-banded, weakly porphyritic dacites are present. The northern exposures of the dacite of Cerro Pelon (**Ttd1**) is gray, crystal-rich (30 to 50%) with phenocrysts of plagioclase 9 to 13 mm across, hornblende up to 6 mm long, and biotite. At least 70 m thick. A dacite on Cañones Mesa (**Ttd2**) is gray, has about 20 to 30 % crystals, with plagioclase, hornblende and biotite. A second dacite on Cañones Mesa, (**Ttd3**) is a medium to light gray, nonvesicular, porphyritic lava with a microcrystalline to vitric groundmass. The lava contains well developed large phenocrysts (10-15% of by volume) of white euhedral zoned plagioclase (up to I cm), dark green pyroxene, and variable amounts of black ascicular hornblende. Ttd3 ocurs as one or more massive flows that overly the basaltic andesite of Cañones Mesa and caps the central to northeastern part of the mesa.

Tta **Tschicoma andesite (Pliocene).** Mainly coarsely porphyritic, 2-pyroxene andesites that occur as massive flows;about 100 m thick. One flow on the northeast side of Cerro Pelon (**Tta1**) is pink to gray, 10 to 20% crystals, with plagioclase phenocrysts up to 10 mm across, with pyroxene and minor (<1%) biotite. Pumice (**Ttp**) is associated with this flow. One flow at Polvadera Creek (**Tta2**) is black to dark gray, slightly vesicular, 30% crystals, with apple-green and forest green pyroxene. A small flow in Chihuahueños Canyon (**Tta3**) is gray crystal-poor (5-10%), fine-grained, with plagioclase and pyroxene phenocrysts.

T1 **Lobato Formation (7 Ma to 8 Ma)**. Includes basalt, andesite, and local dacite pumice occurring as lavas exposed on Cerro Pedernal, Mesa Escoba, and Polvadera Mesa. K-Ar ages are 7.8 ± 0.7 Ma on Cerro Pedernal, 7.9 ± 0.5 on Mesa Escoba, and 7.8 ± 0.5 Ma on Polvadera Mesa (Manley and Mehnert, 1981). An age of 8.1 ± 0.5 Ma is reported by Luedke and Smith (1978) on the lowest basalt flow on Polvadera Mesa. The base of the Lobato flows corresponds to the T1 erosion surface of Gonzalez and Dethier (1991) and Gonzalez (1993). The T1 surface is ~ 1110 m above the Rio Chama on Cerro Pedernal, 730 m on Mesa Escoba, and 540 m on Polvadera Mesa (Gonzalez, 1993).

Tla Lobato andesite (Pliocene). One andesite flow is preserved on Mesa Escoba (Singer, 1985). The andesite is dark gray, fine-grained, weakly porphyritic rock with microphenocrysts of plagioclase, clinopyroxene, olivine and quartz xenocrysts (Singer, 1985). An andesite flow is exposed in Cañones Canyon below Chama-El Rito sandstone. This andesite is gray, with about 15-20% plagioclase, mainly in the form of fine-needles, and pyroxene. At least 10 m thick.

Tlb Lobato basalt (Pliocene). Lobato basalt from Mesa Escoba contains microphenocrysts of olivine, augite, and plagioclase (Singer, 1985). Porphyritic olivine basalt on Cerro Pedernal has phenocrysts of subhedral zoned labradorite (An_5 , 12%, 1.5 mm); subhedral to euhedral olivine (2.5 mm), with strong iddingsite replacement and magnetite rims; subhedral augite (2.5 mm) containing poikilitic plagioclase, partly twinned or with orthopyroxene reaction rims. Basal flow, 17-m thick, in a series of flows and interlayered pyroclastic beds totaling 80 m thick (Lawrence, 1979).

Tsf **Santa Fe Group (late Miocene to Pliocene)**

Tsch **Hernandez Member of the Chamita Formation (late Miocene).** A fluvial unit (Koning et al., 2004) containing well-rounded volcanic pebbles below the Lobato Formation basalt and above the Ojo Caliente Member of the Tesuque Formation on the east end of Mesa Escoba. The gravel is dominated by intermediate composition volcanic rocks with a few basalt and tuff clasts, along with rare quartzite and orthoclase. A similar gravel with volcanic pebbles (mainly andesite), quartzite, glass, sandstone and quartz appears to sit on the Lobato Formation east of Polvadera Creek. A poorly-exposed dacitic pumice with phenocrysts of biotite and hornblende that is likely in the Hernandez Member is interbedded with Lobato Formation basalt flows on the northeastern side of Polvadera Mesa. The Hernandez Member is well exposed on the northwest side of Polvadera Mesa, where it contains pumice clasts up to 17 cm in diameter. 30 to 40 m thick.

Tsto **Ojo Caliente Member of the Tesuque Formation (late Miocene).** Pink to tan-colored, well-sorted, fine-grained feldspathic and quartzo-feldspathic sandstone of eolian origin; cross-beds clearly indicate a prevailing wind from the west. In Cañones

Canyon some exposures of the Ojo Caliente Member are strongly cemented, forming impressive cliffs. Most of the unit, however, is poorly consolidated, forming buff-colored sand and silt on the canyon slope; up to 100 m thick.

Tstc **Chama-El Rito Member of the Tesuque Formation (middle Miocene).** This unit varies in character across the quadrangle. The Chama-El Rito Member is not exposed on Cerro Pedernal, but based on the quantity of gravel float, it is conglomeratic, with clasts of Amalia Tuff, intermediate composition volcanic clasts, and rare Proterozoic granite and quartzite. This unit in the southwestern corner of the quadrangle is tan to gray, medium to coarse-grained fluvial sandstone and granule to pebble conglomerate interbedded with orange-red to red siltstone. Clasts in the conglomerate are dominated by rounded andestitc volcanics, flow-banded rhyolite, ash flow tuff (much of which is lithic-rich Amalia Tuff), rare chert and basalt. Petrified wood locally abundant. In contrast, the Chama-El Rito Member around the village of Cañones is typically red and is generally more fine-grained, consisting mainly of fine to very fine-grained sandstone, siltstone, and a few conglomeratic lenses with volcanic clasts like those described above. Along the east side of the quadrangle, this unit does not have noticeable gravel, but is dominated by siltstone and fine sandstone,.

Ti/Tb Black, fine-grained basalt dikes (Ti) intruding, and basalt flows interbedded with, the Chama-El Rito Member in Arroyo de las Frijoles.

Ta **Abiquiu Formation (late Oligocene to early Miocene).** Informally divided into three subunits including, from younger to older:

Tau **Upper sandstone member.** White, light gray, and buff-colored fine- to medium-grained, tuffaceous and volcaniclastic sandstone, locally conglomeratic. The upper sandstone is a slope-forming unit comprised of moderately sorted, moderately indurated volcanic detritus representing diverse lithologies including pumice, basalt, intermediate volcanics and 25 Ma Amalia tuff. A K-Ar age of 18.9 Ma from a basalt near the top of the unit and an Ar/Ar age of an Amalia Tuff clast of 25 Ma near the base bracket the age of the unit (Smith et al., 2002, Moore, 2000). Up to 460 m thick

Tap **Pedernal Chert Member.** Varicolored, white, blue-gray, black, red and yellow cryptocrystalline, massive chert, limey chert, and limestone containing nodular chert, conspicuous ledge former. The chert is locally interlayered with thin beds of arkosic sandstone and conglomerate and is typically more limey at its base. 2 to 10 m thick.

Tal **Lower conglomerate member.** Pinkish tan to gray, generally coarse arkosic conglomerate and fine- to medium-grained sandstone, slope forming. The lower conglomerate member is poorly sorted, weakly to moderately indurated, calcareous, and characterized by well rounded pebble to boulder-size (up to 50 cm) clasts composed of Precambrian quartzite, granite, pegmatite, gneiss and schist, as well as fine-grained limestone and mudstone. K-Ar ages on a basalt near the base of the unit northeast of the quadrangle and 40Ar/39Ar ages on Amalia Tuff in the upper Abiquiu bracket the age of the unit between 25.1 and 27 Ma (Smith et al., 2002, Moore 2000). ~125 m thick

Ter **E1 Rito Formation (Eocene).** Orange-red to brick-red, hematitic, micaceous mudstone and siltstone and lenses of fine- to medium-grained arkosic sandstone with few pebbles to cobbles of Proterozoic granite and quartzite, slope forming. The E1 Rito Formation locally has a 2- to 10-m-thick basal conglomerate section made up of very well rounded hematitic Proterozoic Ortega quartzite, as well as Proterozoic schist and gneiss cobbles and boulders (up to 1 m) in a weakly to well indurated matrix of coarse ferruginous sand. Underlies the Abiquiu Formation and overlies Cretaceous Mancos Shale, Dakota Sandstone Burro Canyon Formation, or Jurassic

Morrison Formation with erosional unconformity. Estimated 50 to 140 m thick.

Km Mancos Shale (Late Cretaceous). Dark gray and brown, weakly consolidated, calcareous, carbonaceous shale and interlayered thin beds of fossiliferous limestone, slope forming; 0 to 65 m thick. Lowermost part of the Mancos section only is locally present; upper contact is an erosional unconformity of moderate relief.

Kd Dakota Sandstone (Late Cretaceous). White, gray, and tan, fine-grained quartzose sandstone, well sorted, locally kaolinitic, conspicuous as a cliff former, 60 to 67 m thick. The Dakota Sandstone is well sorted, thick bedded to massive, and locally contains thin interbeds of black, carbonaceous shale. The basal contact with the underlying Morrison Formation was arbitrarily determined as the lowest occurrence of carbonaceous matter observed in the rock, whether sandstone or shale.

Kbc Burro Canyon Sandstone (Cretaceous). White to tan, fine-grained, kaolinitic, quartzose sandstone, moderately to well indurated. Contains abundant thin beds of chert and quartz pebble conglomerate; sandstone clasts also occur. The rounded chert pebbles are usually tan, white, and gray, and rarely black to red and much of the chert is tripolitized (Saucier, 1974; Aubrey, 1986). Locally exhibits medium-scale cross bedding. Thin light green to pink mudstone is interbedded with the conglomeritic sandstone, indicating recycling of the underlying Brushy Basin mudstones (Saucier, 1974). Conspicuous cliff-forming unit, thick bedded to massive, 57 to 67m thick.

We follow the Jurassic stratigraphy for the Chama Basin outlined by Lucas and Anderson (1998).

Jm Morrison Formation (Late Jurassic). Shown on the map as an undivided unit, two members are recognized in the map area from younger to older, the subunits are:

Jmj - Jackpile Sandstone in the Brushy Basin Member. Orange red, fine-grained, moderately sorted, carbonate cemented quartz sandstone with abundant clay matrix. Goethite concretions. Quartz angular to subrounded, medium to thin bedded. The sandstone just above the underlying green Brushy Basin siltstone is a granule sandstone to pebble conglomerate with clasts of reworked Morrison siltstone, chert, and quartzite. Conglomeritic material in the Jackpile sandstone is usually sparse and is usually limited to the base of the unit (Aubrey, 1986).

Jmb - Brushy Basin Member. Variegated green to reddish orange to dark reddish brown siltstone and grayish-white to gray, very fine-grained subarkosic, cross-bedded sandstone, slope forming, 110 m thick.

Js Summerville Formation (Late Jurassic). The basal 8 to12 m of this unit consists of white to light gray, fine- to very fine grained quartzose sandstone, thin-bedded, containing small-scale ripple marks, gypsum blade casts, and soft-sediment deformation. The basal sandstone is overlain by variegated maroon and gray quartzose to subarkosic siltstone. This unit tends to form slopes. The upper contact is the stratigraphically highest maroon siltstone that contains abundant pedogenic carbonate concretions, located above the Bluff Sandstone interval. The Bluff Sandstone, a tan fine grained, cross-bedded sandstone that is about 10 m thick, is included in the Summerville Formation on this map. Approximately 60 m thick.

Jt Todilto Formation (Late Jurassic). White to gray, dominantly fine-grained, massive gypsum, sloping-forming unit; with a 2- to 3-m-thick basal section of gray, laminated, fissile shale and/or thin-bedded limestone; total unit thickness 15 to 27 m. A gray, crusty "popcorn" texture typically develops on erosional surfaces of Todilto gypsum.

Je Entrada Sandstone (Late Jurassic). White, pink, and yellowish tan, fine- to very fine-grained quartzose sandstone, well sorted, moderately indurated, exhibits large-scale eolian dunal cross-bedding, cliff former, 60 to 67 m thick.

TRc Chinle Group (Late Triassic). Three units are mapped at the 1:24,000 scale, from younger to older:

TRcu an upper unit that contains the Rock Point Formation and Petrified Forest Formation. The stratigraphically highest unit in the Chile Group is the Rock Point Formation, reddish brown to gray-red siltstone and fine-grained sandstone that is 0-70 m thick (Lucas et al., 2003). The Petrified Forest Formation is composed of a basal red-brown laminated sandstone-dominated section (Mesa Montosa member) and upper red-brown mudstone-dominated section (Painted Desert member) (Lucas et al. 2003). Both the upper and lower contacts of this formation are gradational. The Petrified Forest Formation is up to 200 m thick.

TRcp Poleo Formation – Yellow-brown to yellow- gray, medium to fine-grained, micaceous, quartzose sandstone, conglomeritic sandstone and conglomerate. The conglomerate contains both intrabasinal siltstone clasts and extrabasinal siliceous clasts; locally cross-bedded. This unit forms prominent cliffs. The base of the unit is sharp (corresponds to the Tr-4 unconformity of Lucas (1993)) and the upper contact is gradational into the overlying Petrified Forest Formation, up to 41 m thick at Abiquiu Dam.

TRcl a lower unit that contains the Salitral Formation and the Shinarump Formation –The Salitral Formation is an olive gray to brown sandstone to silty mudstone near the base (Piedra Lumbre member) and a reddish brown mudstone (Youngsville member) near the top. Upper bed of the Piedra Lumbre member, called the El Cerrito Bed, is a yellow to brown intraformational conglomerate (Lucas et al. 2003). The Shinarump Formation, the stratigraphically lowest unit in the Chinle Group, consists of red to orange to brown quartz sandstone, conglomeritic sandstone, and extrabasinal conglomerate that includes clasts of quartz, chert, and quartzite (Lucas et al., 2003). Petrified wood is common. Both the basal and upper contacts are sharp; the basal contact corresponds to the Tr-3 unconformity of Lucas (1993).

Pc Cutler Group (Late Pennsylvanian?- Early Permian) Spencer Lucas (personal communication) recognizes two informal formations in the Chama Basin, the Arroyo del Agua Formation and the El Cobre Formation. Only the upper unit is exposed in the Cañones area.

Pca - Arroyo del Agua Formation - Orange red micaceous siltstone with thin, trough cross-bedded sheet arkosic sandstone. Contains extensive calcrete nodule horizons. Little or no conglomerate is present in this formation. This unit tends to form slopes. About 30 m exposed.

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